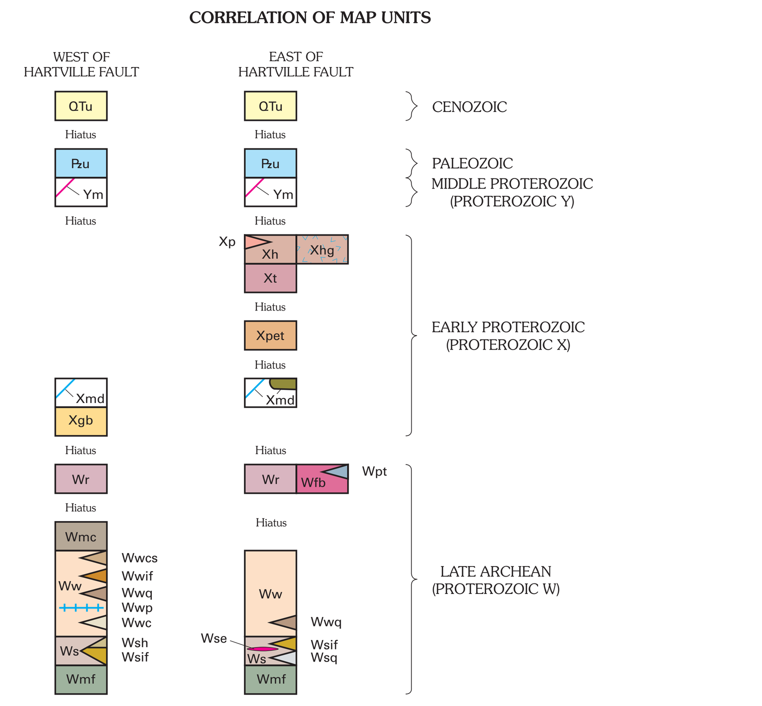
CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

CENOZOIC

QTu — **Quaternary sediments and Tertiary sedimentary rocks, undivided**—Predominantly Tertiary Arikarie Formation but includes Quaternary surficial deposits

PALEOZOIC

Pzu — **Paleozoic rocks, undivided**—Includes Fremont Canyon Formation (Upper Devonian), Guernsey Formation (Mississippian), and Hartville Formation (Mississippian? and Pennsylvanian)

MIDDLE PROTEROZOIC (1,600–900 Ma)

Ym — **Diabase**—Dark-green, medium-grained diabase, with marginal chill zones; probable age, ≈1.4 Ga

EARLY PROTEROZOIC (2,500–1,600 Ma)

Xp — **Pegmatite related to Haystack Range Granite**—White to gray, coarse-grained, zoned to unzoned, feldspar-quartz-muscovite-tourmaline granitic dikes; contains accessory biotite, garnet, and beryl

Xh — **Haystack Range Granite**—Pink, coarse- to medium-grained, massive to foliated, inequigranular biotite granite. Composes a granite dome in the Haystack Range (Casebier Hill quadrangle) and a buried dome in the Reynolds Spring quadrangle; Rb-Sr whole-rock age, 1.72 Ga (Snyder and Peterman, 1982)

Xhg — **Gneissic phase of Haystack Range Granite**—Strongly deformed phase of granite in aureole surrounding buried granite dome in Reynolds Spring and Rawhide Buttes East quadrangles

Xt — **Twin Hills Diorite**—Dark-gray, medium-grained, massive to foliated hornblende-biotite monzonite to mafic diorite; locally contains clinopyroxene and orthoclase; U-Pb discordia intercept age, 1.74 Ga (Snyder and Peterman, 1982)

Xpet — **Tourmaline-bearing granite pegmatite**—White to gray, coarse-grained, unzoned granite pegmatite containing schorl (black iron-rich tourmaline); interpreted to be anatectic melt

Xmd — **Metadiabase**—Dark-greenish-black, medium-grained hornblende-plagioclase-quartz metadiabase; granular amphibolite east of Hartville fault. Estimated age, ≈2.0 Ga, based on age of similar isotopically dated mafic dikes in the Laramie Range (Snyder, 1993; Chamberlain and others, 1997)

Xgb — **Metagabbro**—Dark-grayish-green, fine- to coarse-grained, weakly layered, weakly to strongly foliated metagabbro containing hornblende and chlorite. Gabbro is older than D_2 deformation. Confined to hill south of Graves Ranch (Guernsey quadrangle)

LATE ARCHEAN (2,900–2,500 Ma)

Wr — **Rawhide Buttes Granite**—Pink, red, or gray, medium- to coarse-grained, inequigranular granite. Locally contains abundant muscovite and sillimanite. Mainly foliated but locally gneissic. Rb-Sr whole-rock isochron age, 2.66 Ga (Day and others, 1999)

Wfb — **Flattop Butte Granite**—Pink to red, foliated to gneissic, biotite-muscovite granite. U-Pb zircon age, 2.65 Ga (K.R. Chamberlain, oral commun., 1997)

Wpt — **Tourmaline-bearing pegmatite**—White to gray, coarse-grained, unzoned granite pegmatite containing schorl (black, iron-rich tourmaline); pegmatite interpreted to be related to Flattop Butte Granite

Whalen Group

Wmc — **Muskrat Canyon Metabasalt**—West of Hartville fault: dark-green, fine-grained, locally pillowed, actinolite-biotite-chlorite schist

Ww — **Wildcat Hills Formation**—West of Hartville fault: white to gray dolomite and marble; contains algal stromatolitic mounds near Hartville. East of Hartville fault: white to gray dolomitic marble, tremolite marble, and chondrodite marble

Wwcs — **Calc-silicate rock unit**—White to light-green lenses, commonly 10–15 cm in diameter, compose 30–50 percent of rock, and contain actinolite, diopside, talc, and epidote

Wwif — **Banded, cherty iron-formation unit**—In Muskrat Canyon

Wwq — **Quartzite unit**—Gray to red, crossbedded

Wwp — **Pelite unit**—Thin layer in metadolomite (Ww), east of Hartville

Wwc — **Quartz pebble conglomerate**—Exposed 3,000 ft north of mouth of Muskrat Canyon

Ws — **Silver Springs Formation**—West of Hartville fault: dark-gray, medium- to fine-grained graywacke and argillite containing chlorite and, locally, garnet. In Hartville district, grades laterally into ferruginous sedimentary rocks containing lenses of banded, cherty iron-formation and hematitic iron ore. East of Hartville fault: gray, layered to massive biotite-muscovite schist containing garnet and sillimanite. In Silver Springs area, contains pegmatite lenses (Xpet)

Wse — **Siliceous exhalite**—Thin, horizontal unit within Silver Springs Formation

Wsh — **Hematitic iron ore unit**—In Hartville district

Wsif — **Banded iron-formation and associated ferruginous sedimentary rocks**

Wsq — **Quartzite**—Gray to pinkish gray, medium grained, massive

Wmf — **Mother Featherlegs Metabasalt**—Dark-greenish-gray, massive to layered, locally pillowed metabasalt

Contact—Dashed where inferred

High-angle fault—Showing dip. Dashed where inferred; queried where extent uncertain. Bar and ball on downthrown side where sense of movement is known; opposed arrows indicate relative horizontal movement. L, Laramide in age

Thrust fault of Early Proterozoic age—Dashed where inferred; queried where extent uncertain. Sawteeth on hanging wall. Opposed arrows indicate relative horizontal movement

Folds—Dashed where covered

- **Anticline**—Showing direction of plunge
- **Syncline**—Showing direction of plunge
- **Overturned anticline**—Showing trace of axial plane, direction of dip of limbs, and bearing and plunge of axis
- **Overturned syncline**—Showing trace of axial plane, direction of dip of limbs, and bearing and plunge of axis

Bearing and plunge of symmetrical mesoscopic fold

Bearing and plunge of asymmetrical mesoscopic fold

Bedding

- **Inclined**
- **Upright**
- **Overturned**
- **Vertical**—Top of beds known
- **Vertical**—Stratigraphic way-up direction not determined

Foliation

- **Inclined**
- **Vertical**

Primary magmatic flow

- **Inclined**
- **Vertical**

Bearing and plunge of lineation—May be combined with foliation or bedding symbol

Bearing and plunge of stretching lineation

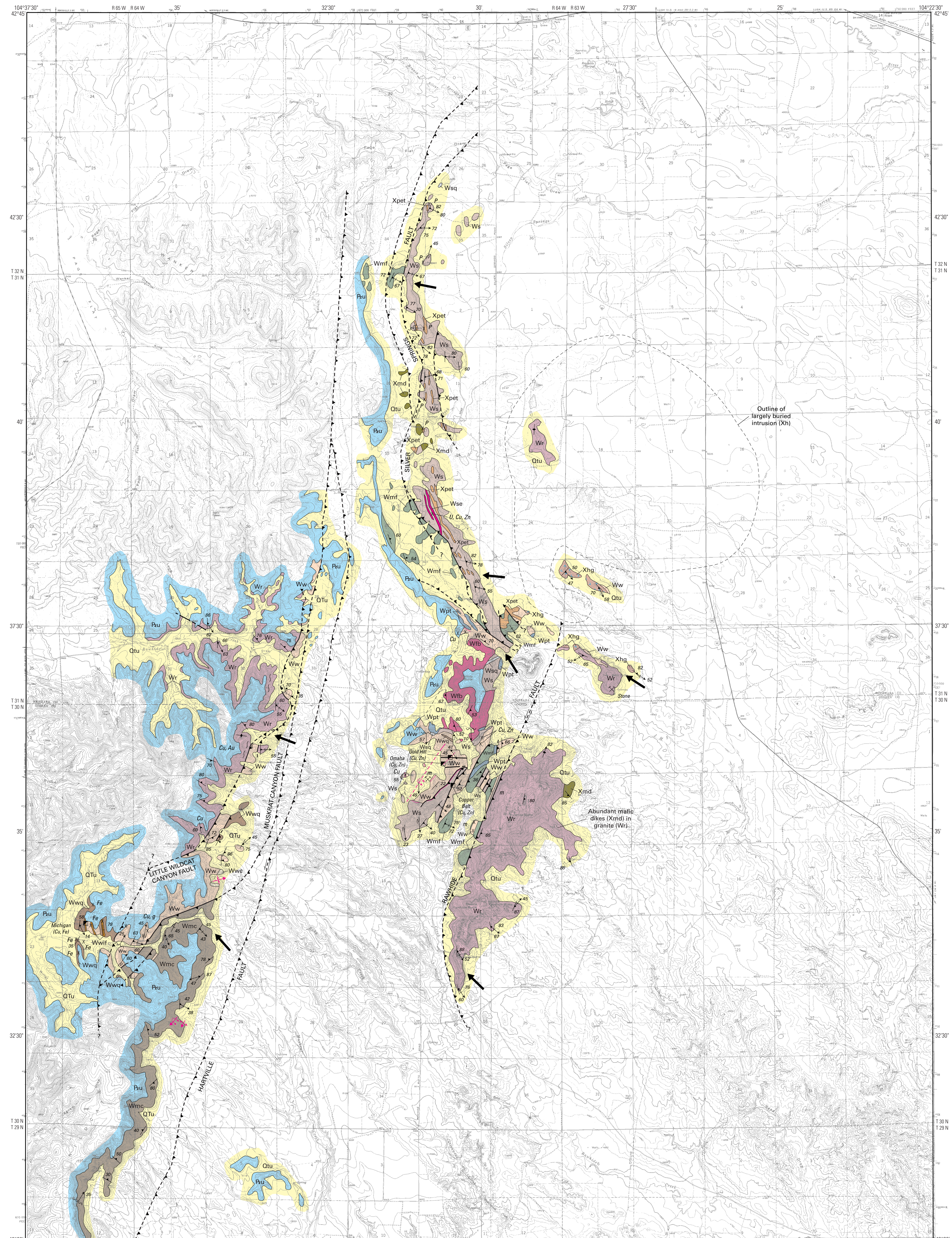
Direction of tectonic transport

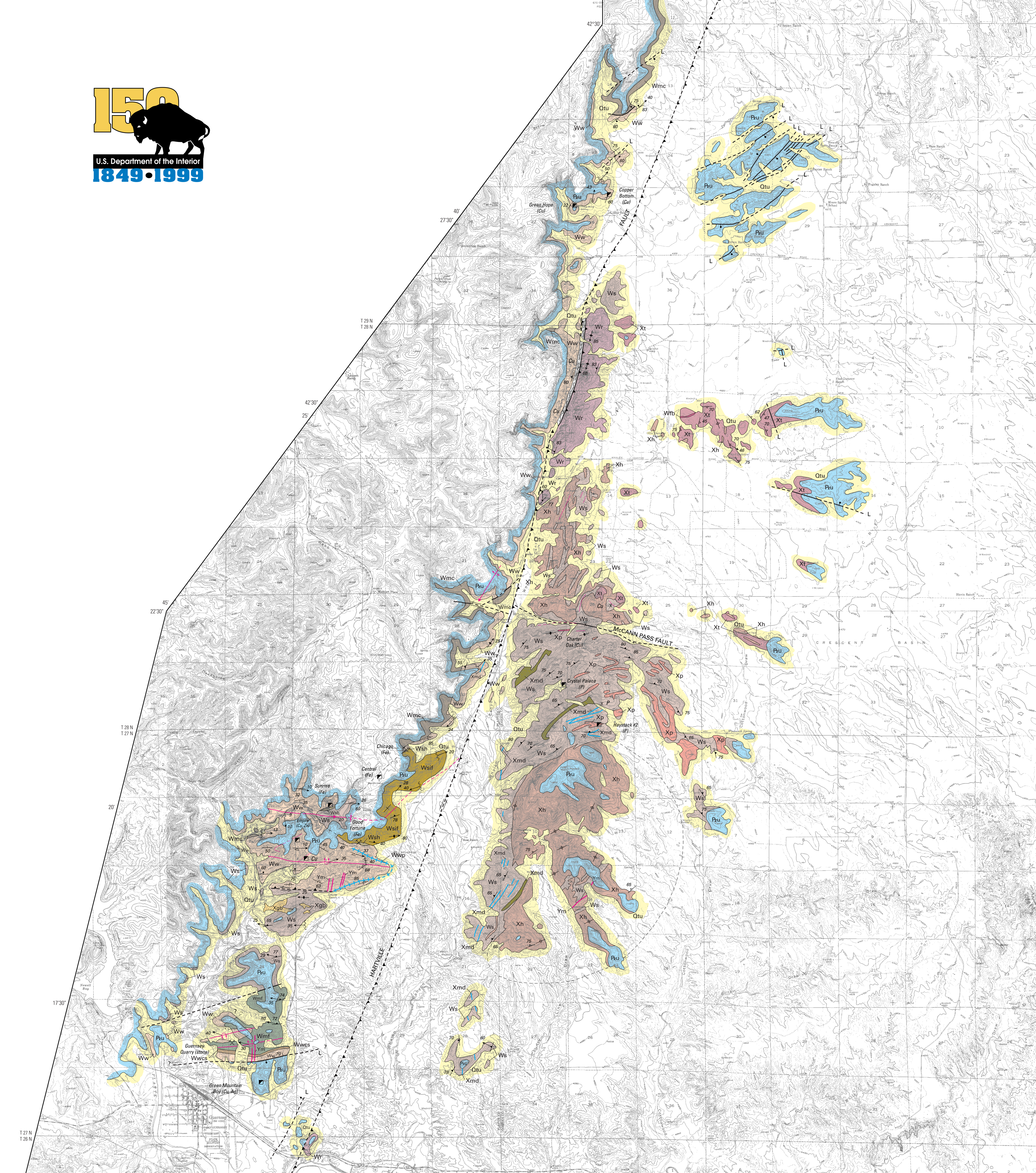
Mylonite

Thin siliceous exhalite layer—Dashed where inferred

Mineral workings—Showing commodity where known or inferred. *Au*, gold; *Cu*, copper; *Fe*, iron; *g*, graphite; *m*, marble; *p*, pegmatite; *U*, uranium; *Zn*, zinc

- **Mine shaft**
- **Quarry or open-pit mine**
- **Prospect**



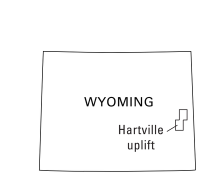


Base from U.S. Geological Survey
Rawhide Buttes East, Reynolds Spring, Silver Springs, 1974; Rawhide Buttes West, 1978.
Projection and 10,000-foot grid ticks: Wyoming coordinate system, east zone (transverse Mercator).
1,000-meter Universal Transverse Mercator grid ticks, zone 13.
Casebier Hill, 1950; Moore Spring, 1951; Guernsey, Guernsey Reservoir, Hell Gap, 1978.
Polyconic projection. 10,000-foot grid based on Wyoming coordinate system, east zone.
1927 North American datum

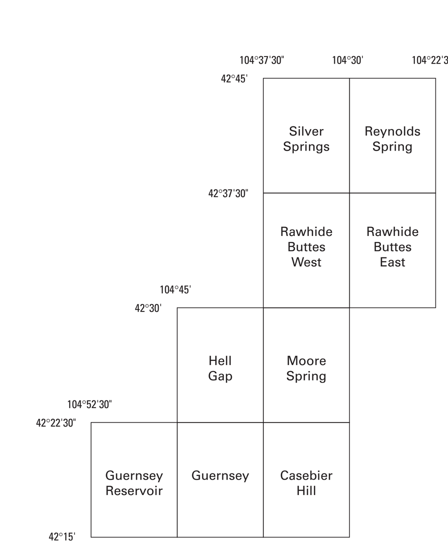
Geology of Precambrian rocks mapped in 1993–97 by P.K. Sims, W.C. Day, A.B. Wilson, and T.L. Klein; geology of Tertiary-Quaternary and Paleozoic units mapped in 1977–79 by G.L. Snyder.
Geology digitized by Techni Graphic Systems, Inc.
Edited by Lorna M. Carter
Digital cartography by Alessandro J. Donatich
Manuscript approved for publication September 10, 1998

SCALE 1: 48 000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



INDEX MAP



INDEX TO QUADRANGLES

GEOLOGIC MAP OF PRECAMBRIAN ROCKS OF THE HARTVILLE UPLIFT, SOUTHEASTERN WYOMING

Compiled by
P.K. Sims and W.C. Day,
with a section on
Mineral deposits in the Hartville uplift *by* Terry Klein

1999

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U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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Pamphlet to accompany
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I–2661

CONTENTS

CONTENTS

FIGURES

TABLES

INTRODUCTION

The Hartville uplift, at the southeast margin of the Archean Wyoming province (fig. 1), is a north-trending Laramide anticline containing a Precambrian core (fig. 2) overlain by gently outward dipping Paleozoic strata and, locally, by flat-lying Tertiary sedimentary rocks and Quaternary sediments. The core is composed of Late Archean, moderately metamorphosed supracrustal rocks of the Whalen Group (Smith, 1903) intruded by Late Archean granite (≈2.65 Ga) bodies (table 1). The supracrustal rocks are also intruded by a circa 2 Ga mafic dike swarm (Sims, 1995, pl. 1*B*) and by the post-tectonic Twin Hills Diorite (1.74 Ga) and Haystack Range Granite (1.72 Ga) (Snyder, 1993). The basement to the Whalen Group, indicated by Nd model ages as being in the range 2.8–3.1 Ga (Frost, 1993; Day and others, 1999), is not exposed in the area.

The Archean rocks in the uplift were deformed during three regional compressional events in Early Proterozoic time, which took place in the interval from about 1.98 Ga to 1.74 Ga (table 1). Recognized compressional events are (1) nappe formation (D_1) in the supracrustal rocks; (2) folding throughout the length of the western side of the uplift on east-west axes (D_2); folds are open to tight, verge southward, and plunge westward; and (3) west-vergent folding on north-trending axes, associated thick-skinned thrusting (D_3) in the central and northern parts of the uplift (table 1), and accompanying prograde metamorphism. A fourth, local deformation was restricted to the uplifted margins of granite domes of 1.72 Ga Haystack Range Granite bodies.

PREVIOUS WORK

Extensive geologic studies, mainly focused on the iron ore deposits in the vicinity of Hartville, Wyo., have been carried out during the past century. In an early study, Smith (1903) formally named the Whalen Group and described its lithologic units, but he did not name any formations. Subsequently, Ball (1907a), Lovering (1933), and Noble and Harder (1948) described the iron-ore bearing section. A thoughtful study of the Good Fortune mine by Ebbett (1956) provided for the first time significant data on the nature and formation of the iron ores. Later studies by Harper (1960) and Millgate (1964) provided additional details of the stratigraphic relations of the iron-bearing rocks. In a regional study, Snyder (1980) compiled for the first time a regional stratigraphy and the stratigraphic succession (Snyder and Peterman, 1982; Snyder, 1989).

PRESENT WORK

A field trip into the Hartville uplift in 1993 led to the recognition that previous stratigraphic interpretations were not consistent with structural observations. Accordingly, geologic mapping at a scale of 1:24,000 was undertaken by us in 1993–1997 in selected areas for the purpose of unraveling the structure and stratigraphy and developing a coherent stratigraphy. The southernmost quadrangles, the Guernsey and Casebier Hill quadrangles (Sims and others, 1997) were mapped; then two rather well-exposed quadrangles, the Rawhide Buttes West and Rawhide Buttes East in the northern part of the uplift, were mapped (Day and others, 1999). Unpublished mapping by T.L. Klein and W.C. Day of the Silver Springs quadrangle provided additional coverage of the northern part of the uplift. To complete geologic coverage, the map accompanying this report was compiled at 1:48,000 scale mainly utilizing Snyder's (1980) previous mapping to fill in areas not mapped during our current study.

ACKNOWLEDGMENTS

The present mapping was facilitated by the earlier geologic mapping by Snyder (1980). He located Precambrian outcrops and mapped the younger Paleozoic and Tertiary-Quaternary materials, thus materially aiding our mapping. Previous geochronology by Zell Peterman (Snyder and Peterman, 1982) and age determinations concurrent with our mapping by Kevin Chamberlain and students at the University of Wyoming (Chamberlain and others, 1997) provided a general time frame for our geologic interpretation.

REGIONAL TECTONIC SETTING

The Wyoming craton (province) is bordered on the east by the Paleoproterozoic Trans-Hudson orogen (Hoffman, 1990; Lewry and Collerson, 1990) and on the south and southeast by the younger (1.78–1.76 Ga) Central Plains orogen (Sims and Peterman, 1986; this report, fig. 1). The Hartville uplift lies near the intersection of the Trans-Hudson and Central Plains orogens (Sims and others, 1991).

The Trans-Hudson orogen is a north-trending orogenic belt as much as 480 km wide and more than 1,900 km long that separates the Wyoming craton from the Archean Superior craton (fig. 3). Seismic reflection profiles across the orogen along the U.S.–Canadian border (fig. 4) are interpreted (Nelson and others, 1993; Baird and others, 1996) to indicate that the orogen has a symmetrical profile. The seismic profiles also suggest westward subduction of oceanic and arc rocks of the orogen beneath the Wyoming craton (on the west) and eastward subduction of similar rocks beneath the Superior craton on the east. The subducted rocks bound an antiformal Archean(?) microcontinent whose crest is approximately in the center of the orogen. Intracrustal reflections to the west of the zone of presumed westward subduction suggest that the eastern margin of the Wyoming craton was imbricated in an east-over-west sense during the Trans-Hudson orogeny. Random drilling in North and South Dakota (Peterman and Futa, 1988) and in adjacent Canada (Collerson and others, 1989) supports the interpretation of Archean rocks in the seismic profile (Baird and others, 1996); Peterman and Futa (1988) concluded that Paleoproterozoic (Hudsonian) granulite facies metamorphism was imposed on a complex terrane consisting of both Archean and Paleoproterozoic rocks in the orogen. The Black Hills uplift lies within the Trans-Hudson orogen (Sims and others, 1991); the Proterozoic rocks and Archean basement in the uplift were multiply deformed during the Trans-Hudson orogeny (Redden and others, 1990). In the Black Hills, the dominant structural trend is north-northwest, subparallel to the structural trend of the Trans-Hudson orogen in the southern, exposed part of the orogen. The width of the foreland metamorphic-deformational belt on the west side of the Trans-Hudson orogen has not been determined at the latitude of the Hartville uplift, but R.L. Bauer (University of Missouri, oral commun., 1997) has recognized folds 80 km west of the uplift in the Laramie Mountains that strike northward, subparallel to the length of the Trans-Hudson orogen, and that are presumably related to it.

The younger Central Plains orogen has been traced by drilling and geophysics from the Medicine Bow Mountains (fig. 1) eastward in the subsurface, where it truncates the southern extent of the Trans-Hudson orogen (Sims and others, 1991). The Central Plains orogen collided with the Wyoming craton along the Cheyenne belt (Karlstrom and Houston, 1984) in the interval 1.78–1.76 Ga (Premo and Van Schmus, 1989). Chamberlain and others (1993) have demonstrated geochronologically that the foreland metamorphic-deformational zone extends 60–100 km northwest of the Cheyenne belt in the Laramie Mountains, and is recorded in the Laramie Peak shear zone (fig. 1).

PRECAMBRIAN ROCK UNITS

Supracrustal rocks of the Whalen Group (Smith, 1903) overlie an Archean basement of unknown composition and are intruded by Late Archean granite (≈2.65 Ga) and younger post-tectonic diorite (1.74 Ga) and granite (1.72 Ga). Although the basement rocks are not exposed in the uplift, Nd isotopic data on the granites indicate that they have Nd model ages in the range 2.8–3.1 Ga (Day and others, 1999), comparable to the ages of Precambrian basement rocks in other Laramide uplifts in Wyoming (Frost, 1993).

In previous reports (Sims and others, 1991; Day and others, 1999), an informal (lithologic) terminology was used for rocks of the Whalen Group. In this report, we propose a formal terminology for four formations in the Whalen Group, form oldest to youngest: (1) Mother Featherlegs Metabasalt, (2) Silver Springs Formation, (3) Wildcat Hills Formation, and (4) Muskrat Canyon Metabasalt. Distinct lithologic strata within the two sedimentary formations are referred to as units, such as quartzite units in both the Silver Springs and Wildcat Hills Formations.

MOTHER FEATHERLEGS METABASALT

Mother Featherlegs Metabasalt is named from the Mother Featherlegs cemetery alongside the Silver Springs road in the southern part of the Silver Springs quadrangle (sec. 27, T. 31 N., R. 64 W.), in Niobrara County. The metabasalt is exposed sporadically in a belt trending through most of T. 31 N. It is about 900 m wide and 8 km long; this belt is designated as the type area. The metabasalt also is exposed on the hill north-northeast of Guernsey. It is predominantly a dark-greenish-gray rock that ranges from medium-grained amphibolite to a fine-grained actinolite-biotite-chlorite schist. Some parts are layered, and pillows are present locally. Metabasalt near Guernsey has an estimated thickness of 150–180 m; that northeast of the cemetery is perhaps as much as 1,500 m thick.

SILVER SPRINGS FORMATION

The Silver Springs Formation is named from outcrops of subgraywacke and metashale in the vicinity of Silver Springs (SW1/4 sec. 11, T. 31 N., R. 64 W.), which is the type area.

The outcrops compose a north-trending belt as much as 900 m wide and 10 km long immediately east of the belt of Mother Featherlegs Metabasalt. The Mother Featherlegs Metabasalt is interpreted to be overridden by the metagraywacke along the Silver Springs thrust fault. Another large exposed area of the formation is in the vicinity of Haystack Range, in the western part of the Casebier quadrangle; the graywacke in this area is intruded by the 1.72 Ga Haystack Range Granite. In the vicinity of Hartville (Guernsey quadrangle), a ferruginous schist unit that hosts the hematite ore bodies in the Hartville district is interpreted (Sims and others, 1997) as being laterally equivalent to graywacke as exposed on the hill southwest of the Graves Ranch. The iron-bearing unit is considered as being part of the Silver Springs Formation. The Silver Springs Formation is absent in the central part of the Hartville uplift. The predominant rock type varies from gray, medium-grained, granular biotite-quartz-plagioclase schist and quartz granular metagraywacke to biotite-muscovite-garnet-sillimanite schist. The formation is estimated to range in thickness from 0 to 1,500 m.

WILDCAT HILLS FORMATION

The Wildcat Hills Formation is a metacarbonate unit named from outcrops on the east slope of Wildcat Hills. Outcrops form a narrow band extending south from Wildcat Hills to Hartville, where the rock is folded on east-trending axes. Another band of dolomite extends north from Muskrat Canyon to the vicinity of Rawhide Creek, west of the Hartville fault. A third area of outcrop is on the west flank of Rawhide Buttes. The type area is the Hartville-Sunrise area. In the type area, the formation contains abundant concentrically layered algal stromatolitic mounds, which have been used to determine stratigraphic way-up. The rock is predominantly gray, buff, pink, and white, medium-grained dolomite and siliceous dolomite, and locally limestone. In northern outcrops east of the Hartville fault, tremolite dolomite and chondrodite dolomite are common. Thicknesses range from 0 to about 1,500 m.

MUSKRAT CANYON METABASALT

The Muskrat Canyon Metabasalt is named from excellent exposures of metabasalt in Muskrat Canyon, which is the type area. The metabasalt extends continuously from Muskrat Canyon southward for a distance of 10 km on the east slope of Wildcat Hills. The rock is predominantly dark-green actinolite-biotite-chlorite schist. The metabasalt is locally pillowed; excellent pillows are exposed on the south bank of the stream in Muskrat Canyon. Thicknesses are estimated to range from 0 to about 1,500 m.

GRANITOID ROCKS

Rocks of the Whalen Group are intruded, from oldest to youngest, by the Rawhide Buttes Granite (2.66 Ga), Flattop Butte Granite (2.65 Ga), Twin Hills Diorite (1.74 Ga), and Haystack Range Granite (1.72 Ga) (Sims and others, 1997; Day and others, 1999). Compositionally, the three granites indicate successive origins through partial melting of crustal material. This observation is consistent with the Sm-Nd model ages (crustal-residence ages), which are considerably older than zircon and Rb-Sr crystallization ages.

The granite bodies have been described in the two previously published maps of the area (Sims and others, 1997; Day and others, 1999). A note of explanation for our interpretation of the northernmost granite body is warranted. We interpret this body as a buried, domal pluton of 1.72 Ga Haystack Range Granite because of (1) its geophysical expression (circular shape) and resemblance to the granite pluton exposed in the Haystack Range, to the south, and (2) the presence of 1.72 Ga granite gneiss (K.R. Chamberlain, oral commun., 1996) on the south (deformed) margin of the granite dome. This granite gneiss is interpreted by us to have been deformed during emplacement of the granite dome. An outcrop of granite within the outline of the buried body (see map) is a large Archean granite inclusion; an Archean age is indicated by the presence of mafic dikes in the granite body.

CHEMISTRY OF METAVOLCANIC ROCKS

The mafic metavolcanic rocks can be divided into two stratigraphic and geochemically distinct units: the Muskrat Canyon Metabasalt and the Mother Featherlegs Metabasalt. Rocks in both units occur as metamorphosed pillow lavas, as massive flows, and as gabbro sills and dikes. The major and trace element geochemistry for samples from the Mother Featherlegs Metabasalt is listed in table 2 and that for the Muskrat Canyon Metabasalt is given in table 3.

The Mother Featherlegs Metabasalt is distinguished from the Muskrat Canyon Metabasalt mainly on the basis of trace element geochemistry. Whereas both metabasalt units have similar major element geochemistry (tables 2 and 3), the Muskrat Canyon Metabasalt is enriched in light-rare earth elements (LREE), as shown in figure 5*A*. The Mother Featherlegs Metabasalt has a relatively flat REE pattern (fig. 5*B*). The relative enrichment of the Muskrat Canyon Metabasalt in the LREE abundance is also shown in figure 6. Both units show a similar range in SiO_2 content. However, the La/Lu normalized ratio for the Muskrat Canyon Metabasalt is greater than 2 (and as high as about 15) as compared with the Mother Featherlegs Metabasalt, for which the ratio remains less than 2 even for rocks of similar SiO_2 content.

STRUCTURE

The three compressional deformations (D_1–D_3) recognized in the Hartville uplift have been distinguished mainly by field relationships, particularly mesoscopic structures (foliations and lineations). Only one event, D_2 deformation, has been dated geochronologically (Day and others, 1999). The deformational episodes took place during the time span ≈2.0 Ga to 1.74 Ga and were followed by local doming related to post-tectonic (1.72 Ga) Haystack Range Granite bodies (table 1). The compressional deformations represent discrete orogenies; evidence for strain continuums is lacking.

D_1 DEFORMATION

Following deposition of the Whalen Group, fold nappes of regional extent produced widespread overturned beds. Inverted stromatolitic structures in metadolomite in the southern part of the uplift, near Hartville, suggest that these beds and possibly all of the section south of Hartville are upside down; the Sunrise syncline is a downward-facing syncline (Sims and others, 1997). Also, overturned quartzite crossbeds indicate inverted beds in the western part of Muskrat Canyon. Neither fold hinges nor an S_1 cleavage has been identified for the nappes, suggesting that the nappes could have formed by soft-sediment deformation, as suggested by Hudleston (1976) for similar folds in Archean graywacke in northern Minnesota. The strata east of the Hartville fault generally lack "way-up" sedimentary structures because of the amphibolite-grade metamorphism and internal shearing.

D_2 DEFORMATION

Following nappe formation and the emplacement of Late Archean granite plutons and ≈2.0 Ga mafic dikes (table 1), D_2 deformation folded the supracrustal rocks, the granite bodies, and probably the basement. F_2 folds trend east-west, are generally tight to moderately open and overturned to the south, and have north-dipping axial surfaces and an accompanying axial-planar cleavage (fig. 7*A*). S_0–S_2 intersection lineations (L_2) and related F_2 fold axes plunge moderately to gently westward (fig. 7*B*). The D_2 flexures are similar-type folds, and accordingly it is probable that the compressional axis for folding was approximately north-south.

D_2 folds are exposed in the Hartville area and areas to the south, where D_3 and younger structures are absent in outcrop (Sims and others, 1997). In a transitional zone about 3 km wide parallel to the trend of uplift, extending northward beyond the Chicago mine (fig. 2), D_3 structures are variably superposed on D_2 structures. Notably, the fold axis of the Sunrise syncline is bent from its original east-west trend to a northeast strike; also, intersections of D_3 structures with older, largely obscured F_2 folds plunge either to the south or north, depending upon which limb of the original D_2 fold is involved. A pre-D_3 prominent west-northwest-trending foliation, and more rarely a lineation, are present on the western side of the uplift northward from the transition zone to the northern limit of the Hartville uplift; we interpret these pre-D_3 structures as S_2 and L_2, respectively. S_2 structures have been reoriented, generally to a northeast trend, whereas L_2 generally plunges east-southeast.

Because D_2 deformation was of regional scope, we propose the name "Oregon Trail orogeny" for this deformation. The type area for the D_2 deformation is that between Guernsey and Hartville (Sims and others, 1997).

D_3 DEFORMATION

D_3 deformation was the major compressive event in the Hartville uplift. It produced a north-trending foreland fold-and-thrust belt that parallels the axis of the uplift and spans the length of it. Of the several D_3 thrust faults, the principal one is the Hartville fault, which juxtaposes middle amphibolite facies rocks on the east with upper greenschist facies rocks on the west. Based on the petrology and mineralogy, the eastern block is estimated to have been uplifted about 5 km relative to the western block (K.R. Chamberlain, University of Wyoming, oral commun., 1993). Where exposed in the Hell Gap quadrangle (location A, fig. 2), the Hartville fault is a nearly vertical, 100-m-wide mylonite zone that has a steep stretching lineation and a late component of sinistral strike-slip offset. D_3 folds are present throughout the uplift north of the Chicago mine (fig. 2). The folds are upright to recumbent, west-vergent structures that fold an older (D_2) foliation (fig. 7*A*); S_3 is poorly developed in many areas (see for example, fig. 8*A*). The folds plunge both to the south and north, but mainly plunge north (fig. 8*B*).

At places within mylonitic zones in the northern part of the Hartville uplift, a moderately plunging stretching lineation bearing about N. 45° W. is present. These areas are shown by heavy arrows on the map. The stretching lineation is interpreted as local high strain areas in the D_3 deformation. It represents the X-axis of the strain ellipsoid (maximum extension) and thus indicates the direction of tectonic transport during D_3 deformation.

D_4 DEFORMATION

Local deformation related to doming around two subcircular Haystack Range Granite bodies interrupts the trends established by the older regional compressional events. Both granite bodies are in the hanging (east) wall of the Hartville fault. The southern body is moderately well exposed about 6 km east of Hartville (Sims and others, 1997). The body has a weak internal foliation, interpreted as a primary flow structure, that is accentuated at the margins. Steeply dipping foliation in the biotite-quartz-plagioclase schist host rock wraps around the northern and western margins of the granite body (Sims and others, 1997). A second dome lies in the northern part of the uplift, about 4 km north of Rawhide Buttes. The northern granite body is not exposed, but can be outlined on the basis of (1) its having greater magnetic susceptibility than surrounding country rocks and (2) the dome-shaped conformable foliation in surrounding rocks. On the south side of the dome, in section 31, T. 31 N., R. 63 W., and on Bald Butte, to the south, tongues of Haystack Range Granite, now granite gneiss (unit Xhg), are infolded with the metamorphosed Whalen Group rocks. A sample of the granite gneiss has been dated by the U-Pb zircon method at ≈1.73 Ga (K.R. Chamberlain, University of Wyoming, written commun., 1997), indicating that it is a metamorphosed equivalent of the Haystack Range Granite. The granite gneiss has a pronounced steep stretching lineation caused by upward, plastic transport of the dome during granite emplacement. Also, doming at this locality rotated older D_3 structures from a northeast to a northwest trend, as can be seen on the geologic map.

At Bald Butte (sec. 31, T. 31 N., R. 63 W.), large-scale mullions that plunge steeply southwest—parallel to the stretching lineation—are exposed in quarry walls. The mullion structures warp older northwest-trending foliation interpreted as S_2.

POSTDEFORMATION EVENTS

Following development of the granite domes (D_4 deformation; table 1), two unrelated events are recorded in the uplift. Krugh and others (1993) obtained a monazite age of 1.66 Ga from a phase of the Rawhide Buttes Granite, which has a zircon crystallization age of circa 2.4 Ga. Krugh and others (1993) interpreted the monazite age as marking a prograde metamorphic event possibly related to the tectonism within the Central Plains orogen. Lacking structural evidence for a late event, we interpret the age as a cryptic thermal event of unknown cause. Scattered mafic dikes (Ym) in the southern part of the uplift are presumed to be related to emplacement of the 1.4 Ga Laramie anorthosite complex and the Sherman batholith.

CORRELATION OF DEFORMATION EPISODES

The compressional deformations in the Hartville uplift, D_1 through D_3, represent distinct, separate tectonic events. The sequence of events has been determined by geologic observations, mainly superposition of older mesoscopic structures by younger ones. The deformation events took place in the interval 2.6–1.74 Ga, but only D_2 has been dated isotopically. The 2.65 Ga Flattop Butte Granite has a Rb-Sr whole-rock age of 1.98 Ga where deformed by D_2; this age is interpreted as a metamorphic (D_2) age (Zell Peterman, *in* Day and others, 1999).

D_1 deformation (nappe formation) followed an unknown period of time after deposition of the Whalen Group rocks; deposition preceded 2.65 Ga, the age of the Flattop Butte Granite, which intruded the Whalen Group rocks. The absence of an associated axial-planar fabric suggests that the nappes could have formed by soft-sediment deformation.

Following nappe formation and emplacement of the Late Archean granite bodies, D_2 deformation was developed throughout the Hartville uplift. F_2 folds are preserved as the youngest exposed structures in the area south of Sunrise. (See map, and recall discussion of D_2 folds, p. 4.) North of Sunrise, the F_2 folds are overprinted by D_3 structures, and in the northern part of the uplift D_2 is represented by a prominent pre-D_3 foliation, and more locally, a lineation. Possibly D_2 is correlative with north-vergent thrusting on the Reservoir Lake fault (Houston and Karlstrom, 1992) in the Medicine Bow Mountains. In the Medicine Bow Mountains, Karlstrom and others (1981) assigned deformation of rocks north of the Reservoir Lake fault to their D_2; this deformation preceded intrusion of gabbroic sills in the Deep Lake Group, whose intrusive age is 2,092±4 Ma (Houston and Karlstrom, 1992, p. 39). The Reservoir Lake fault and adjacent rocks were folded later by their D_3, caused by collision along the 1.78–1.76 Ga Cheyenne belt.

D_3 deformation is attributed to the Trans-Hudson orogeny inasmuch as D_3 structural trends are northerly, subparallel to the trend of the western margin of the Trans-Hudson orogen (Sims and others, 1991; this report, fig. 3). The direction of tectonic transport during D_3 deformation was mainly N. 45° W., which is compatible with the Trans-Hudson orogeny. Its age is intermediate between 1.98 Ga and 1.74 Ga, which is consistent with the age of the culmination of metamorphism (circa 1.81 Ga) in the orogen in northern Saskatchewan (Lewry and others, 1996). The location of the Hartville uplift relative to the Trans-Hudson orogen is analogous to the Wollaston domain of the Cree Lake mobile belt in northern Saskatchewan (Annesley and others, 1992).

Although deformation related to the Cheyenne belt (1.78–1.76 Ga) has been recognized in the adjacent Laramie Mountains by isotopic data (Chamberlain and others, 1993; Resor and others, 1996), this deformation has not been definitely recognized in the Hartville uplift. The above authors have shown that the Laramie Peak shear zone, which is in the Laramie Mountains about 65 km north-northeast of the Cheyenne belt, was deformed at 1.76 Ga, concurrent with movement on the Cheyenne belt. We considered the stretching lineations indicated by the heavy arrows in the northern part of the map area as possibly being related to Cheyenne belt deformation, but lacking definitive age data on the mylonite we now interpret these stretching lineations as late stage D_3 deformation structures.

Laramide deformation had minimal effect on the Precambrian rocks in the Hartville uplift. During this deformation, the Precambrian rocks were gently uplifted, as indicated by nearly horizontally bedded Paleozoic rocks in the core of the uplift and gently outward dipping Paleozoic rocks on each flank. An exception occurs in the valley of Whalen Canyon in the northern part of the uplift (Niobrara County and adjacent Goshen County to the south). In this area the Paleozoic rocks have a homoclinal dip to the west of about 45° as a consequence of Laramide(?) normal faulting (Day and others, 1999).

OUTLYING AREAS

Precambrian rocks are exposed at five localities outside of but near the Hartville uplift, from north to south, (1) Sullivan Ridge, 10 km north of Lusk; (2) Lusk; (3) Lone Tree Hill, in Niobrara County; (4) Cassa anticline, in Platte County; and (5) Antelope Hills, in Platte County (fig. 9). Approximate modes of selected granitoid rocks are given in table 4.

SULLIVAN RIDGE

Metagraywacke (biotite-muscovite schist) is exposed sporadically on Sullivan Ridge, in Niobrara County. The unit presumably belongs to the Silver Springs Formation. Foliations strike about north and dip steeply. This structure is interpreted as deformation D_3.

LUSK AREA

Metagraywacke (biotite-muscovite schist), presumably a part of the Silver Springs Formation, is exposed locally in the western part of Lusk, on both sides of the Niobrara River. The schist has a strong foliation (N. 2°–5° E.) that dips 60°–85° E. and a stretching lineation that plunges about 72° S. 80° E. This structure is interpreted as deformation D_3.

LONE TREE HILL

Medium- to coarse-grained augen granite gneiss and biotite granite are exposed sparsely on Lone Tree Hill. The granite is inferred to be equivalent to the Rawhide Buttes Granite. The gneiss has a foliation of N. 70° W. (dip 55° N.) and a west-plunging lineation, indicating deformation by D_2.

CASSA ANTICLINE

Biotite-quartz-plagioclase augen gneiss, muscovite schist, and crosscutting foliated granodiorite are exposed along the axis of the Cassa anticline. Possibly the granodiorite is correlative with the 2.66 Ga Rawhide Buttes Granite, and if so, the layered gneiss represents Archean basement. Rb/Sr model ages on the gneiss range from 2.85 to 3.3 Ga, which supports an affinity with the basement (Peterman and others, *in* Day and others, 1999). A U-Pb zircon age of 2.36 Ga is anomalously young (the zircons are metamict). Foliations in the rocks trend about N. 40° E., but have been reoriented by the Laramide deformation. We interpret the deformation as D_2.

ANTELOPE HILLS

Biotite-quartz-plagioclase-microcline gneiss (table 2), amphibolite, marble, and quartzite are exposed sparsely in the Antelope Hills, 13 km south of Guernsey, on the south side of Grayrocks Reservoir. These rocks are intruded by bedding-parallel tourmaline-bearing pegmatite. The pegmatite and supracrustal rocks are highly deformed (deformation D_2). The foliation is folded into a Z-fold that lacks an axial-planar cleavage; possibly the folding is Cheyenne belt deformation.

DISCUSSION

Areas adjacent to the Hartville uplift, as defined here, provide additional insights into the Precambrian geology of the region. Outcrops of metagraywacke at Lusk and Sullivan Ridge and supracrustal rocks in the Antelope Hills area extend the strike length of Whalen Group rocks to a total distance of at least 85 km, supporting interpretation of these rocks as largely composing a north-trending continental Archean margin assemblage.

To the west of the exposed metasedimentary and metavolcanic rocks, granite and gneiss are exposed locally in faulted Laramide anticlines of small scale. At Lone Tree Hill, foliated biotite granite (HU-18, table 4) cuts granodioritic gneiss, suggesting that the gneiss is basement, possibly older than 2.9–3.0 Ga. Similarly, foliated granodiorite cuts a granitic gneiss, which also is possible basement of the Wyoming province.

At the Lone Tree Hill and Cassa anticline localities, the Precambrian rocks were deformed by D_2 deformation (fig. 9). Similarly at the Antelope Hills locality, the rocks were deformed by D_2, then subsequently folded, possibly by the Cheyenne belt (1.78 Ga) deformation. At Lusk and Sullivan Ridge, the graywacke was folded by D_3 deformation; this deformation folded a foliation presumably of D_2 origin.

MINERAL DEPOSITS IN THE HARTVILLE UPLIFT

By

Terry L. Klein

INTRODUCTION

Mineral production began in the Hartville uplift as early as 1880, with the production of copper in the Hartville district. Shortly after copper production ceased, mining of hematitic iron deposits associated with these copper deposits began in 1898 and continued for more than 80 years. Volumetrically, the major mineral commodity produced from the uplift has been iron. Currently, the only commodity being produced is crushed stone from metadolomite near Guernsey, Wyo. In addition to iron, copper, and crushed stone, minor amounts of muscovite, gold, silver, uranium, and ornamental stone have been produced from the uplift. Most of the mineral production has come from metasedimentary units of the Whalen Group. Of the eight commodities produced in the uplift, this report covers only deposits of iron, copper, uranium, and pegmatite-related minerals.

IRON DEPOSITS

Iron was first produced from the Sunrise mine in the Hartville district in 1898, after the site was initially developed in the early 1880's for copper. The district is located in the southern part of the map area (secs. 5, 7, and 8, T. 27 N., R. 65 W.) near the town of Hartville. It includes the Sunrise mine and three other nearby mines, the Chicago, Central, and Good Fortune, which were developed on the same iron-rich ore zone, as well as several copper deposits (for example, the Empire and Green Mountain Boy). These iron mines produced direct-shipping hematite ore for the Colorado Fuel and Iron Corporation open-hearth furnaces in Pueblo, Colo. At the time mining ceased at the Sunrise mine in 1980, the district had produced about 41 million t (metric tons) of iron ore (Hausel, 1989).

Two distinct types of iron deposits occur in the Hartville uplift: (1) structurally controlled pods of soft, earthy, massive hematite ore that grades downward to a vuggy to massive, bluegray, specularite ore (for example, deposits of the Hartville district), and (2) layers of Lake Superior-type hematite-quartz iron-formation (for example, Michigan mine). Both types are associated with iron-rich schist (Sims and others, 1997), immediately below the contact with overlying metadolomite in the Whalen Group.

The iron-rich layer along which the iron deposits in the Hartville district are distributed is folded by east-trending folds related to deformation D_2. All the large mines in this district are located in the same stratigraphic position within iron-rich biotite schist, which was probably derived from a pelite protolith, immediately below the contact with metadolomite (fig. 10). The Sunrise ore body is located in a steeply easterly plunging fold that is S-shaped in map view (Osterwald and others, 1966) and extends to a depth of at least 300 m (Ball, 1907a). Oxidation resulting in soft, earthy hematite ore extends to about 60 m below the present-day surface (Osterwald and others, 1966). The origin of the deposits is problematic. Much of the soft, earthy hematite ore in the upper parts of the deposits was the product of ground-water oxidation of the gray specularite ore; this oxidation occurred after the deposition of the Mississippian Guernsey Formation. Ball (1907a) described earthy hematite pseudomorphs after rounded specularite pebbles and cobbles in the basal conglomerate of the Guernsey Formation, indicating that the oxidation of specularite took place after the deposition of the Guernsey Formation. In addition, oxidation must have taken place along the pre-Mississippian unconformity. A zone rich in earthy hematite replacing, in part, massive specularite ore in Precambrian rocks parallels the unconformity generally to a depth of 10–20 m (Chance, 1897). Earthy hematite is also concentrated along fractures extending downward from the unconformity into the specularite ore below the level of general oxidation, indicating that oxidizing fluids migrated downward. The distribution of the vuggy, massive, and (or) brecciated specularite ore follows an iron-rich sedimentary protolith layer that was folded by D_2. Alteration of the sedimentary protolith by fluids to form specularite probably took place after D_2 folding, as suggested by the lack of penetrative fabric in the specularite ore. However, the character of the iron-rich protolith and the source and physical character of the altering fluids are not known.

In the area of the Michigan mine (sec. 24, T. 30 N., R. 65 W.) in Muskrat Canyon (in the central part of the uplift) three layers of hematitic iron-formation lie in moderately east dipping slates that are interbedded with a thin- to thick-bedded quartzite unit of the Whalen Group. The western contact of the thickest (westernmost) iron-formation with metadolomite is a northwest-trending, steeply east dipping normal fault. A small amount of iron was produced from this mine. Iron ore reserves at the mine were estimated to be about 105 million t averaging about 25 percent iron. Several grab samples were reported to contain about 1 percent copper (Hausel, 1989).

COPPER DEPOSITS

Copper was the first commodity mined in the Hartville uplift. During the period 1880–1887, several mines in the area now covered by the Sunrise mine produced more than 630 t of copper and more than 70 kg of silver (Hausel, 1989) from oxide and carbonate deposits lying above the hematitic iron ore near the Paleozoic unconformity. In addition, about 100 t of copper was produced from hematitic iron-formation at the Michigan mine (Knight, 1893), about 185 t of copper and 8.5 kg silver from a replacement deposit at the Green Mountain Boy mine (sec. 36, T. 27 N., R. 66 W.), and about 85 t of copper from the Greenhope mine (sec. 26, T. 29 N., R. 65 W.).

Three types of copper deposits are present in the uplift: (1) copper sulfides in sediment-hosted massive sulfide deposits—for example, Omaha mine (sec. 2, T. 30 N., R. 64 W.), Empire mine (sec. 12, T. 27 N., R. 66 W.), and Charter Oak prospect (sec. 26, T. 27 N., R. 65 W.); (2) disseminated copper sulfide deposits in shear zones—for example, prospects in Muskrat Canyon (sec. 19, T. 30 N., R. 64 W.) and the Copper Bottom prospect (sec. 23, T. 29 N., R. 65 W.); (3) copper oxide and carbonate replacement deposits associated in the basal Guernsey Formation—for example, Green Mountain Boy and the Greenhope mines, or immediately below the Paleozoic/Precambrian unconformity in iron-rich rocks—for example, copper in the Sunrise and Michigan mines. Both gold and silver are associated with shear zone-hosted copper deposits, sediment-hosted massive sulfide deposits, and copper deposits in iron-formation.

Sediment-hosted massive sulfide deposits

Several prominent gossans overlie massive sulfide lenses in a muscovite schist unit in the Whalen Group in the Silver Springs quadrangle (for example, in sec. 23, T. 31 N., R. 64 W.) and in the Omaha mine area, south of Flattop Butte. The zones are typically associated with layers of graphitic metapelites and cherty exhalites within muscovite schist; some zones are also associated with thin carbonate layers in the schist. Throughout the map area most of these zones are at or near the transition between metapelite and metadolomite. A schematic stratigraphic section for the Hartville uplift (fig. 10) illustrates that not only are cherty exhalites and massive sulfides interpreted to be associated with this transition, but also the Sunrise-type hematite ore. At the Omaha mine, a thin layer of mineralized schist and a cherty exhalite layer lying between two thick metadolomite layers were exploited. At the Gold Hill mine, which is located about 150 m N. 30° E. of the Omaha mine along the same cherty exhalite layer, ore samples assayed 6 percent copper and 6.9 g/t gold (recalculated from Ball, 1907b). The deposits in this area contain copper carbonates and silicates at the surface; below the weathering zone, chalcopyrite is the dominant copper mineral, and barite is reported to be a common gangue mineral in these deposits (Ball, 1907b). The adjacent Copper Belt mine (sec. 11, T. 30 N., R. 64 W.) was developed to a depth of about 90 m and included more than 1,000 m of underground workings (Osterwald and others, 1966). This deposit is along and adjacent to a D_3 thrust that is characterized by some left-lateral displacement. The deposit consists of two ore lenses that range from 0.3 to 1 m thick and which assayed from 2 to 8 percent copper, 1.7 to 20 g/t gold, and 69 to 170 g/t silver (Ball, 1907b). These lenses are hosted by biotite schist (metapelite) immediately below a 1-m-thick metadolomite layer. All these deposits show some remobilization of sulfide minerals from massive sulfide/cherty exhalite layer into discordant veins. These veins may have developed during D_3 folding. Two laterally extensive exhalite units are recognized in this area, the most continuous of which can be traced for at least 1 km; they outline a large F_3 fold southwest of the Omaha mine. The Empire mine, about 1 km southwest of the Sunrise mine, is a metadolomite-hosted exhalite-associated copper deposit similar to the Omaha and Gold Hill mines.

In the McCann Pass area, located in the southeastern part of the map area, several strata-bound sulfide-rich lenses are exposed as gossans along the west-northwest-striking McCann Pass fault and north of the fault where the lenses are conformable to bedding (S_0) in schist. These gossans are associated with a thick graphite-rich metapelite (Ball, 1907b) which contains fine-grained quartz-rich rocks that are probably metamorphosed siliceous exhalites. The Charter Oak prospect is the most significant in this area. Copper minerals in this prospect include malachite, chrysocolla, and chalcocite which are found in a zone about 1 m wide. Assays of as much as 33 g/t gold and 150 g/t silver were reported by Ball (1907b). These gossans are composed of siliceous breccia clasts in an earthy hematitic matrix and were derived by weathering of the primary sulfide minerals, pyrrhotite, pyrite, and chalcopyrite. This sulfide mineral assemblage was encountered during exploration drilling in the 1970's (Zahoney, 1976). Chemical analyses of surface samples from the McCann Pass gossan lens, which is about 1 km long and 100 m thick, yield values of 20–300 ppm copper, 200–900 ppm zinc, as much as 7,000 ppm arsenic, and 30–3,000 ppm boron (Zahoney, 1976). In the northern part of the Hartville uplift, gossans occur in several places (for example in the western part of sec. 23, T. 31 N., R. 64 E.), and are similar to those described at McCann Pass. These deposits share many characteristics with Besshi-type massive sulfide deposits, including host-rock lithology (pelitic sedimentary rocks), associated rock lithology (mafic volcanic rocks), tectonic setting (continental margin), and principal sulfide mineral assemblage (pyrrhotite, pyrite, chalcopyrite) (Slack, 1993). Metal ratios of the deposits in the Hartville uplift (Cu/Zn, Zn/Pb) are not known because of the lack of samples from unoxidized sulfide-bearing rock units.

Disseminated copper sulfide deposits in shear zones

Several prospects in Muskrat Canyon and along the Hartville fault, near Hell Gap (secs. 2 and 10, T. 29 N., R. 65 W.), contain disseminated secondary copper minerals associated with quartz-calcite veins in graphite-rich rocks. Locally abundant graphite is associated with alteration in metadolomite and probably formed from leaching of carbonate rocks by hydrothermal fluids focused along the shear zones. This leaching caused a residual enrichment of insoluble carbon from the metadolomite to form graphite. The prospect in Muskrat Canyon is located in metadolomite of the highly deformed footwall along the Muskrat Canyon fault. Malachite and chrysocolla, associated with iron oxide lenses in quartz veins or as fracture coatings on graphitic rocks or metadolomite, are locally abundant. Quartz and calcite stringers and pods are exposed in the prospect where they are enclosed in an intensely deformed graphite-rich zone that ranges from 0.1 to 0.3 m wide. Locally, thin crossfiber tremolite veins are generally conformable to the trend of the graphitic vein but formed later than minor folds in surrounding graphite; these veins indicate that high-temperature hydrothermal activity took place after deformation. Regionally, exploration drilling along these graphitic zones has encountered zinc and gold concentrations in disseminated sulfide minerals of as much as 1.2 percent and 2.4 g/t, respectively (Woodfill, 1987).

In a prospect near the southwest corner of sec. 10, T. 30 N., R. 64 W., a large quartz vein containing copper minerals (azurite, malachite, and chalcopyrite) was emplaced in Archean granite along the Little Wildcat fault, a D_3 structure. The quartz vein is sheared parallel to the tectonic foliation associated with the fault as are ore minerals within the vein. This vein is as much as 10 m thick and is continuous for at least 150 m. Farther north along the Little Wildcat Canyon fault in SE 1/4 sec. 5, T. 30 N., R. 64 W., low-level gold enrichment (0.1 ppm Au) accompanies copper minerals in a large, strongly deformed quartz vein at the faulted contact of gneissic Rawhide Buttes Granite and metadolomite (T.L. Klein and W.C. Day, unpub. data, 1997). Silicic and propylitic alteration is common in the footwall along the exposed length of the Little Wildcat Canyon fault.

The structures (D_3) that control these copper and precious-metal deposits in the Hartville uplift are similar to those controlling low-sulfide quartz-Au deposits in metamorphic terranes throughout the world (that is, reverse/tranpressive regional faults). Faults or shear zones with a reverse sense of movement are typically the principal controlling structures for epigenetic precious-metal mineralization, at both regional and local scales (see Hodgson, 1989; Poulsen and Robert, 1989). These faults and shear zones also typically have a component of lateral movement. Within these compressive domains, precious metals are generally localized in tensional environments (dilational zones) produced during deformation and (or) in related secondary structures. Deposition also preferentially occurs in lithologies and (or) environments where rocks in the shear zones behaved in a brittle or brittle-ductile manner during deformation.

Copper oxide and carbonate replacement deposits

Much of the early copper production from the Hartville area was from copper oxide and carbonate replacement deposits located near the Paleozoic unconformity in the basal Guernsey Formation. The deposits occur in both carbonate rocks and the coarse basal conglomerate of the Guernsey Formation and below the Paleozoic/Precambrian unconformity iron-rich Precambrian rocks. One of the largest deposits in the Guernsey Formation, the Green Mountain Boy mine, is located near the site of the present-day dolomite quarry east of Guernsey, Wyo. It consisted of a thick, keel-shaped chalcocite replacement body in the Guernsey Formation (Ball, 1907a). As much as 500 t of high-grade copper ore (37 percent copper and as much as 17 g/t silver) was produced from this deposit (Ball, 1907a). At the Greenhope mine, north of Hell Gap, secondary copper minerals occur in the basal Guernsey Formation along the Paleozoic/Precambrian unconformity. The underlying metadolomite of the Whalen Group is characterized by the development of small-scale karst features (Ball, 1907a).

Copper deposits in iron-formation and other iron-rich rocks were economically important in the early history of mining in the uplift. All the ore that was exploited consisted of secondary copper minerals. The Village Belle mine produced significant amounts of copper from the Precambrian hematite-rich rocks in the area of the later Sunrise iron mine. The copper was primarily enriched in permeable zones related to fractures in the iron-rich rocks (Ball, 1907a). This mine site was destroyed during development of the Sunrise mine. Most of the development on the iron-formation at the Michigan mine was for copper in the early 1880's. Copper carbonate and silicate minerals are disseminated in the iron-formation in the hanging wall of the northwest-trending normal fault that forms the western contact of the iron-formation and in both iron-formation and basal Guernsey Formation along the Paleozoic/Precambrian unconformity. The copper at both of these deposits appears to be supergene in origin, probably related to low-temperature meteoric water migrating along the base of the Paleozoic sedimentary rocks. A hypogene source of copper has not been identified for these two deposits.

MINERAL DEPOSITS IN PEGMATITES

Small amounts of muscovite were produced between 1881 and 1900 from pegmatites associated with the Haystack Range Granite near the south end of the Hartville uplift (T. 27 and 28 N., R. 65 W.). These bodies are the youngest phases of the Haystack Range Granite (1.72 Ga). In the northern part of the uplift near Silver Springs (T. 31 and 32 N., R. 64 W.), pegmatite bodies were prospected for beryl (Osterwald and others, 1966). All the pegmatite bodies in the Hartville uplift are relatively small and from poorly zoned to well zoned; most contain minor amounts of tourmaline and beryl (Ball, 1907c). The pegmatites associated with the Haystack Range Granite are discontinuous bodies ranging from 10 to 100 m in length. They intruded along the principal schistosity related to D_4, which forms a domal pattern (Hanley and others, 1950; Sims and others, 1997), but they do not exhibit a penetrative fabric. Pegmatite bodies in the northern part of the Hartville uplift are as much as 350 m long and 60 m wide, roughly parallel to S_2, and deformed by D_3 folds. Pegmatites throughout the uplift generally occur within muscovite-rich (metapelitic) schists in the Whalen Group.

URANIUM DEPOSITS

Uranium has been produced in the Hartville uplift from the Silver Cliff mine, located approximately 1 km north of the map area at Lusk, Wyo., and from several prospects in the map area. Uranium, as well as silver and copper, at the Silver Cliff mine is enriched in a carbonate-rich, brittle, northeast-trending reverse fault that is probably Laramide in age. This fault produced a gouge zone as much as 1 m thick in basal Paleozoic rocks (Wilmarth and Johnson, 1954); it is coincident with a portion of a Precambrian shear zone that controlled primary copper and low-grade gold mineralization. Production of six carloads of uranium ore containing 3 percent U_3O_8 was recorded from 1918 to 1922 (Osterwald, 1950).

Anomalous radioactivity has been recorded in many prospects throughout the Hartville uplift; several prospects have produced a few tons of low-grade uranium ore (for example, the gossan in sec. 23, T. 31 N., R. 64 W.). Several are associated with the earthy hematite in gossans that developed from weathering of the sediment-hosted massive sulfide deposits or graphite-rich zones in metasediments of the Whalen Group. These deposits were probably formed by the reduction of dissolved uranium by graphite or sulfide minerals in rocks of the Whalen Group. Uranium may have been transported along Laramide(?) fault or fracture zones by oxygenated low-temperature meteoric water and then precipitated at or below the Precambrian/Paleozoic unconformity by reductants along the unconformity and in the Precambrian rocks. Uranium at the Silver Cliff mine is primarily concentrated in sandstone and conglomerate at the base of the Guernsey Formation. Here, uraniferous ground water was concentrated along a Laramide structure and was precipitated in subsidiary fractures in the locally carbonate rich Paleozoic clastic rocks in the footwall of the Laramide fault (Wilmarth and Johnson, 1954).

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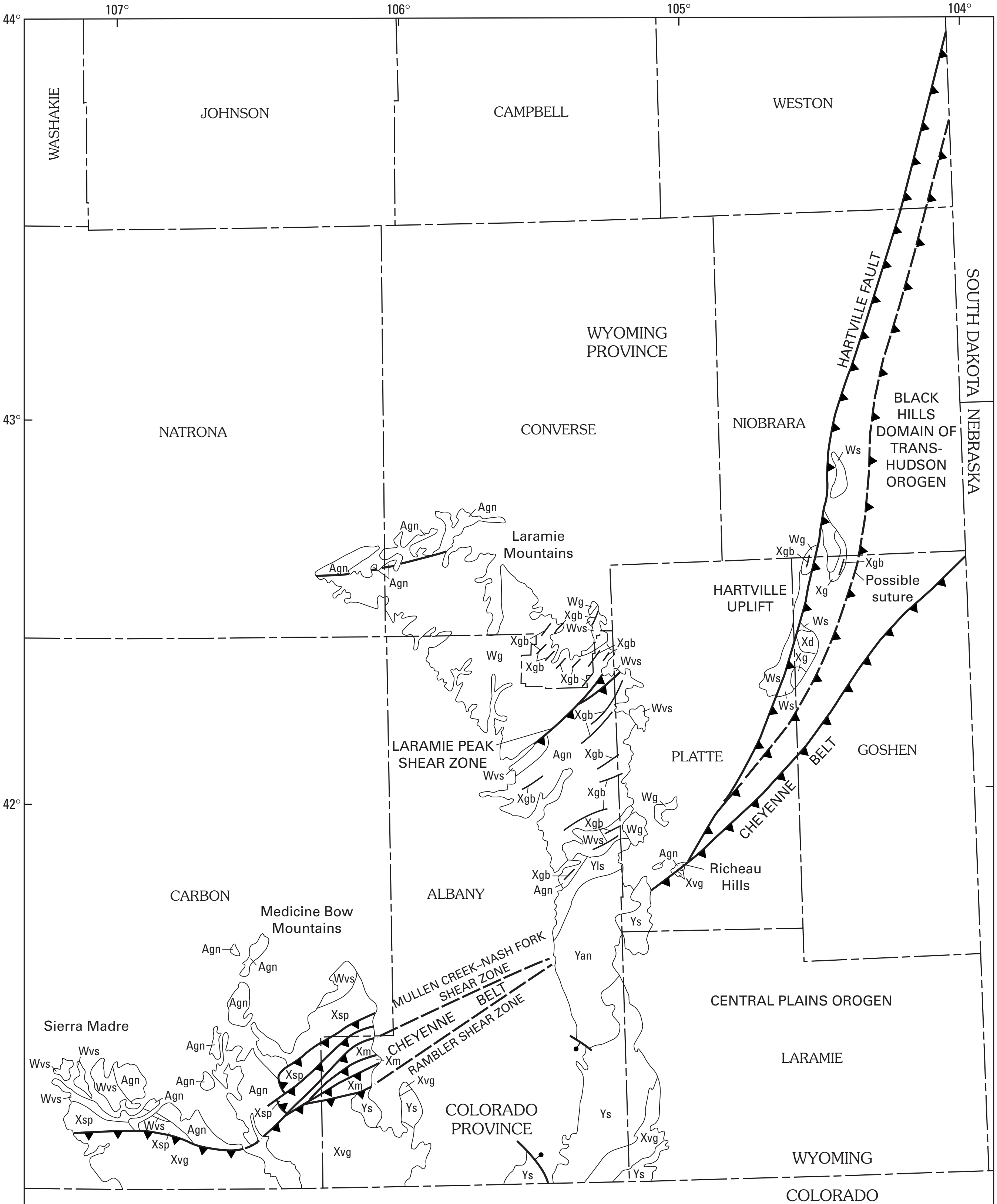


Base from U.S. Geological Survey
Wyoming State base map, 1:500,000, 1964
Revised 1980

0 25 50 100 KILOMETERS

EXPLANATION

MIDDLE PROTEROZOIC

Yls	**Syenite of Laramie Mountains (1.43 Ga)**
Yan	**Anorthosite of Laramie Mountains (1.43 Ga)**
Ys	**Sherman Granite**

EARLY PROTEROZOIC

Xg	**Haystack Range Granite, Hartville uplift (1.72 Ga)**
Xd	**Twin Hills Diorite, Hartville uplift (1.74 Ga)**
Xvg	**Metamorphosed volcanic and sedimentary rocks and mafic to felsic intrusive rocks of Colorado province (Central Plains orogen) (1.8–1.63 Ga)**
Xm	**Mylonite and granite in Cheyenne belt, Medicine Bow Mountains**
Xgb	**Metamorphosed mafic dike (≈2.0 Ga)**
Xsp	**Metasedimentary rocks of Snowy Pass Supergroup, Sierra Madre and Medicine Bow Mountains**

ARCHEAN

Wg	**Granite of Laramie Mountains and Hartville uplift (Late Archean)**
Ws	**Ferruginous schist, including iron-formation, metadolomite, and metabasalt (Whalen Group) of Hartville uplift (Late Archean)**
Wvs	**Metavolcanic and metasedimentary rocks (Late Archean)**
Agn	**Paragneiss and orthogneiss**

Contact

Fault—Bar and ball on downthrown side

Thrust fault—Dashed where inferred. Sawteeth on upper plate

Figure 1 (above and facing page). Geologic-tectonic map of Precambrian rocks exposed in Laramide uplifts, southeast Wyoming. Modified from Sims (1995).

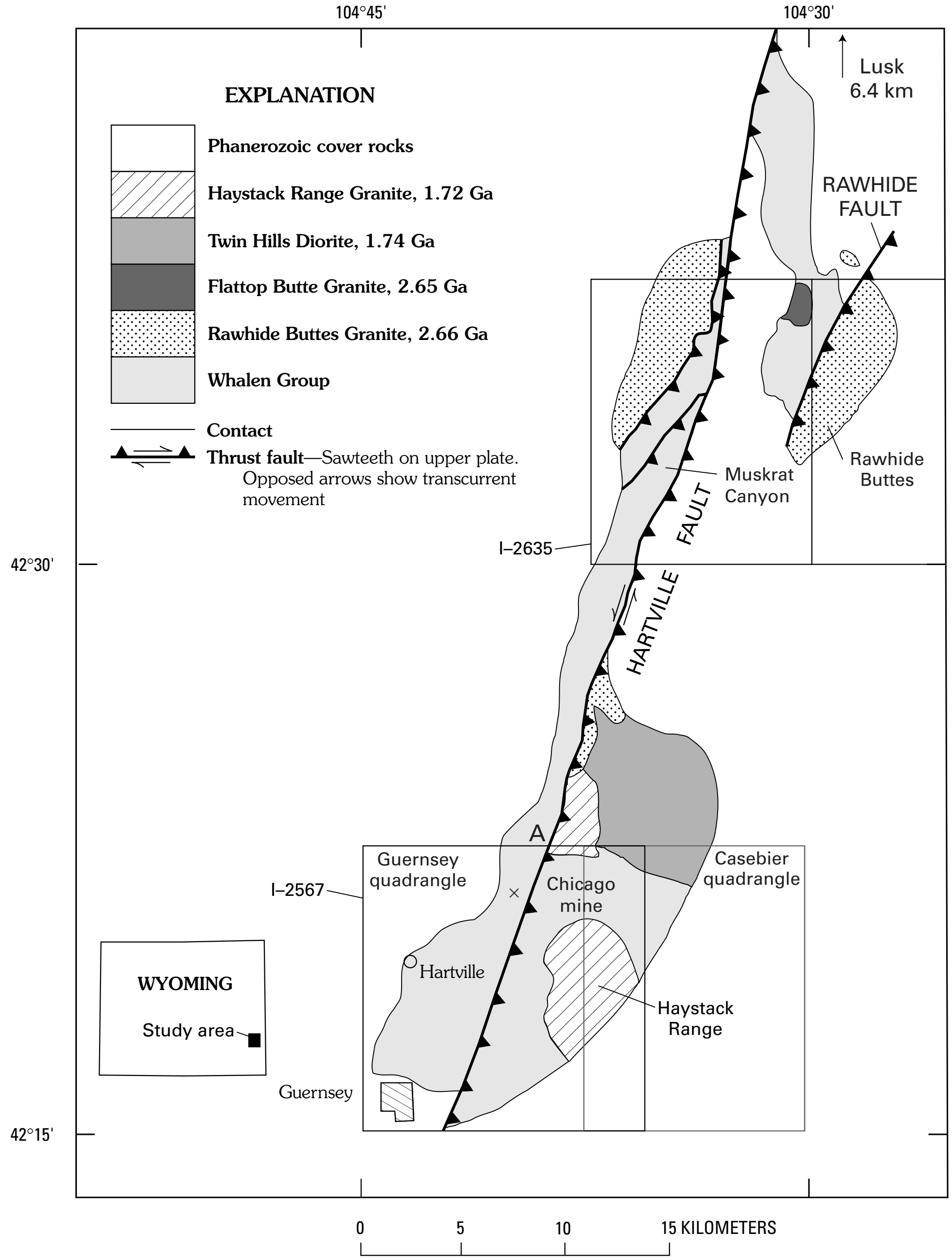
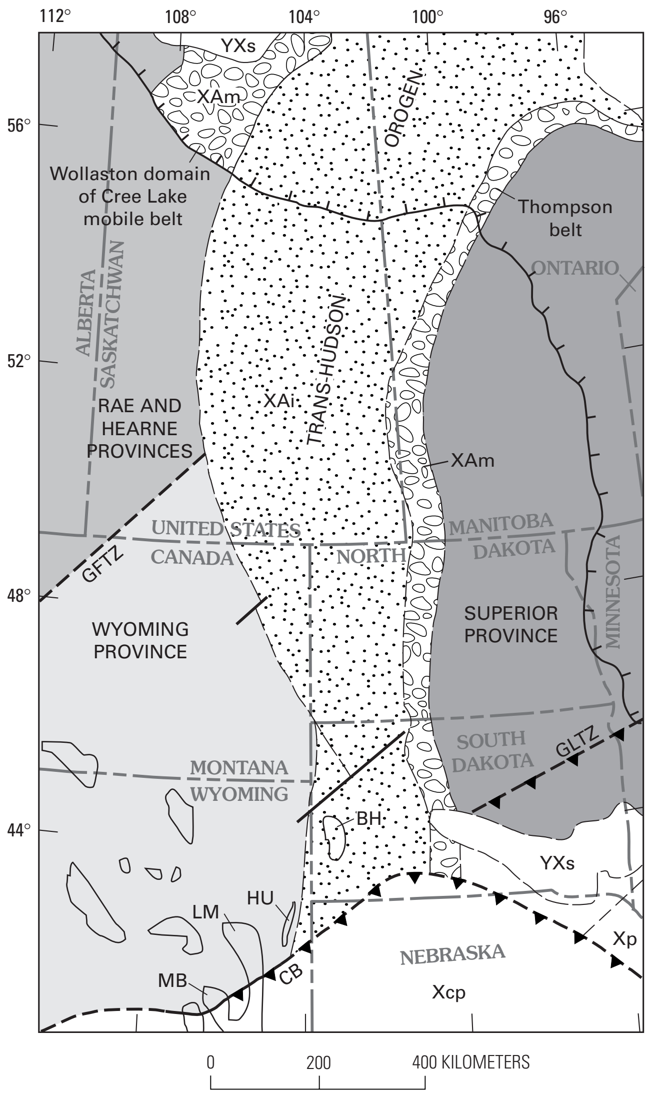


Figure 2. Simplified geology of Precambrian rocks of Hartville uplift, southeastern Wyoming. Location of published geologic maps shown for reference. A, Hartville fault exposed near Hell Gap.



EXPLANATION

MIDDLE AND EARLY PROTEROZOIC

YXs — **Athabasca Sandstone and Sioux Quartzite**

EARLY PROTEROZOIC (2.5–1.6 Ga)

Xcp — **Central Plains orogen (1.78–1.64 Ga)**

Xp — **Penokean orogen (2.2–1.84 Ga)**

EARLY PROTEROZOIC AND ARCHEAN
TRANS-HUDSON OROGEN

XAi — **Juvenile terranes**

XAm — **Miogeoclinal belt**

ARCHEAN (2.5 Ga and older)

Rae and Hearne provinces

Wyoming province

Superior province

CB — **Cheyenne belt**

GFTZ — **Great Falls tectonic zone**

GLTZ — **Great Lakes tectonic zone**

Laramide uplifts

BH — **Black Hills uplift**

HU — **Hartville uplift**

LM — **Laramie Mountains**

MB — **Medicine Bow Mountains**

Thrust fault—Sawteeth on upper plate. Dashed where approximately located

Fault—Dashed where approximately located

Boundary between exposed geologic domains

Boundary between domains in the subsurface

Edge of exposed Precambrian rocks—Hachures point toward exposed area

Figure 3. Regional geology of the Trans-Hudson orogen. It separates the Wyoming and Superior cratons, and is truncated to the south by the Central Plains orogen.

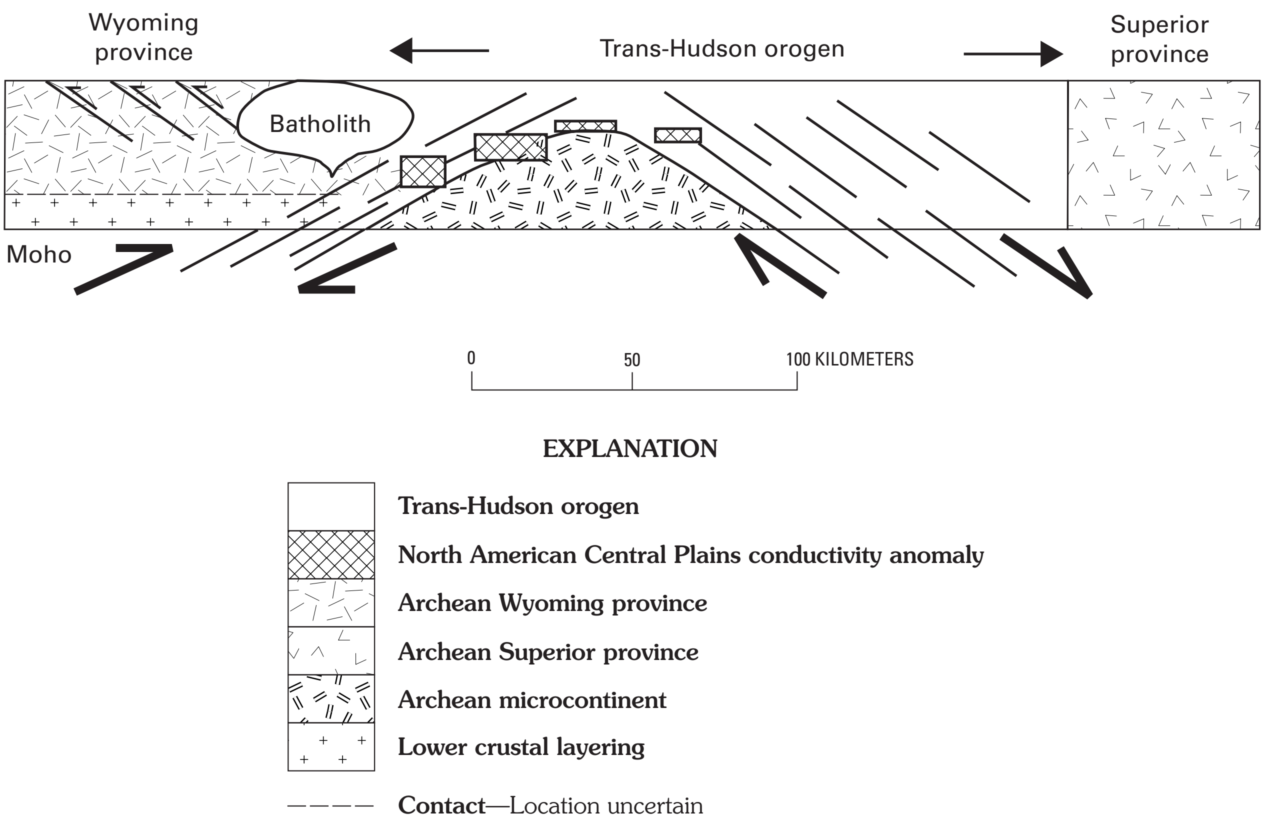


Figure 4. Schematic diagram showing interpretation of COCORP data of crustal structure of Trans-Hudson orogen at lat 48°30' N. Figure is at crustal velocity of 6 km/s. Modified from Nelson and others (1993).

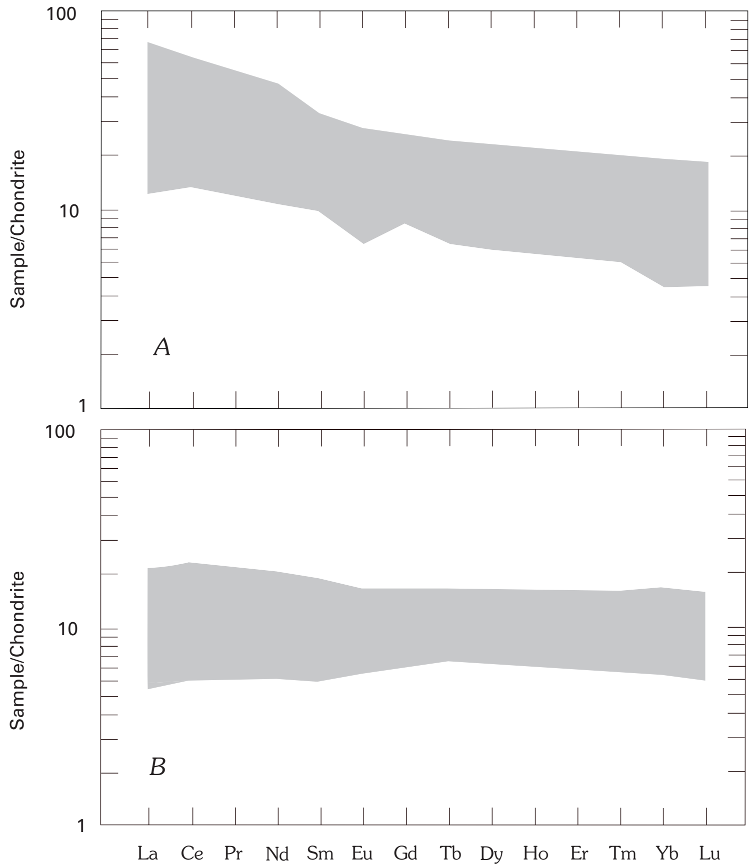


Figure 5. Chondrite-normalized rare earth element plot for samples of *A*, Muskrat Canyon Metabasalt, and *B*, Mother Featherlegs Metabasalt.

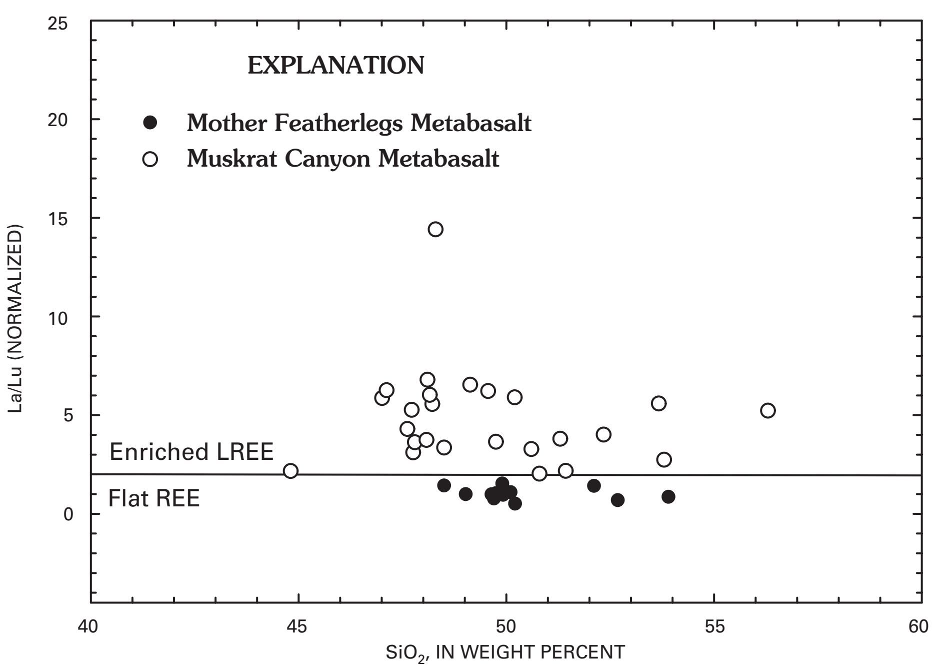
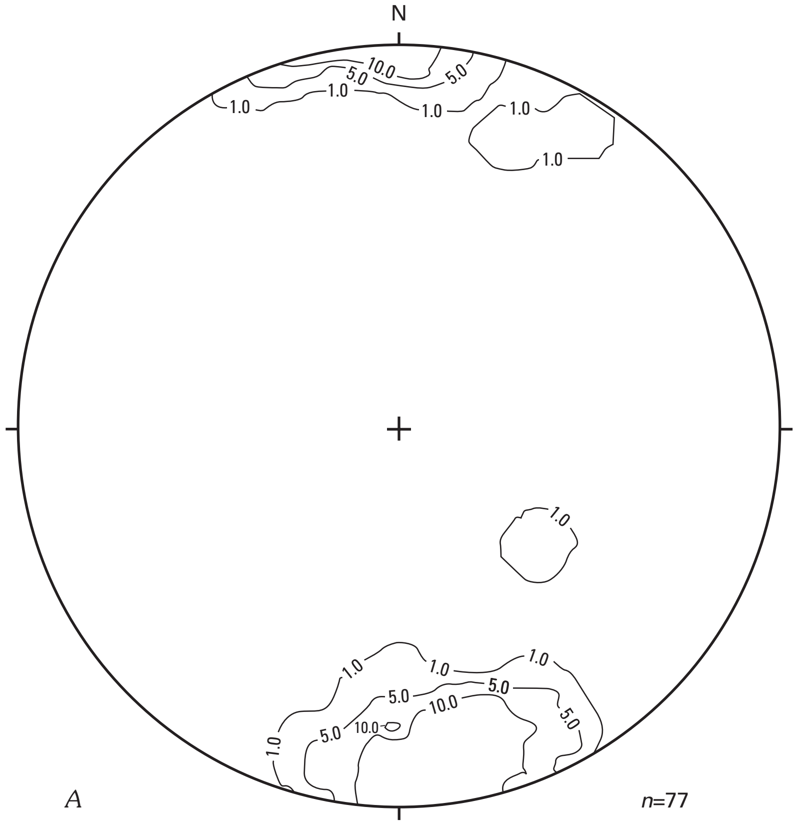


Figure 6. La/Lu (normalized) versus SiO_2 (weight percent) diagram showing relative amounts of flat REE and enriched light REE in Muskrat Canyon Metabasalt and Mother Featherlegs Metabasalt.



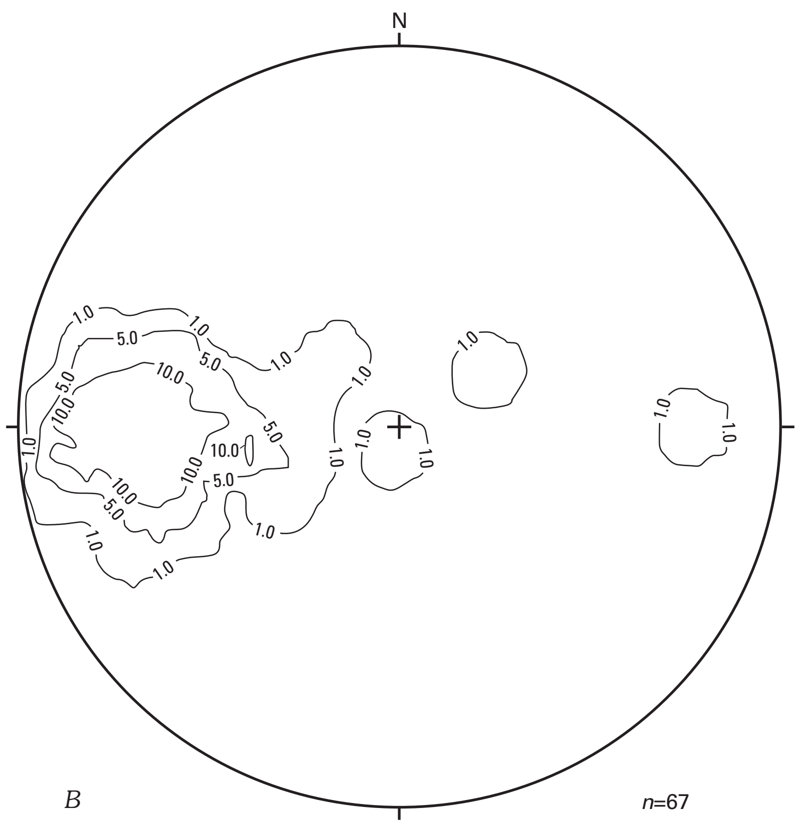


Figure 7. Equal-area projections (lower hemisphere) of D_2 deformation structures in Guernsey quadrangle. *A*, poles to S_2; *B*, azimuth and plunge of F_2 fold axes and L_2 (S_0/S_2 intersection).

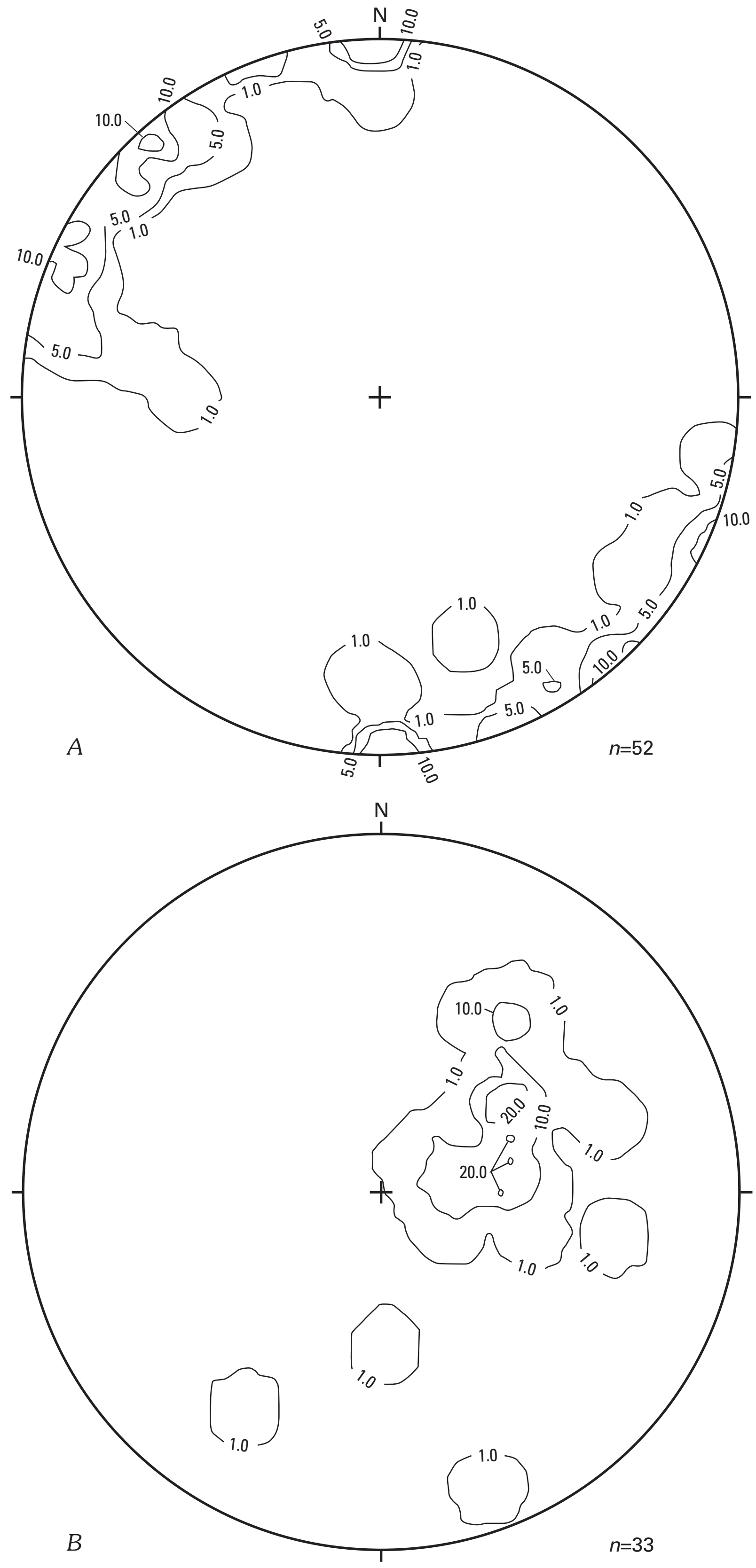
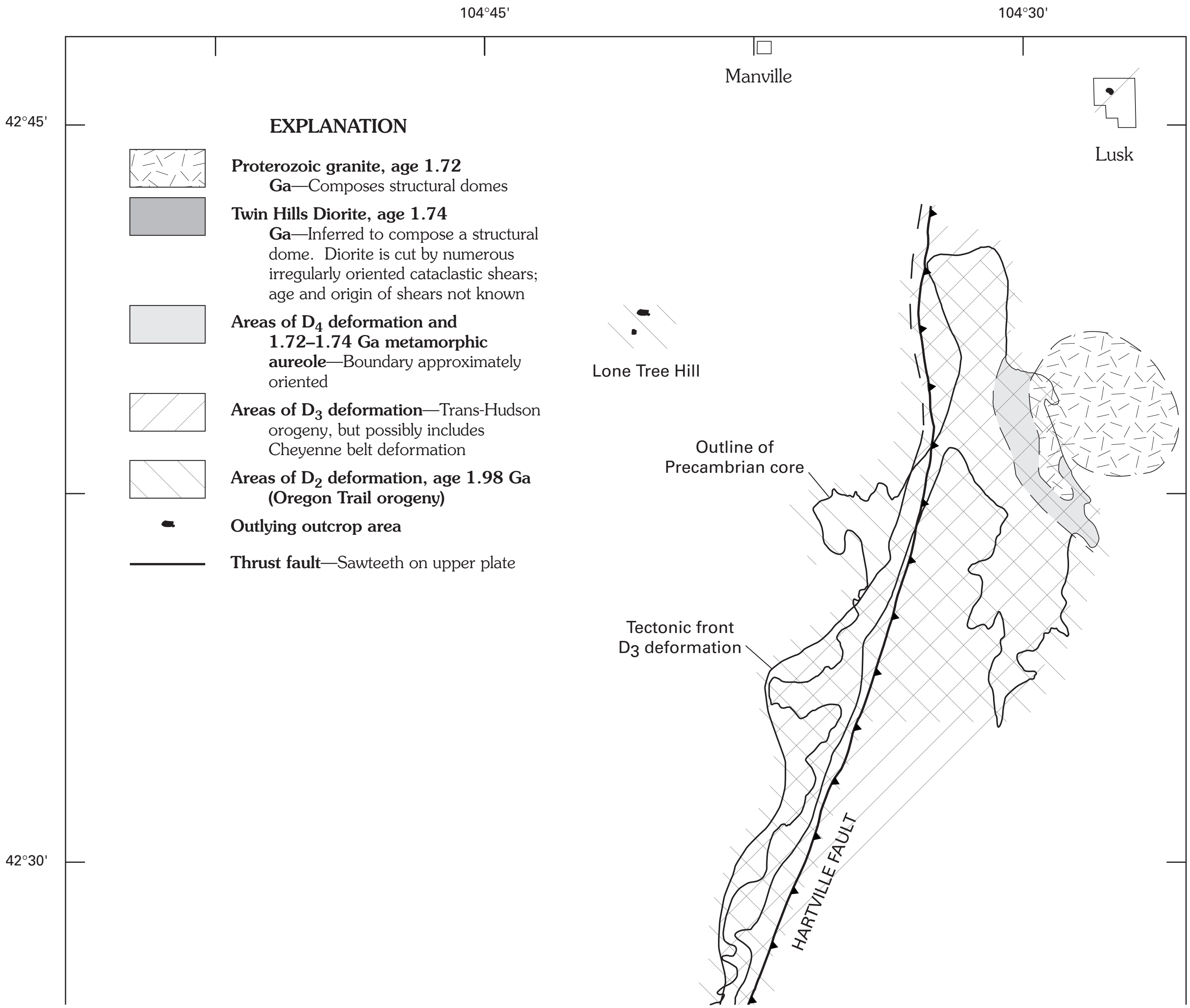


Figure 8. Equal-area projections (lower hemisphere) of D_3 deformation structures in a typical area in central part of Hartville uplift. *A*, poles to S_3; *B*, azimuth and plunge of F_3 fold axes and L_3 lineatons.


104°45'
104°30'
42°45'
42°30'
Manville
Lusk
EXPLANATION
Proterozoic granite, age 1.72 Ga—Composes structural domes
Twin Hills Diorite, age 1.74 Ga—Inferred to compose a structural dome. Diorite is cut by numerous irregularly oriented cataclastic shears; age and origin of shears not known
Areas of D4 deformation and 1.72–1.74 Ga metamorphic aureole—Boundary approximately oriented
Areas of D3 deformation—Trans-Hudson orogeny, but possibly includes Cheyenne belt deformation
Areas of D2 deformation, age 1.98 Ga (Oregon Trail orogeny)
Outlying outcrop area
Thrust fault—Sawteeth on upper plate
Lone Tree Hill
Outline of Precambrian core
Tectonic front D3 deformation
HARTVILLE FAULT

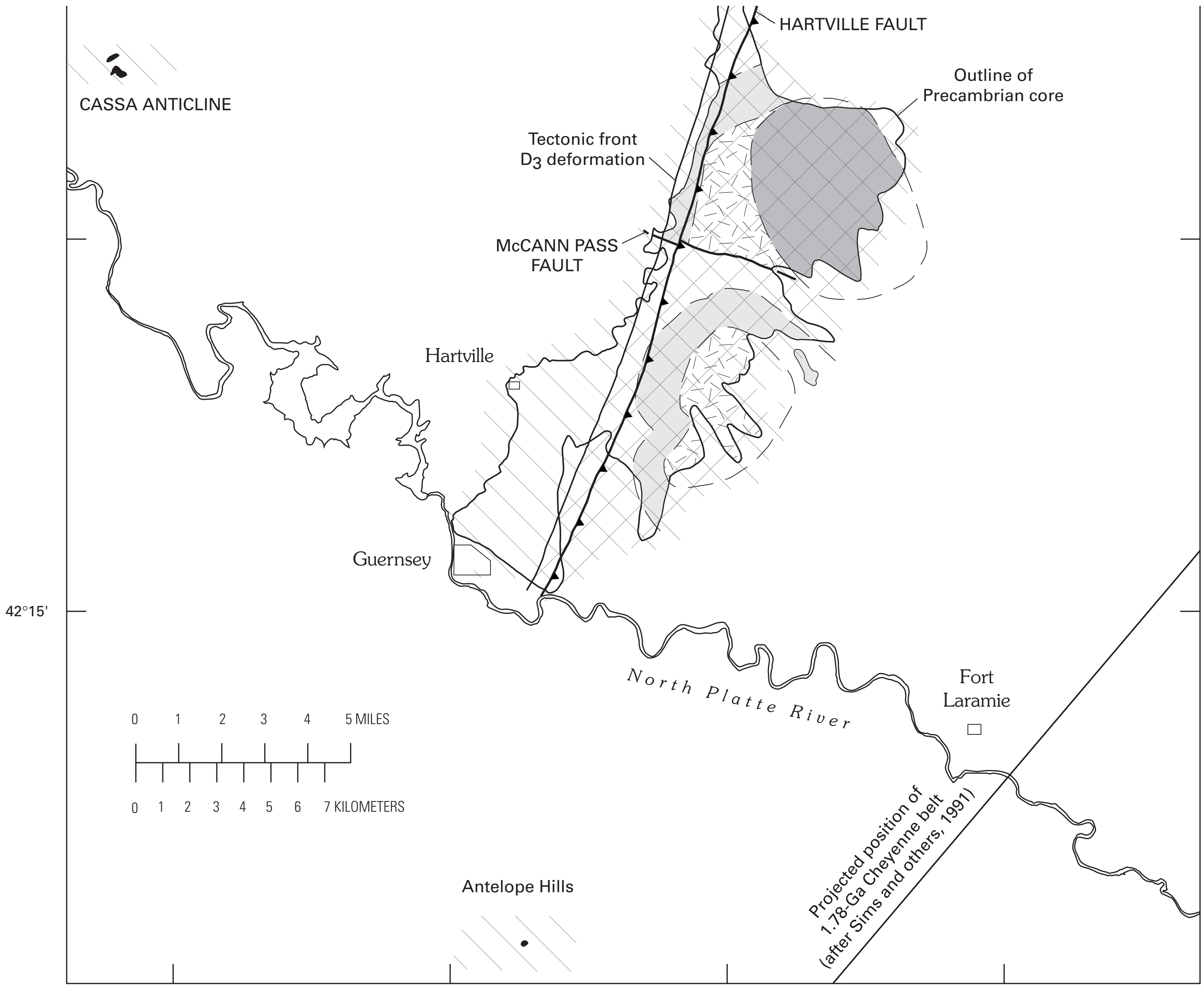


Figure 9. Precambrian tectonic events of Hartville uplift and outlying areas, southeastern Wyoming. Sullivan Ridge is 10 km north of Lusk.

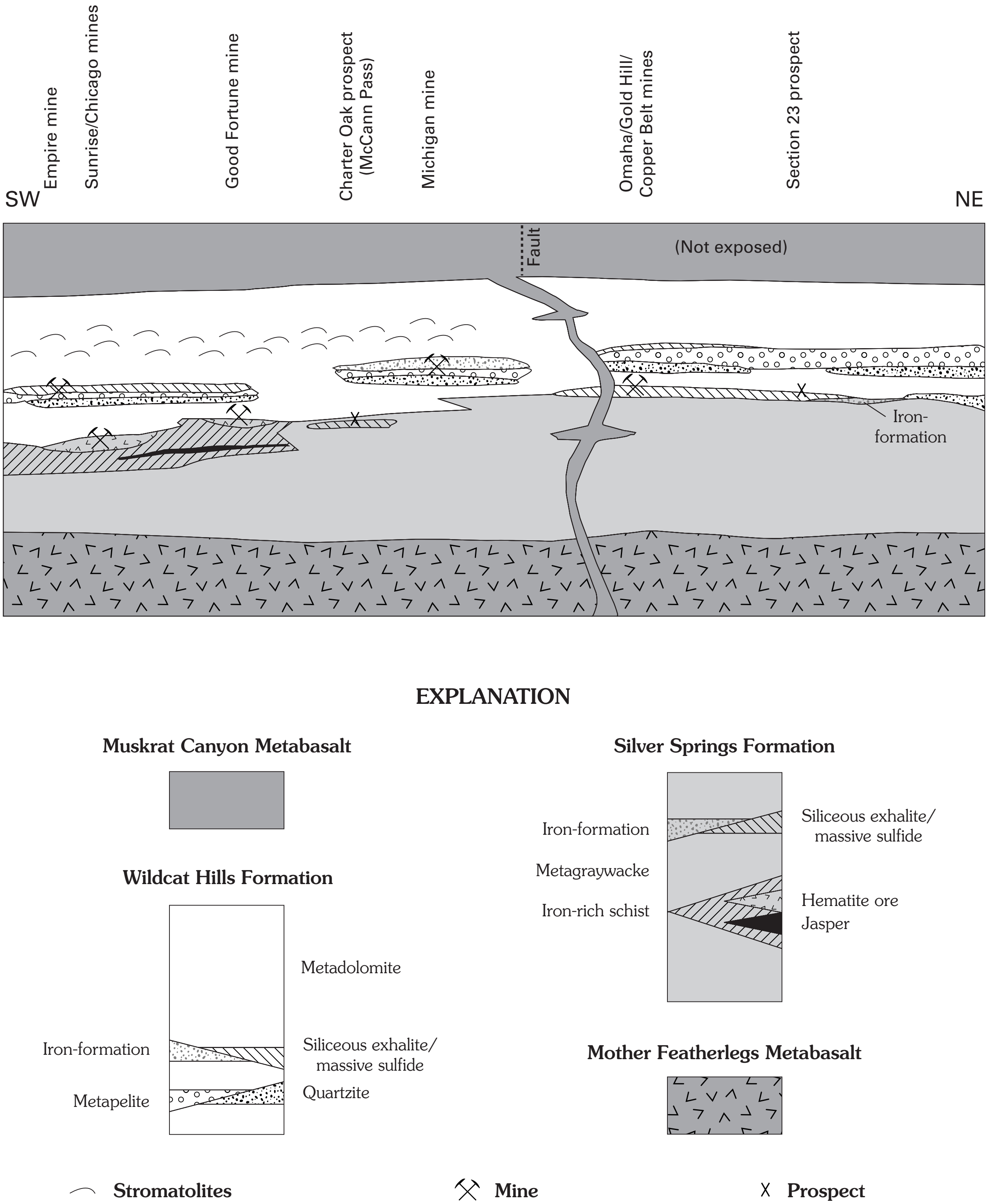


Figure 10. Schematic section showing stratigraphic position of principal mineral deposits.

Table 1. *Tectonic, stratigraphic, and magmatic evolution of Hartville uplift during the Precambrian*

Age, in Ga	Event
circa 1.4	Emplacement of mafic dikes; undeformed
circa 1.66	Cryptic thermal event, indicated by apatite and monazite ages (Krugh and others, 1993).
1.72	Emplacement of granite domes (D_4 deformation)
circa 1.8*	D_3 deformation; fold-and-thrust belt developed along length of uplift (Trans-Hudson orogen).
circa 1.98	D_2 deformation; folding on east-west axes and accompanying metamorphism
circa 2.0	Mafic dike swarm
2.66–2.65	Emplacement of Rawhide Buttes and Flattop Butte Granites
2.8–2.65	Deposition of Whalen Group in miogeoclinal environment, followed by nappe development (D_1 deformation).
3.1–2.8	Crystalline basement, indicated by Nd model ages

*Isotopic age indications for 1.78–1.76 Ga Cheyenne belt deformation (Central Plains orogeny) are lacking for the Hartville uplift.

Table 2. *Geochemistry of the Mother Featherlegs Metabasalt, Hartville uplift, Wyoming*

[Quadrangle names: G, Guernsey; RBE, Rawhide Buttes East; RBW, Rawhide Buttes West; RS, Reynolds Spring; SS, Silver Springs. LOI, loss on ignition. n.a., not available]

Field No.	72	129	147	148	195	665	666	714	2539	2593
Description	metabasalt	metabasalt pillowed	amphibolite dike in marble	metabasalt	metabasalt pillowed	amphibolite xenolith	metabasalt	amphibolite dike	amphibolite dike	amphibolite dike
Latitude N.	42.58304861	42.29468139	42.27914444	42.28818944	42.63881806	42.63385111	42.63881806	42.56342806	42.57559722	42.611975
Longitude W.	104.509003	104.715715	104.721747	104.718463	104.520078	104.464434	104.520078	104.499397	104.501719	104.462836
Quadrangle	RBW	G	G	G	SS	RS	SS	RBE	RBW	RBE
Major element oxides by X-ray fluorescence analysis (weight percent)										
SiO_2	52.38	50.21	49.74	52.68	48.64	52.11	51.09	49.36	49.7	49.9
Al_2O_3	13.73	15.23	13.25	13.95	14.25	11.02	13.77	14.57	14.4	13
Fe_2O_3T	11.94	12.57	15.59	10.68	12.43	19.94	12.78	11.44	12.6	14.5
FeO	7.10	7.80	9.30	n.a.	n.a.	11.20	7.40	5.80	8.80	7.78
MgO	6.93	7.52	5.85	6.00	7.10	2.94	8.11	8.29	7.45	6.35
CaO	11.49	9.81	9.53	10.15	15.35	8.53	9.20	11.22	1.70	7.71
Na_2O	1.96	2.27	2.16	2.28	1.00	1.55	3.11	2.94	2.38	0.82
K_2O	0.12	0.18	0.18	0.18	0.14	0.99	0.10	0.83	0.78	5.78
TiO_2	0.86	0.97	1.43	0.94	0.96	2.67	0.97	0.65	0.76	1.32
P_2O_5	0.08	0.08	0.12	0.10	0.08	0.20	0.08	0.05	0.05	0.11
MnO	0.17	0.15	0.2	0.14	0.18	0.24	0.18	0.19	0.21	0.2
LOI	0.75	1.29	1.05	1.11	0.78	<0.01	0.6	0.69	0.49	1.31
Total	100.41	100.3	99.12	98.21	100.9	100.19	99.99	100.23	99.54	100.14
Trace element analysis by X-ray fluorescence analysis (parts per million)										
Nb	<2	2	4	3	3	7	<2	<2	n.a.	n.a.
Zr	56	58	83	56	61	137	66	39	n.a.	n.a.
Y	18	21	27	22	20	45	20	19	13	28
Sr	116	96	139	106	69	61	42	110	n.a.	n.a.
Rb	4	3	3	3	6	20	4	8	n.a.	n.a.
Zn	81	101	112	81	72	110	90	68	n.a.	n.a.
Cu	142	62	61	38	55	789	85	14	n.a.	n.a.
Trace element analysis by instrumental neutron activation analysis (parts per million)										
Co	43.4	51.8	54.1	44.3	56.9	42.4	49.6	50.1	49.1	49.4
Cr	105	121	88.8	182	103	5.3	113	155	141	59.3
Hf	1.4	1.5	2.2	1.4	1.4	3.4	1.5	0.9	1.11	2.3
Ni	80	130	<50	130	<50	<50	105	82	n.a.	n.a.
Sc	37.7	46.8	41.6	44.2	35.7	38.2	38.1	45.4	51.4	49.1
Ta	0.5	<0.3	<0.3	<0.3	0.5	0.5	<0.3	<0.3	0.101	0.49
Th	0.4	0.2	0.5	0.3	0.4	1.9	0.4	0.2	0.281	0.865
U	<0.1	<0.1	<0.1	<0.1	<0.1	1.3	<0.1	<0.1	0.082	0.708
La	4	1.6	4.3	2	3.8	8.1	4.1	2.3	2.69	7.38
Ce	10	6	14	7	11	26	12	6	5.3	21
Nd	7	4	9	4	8	18	7	4	4	13.8
Sm	2.06	1.4	2.74	1.48	1.97	4.97	2.19	1.47	1.81	4.16
Eu	0.78	0.63	1.05	0.67	0.84	1.69	0.81	0.62	0.725	1.22
Gd	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.5	4.89
Tb	0.5	0.4	0.7	0.4	0.5	1.2	0.5	0.4	0.44	0.795
Dy	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	3.1	5.35
Tm	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.33	0.525
Yb	1.69	2.1	2.87	2.05	1.78	4.19	1.98	1.88	2.27	3.22
Lu	0.25	0.32	0.43	0.3	0.27	0.59	0.27	0.26	0.358	0.499

Table 2. *Geochemistry of the Mother Featherlegs Metabasalt, Hartville uplift, Wyoming*—Continued

Field No.	2614	2624	2688	0709C	0835A	HU-010	HU-022	TKHU 044	TKHU 090	TKHU 117	2507
Description	metabasalt pillowed	amphibolite dike	metabasalt	amphibolite	amphibolite dike	metabasalt pillowed	amphibolite dike	metagabbro	metabasalt	metabasalt	metabasalt
Latitude N.	42.638875	42.61777778	42.59976111	42.57490417	42.614765	42.638875	42.59640278	42.67207639	42.69668917	42.70146222	42.28846944
Longitude W.	104.520089	104.566333	104.497217	104.48847	104.454859	104.520089	104.478036	104.520741	104.522882	104.517681	104.718131
Quadrangle	SS	RBW	RBE	RBW	RBE	SS	RBE	SS	SS	SS	G
Major element oxides by X-ray fluorescence analysis (weight percent)											
SiO_2	50.1	50.9	48.5	49.02	49.53	49.1	49.7	49.64	49.92	49.13	53.9
Al_2O_3	13.4	13.2	14.3	15.35	13.88	14.7	13.5	16.13	14.48	15.06	14.4
Fe_2O_3T	12.17	14.9	14	11.76	14.49	11.5	16.2	8.73	13.24	16.29	8.7
FeO	9.70	8.94	10.80	6.10	n.a.	9.11	11.46	5.40	8.00	9.60	7.83
MgO	8.80	6.19	8.20	8.06	6.44	6.26	5.79	8.91	7.77	4.41	7.07
CaO	10.40	10.10	9.60	11.68	9.57	17.60	9.75	14.10	11.76	8.37	8.99
Na_2O	2.90	1.61	2.30	2.27	2.72	0.67	2.62	1.30	1.21	3.75	2.43
K_2O	0.08	1.01	0.12	0.99	0.81	0.07	0.64	0.13	0.14	0.49	0.13
TiO_2	0.96	1.30	1.30	0.73	1.28	0.95	1.67	0.54	0.84	2.22	0.93
P_2O_5	0.11	0.12	0.10	0.06	0.06	0.07	0.08	0.07	0.07	0.18	0.08
MnO	0.18	0.22	0.22	0.17	0.2	0.19	0.23	0.15	0.2	0.24	0.14
LOI	0.66	1.24	n.a.	0.6	0.47	0.46	0.39	1.1	0.95	0.33	n.a.
Total	99	99.8	99	100.67	99.45	100.56	99.3	100.79	100.58	100.48	98.82
Trace element analysis by X-ray fluorescence analysis (parts per million)											
Nb	n.a.	n.a.	n.a.	<2	3	n.a.	n.a.	2	2	3	5
Zr	n.a.	n.a.	n.a.	44	46	n.a.	n.a.	41	50	109	42
Y	20	28	5.6	18	17	13	20	16	18	38	15
Sr	n.a.	n.a.	n.a.	133	136	n.a.	n.a.	124	124	296	113
Rb	n.a.	n.a.	n.a.	15	15	n.a.	n.a.	3	5	11	n.a.
Zn	120	n.a.	140	76	93	n.a.	n.a.	49	83	124	143
Cu	54	n.a.	160	73	99	n.a.	n.a.	80	105	32	70
Trace element analysis by instrumental neutron activation analysis (parts per million)											
Co	47.3	51.9	44.4	49.2	52.9	48.4	58.1	39	53.6	41.9	40.4
Cr	109	54.8	302	303	123	132	97.6	567	131	15.6	195
Hf	1.42	2.1	1.76	1.1	1.2	1.63	2.11	0.9	1	2.8	1.25
Ni	n.a.	n.a.	n.a.	<50	95	n.a.	n.a.	164	83	<50	87
Sc	39.6	47.4	39.6	43.7	37.3	40.9	43.9	38.1	43.1	42.4	46.9
Ta	0.157	0.249	0.204	<0.3	0.3	0.193	0.291	<0.3	<0.3	0.5	0.132
Th	0.318	1.6	0.315	0.3	0.3	0.4	0.185	<0.1	0.2	1	0.313
U	0.05	0.428	0.432	<0.1	0.1	0.1	0.83	<0.1	<0.1	0.4	0.3
La	2.86	6.56	4.19	2.5	3.9	3.95	3.06	2	2.7	6.5	2.73
Ce	6.39	16.8	12	8	10	12.5	12.2	6	9	20	7.76
Nd	5.4	9.98	9	6	7	n.a.	9.28	5	5	13	6.1
Sm	1.95	3.1	2.72	1.63	1.85	2.5	3.3	1.26	1.78	3.7	1.97
Eu	0.694	1.06	0.911	0.63	0.75	0.901	0.883	0.52	0.68	1.36	2.7
Gd	2.4	3.36	3.18	n.a.	n.a.	n.a.	4.2	n.a.	n.a.	n.a.	0.692
Tb	0.419	n.a.	0.55	0.4	0.4	0.54	0.6	0.4	0.5	0.9	0.5
Dy	2.85	4.01	3.61	n.a.	n.a.	3.6	3.78	n.a.	n.a.	n.a.	3.27
Tm	0.29	0.433	0.33	n.a.	n.a.	0.33	n.a.	n.a.	n.a.	n.a.	0.34
Yb	1.78	2.97	2.03	1.78	1.78	1.95	2.39	1.44	1.94	3.83	2.2
Lu	0.27	0.486	0.302	0.26	0.27	0.275	0.382	0.21	0.29	0.57	0.329

Table 3. *Geochemistry of the Muskrat Canyon Metabasalt, Hartville uplift, Wyoming*

[Quadrangle names: CH, Casebier Hill; G, Guernsey; HG, Hell Gap; MS, Moore Spring; RBE, Rawhide Buttes East; RBW, Rawhide Buttes West; SS, Silver Springs. LOI, loss on ignition. n.a., not available]

Field No.	254	257	275	307	314	332	506	510	829	930	2343	2703
Description	gabbro sill in graywacke	metabasalt pillowed	gabbro sill in graywacke	metabasalt pillowed	metabasalt	metabasalt	metabasalt	metagabbro	metagabbro	amphibolite layered	metagabbro dike	metabasalt pillowed
Latitude N.	42.31158444	42.32716806	42.30998556	42.37389917	42.368285	42.376585	42.31084139	42.31120833	42.69777667	42.62679944	42.03718333	42.56415
Longitude W.	104.7065828	104.7239464	104.7118364	104.6569775	104.661005	104.6637161	104.71028	104.7072353	104.5211506	104.5002417	104.6179889	104.5848167
Quadrangle	G	G	G	G	G	HG	G	G	SS	SS	CH	RBW
Major element oxides by X-ray fluorescence analysis (weight percent)												
SiO_2	47.76	48.22	49.75	49.13	53.67	47.01	47.8	47.72	49.56	48.08	48.5	51.3
Al_2O_3	14.11	16.24	14.19	14.56	16.30	15.45	13.87	14.88	14.96	11.05	16.90	12.10
Fe_2O_3T	15.46	13.82	14.48	12.72	10.23	13.02	15.34	13.29	11.53	13.21	11.30	11.13
FeO	n.a.	n.a.	7.90	6.70	n.a.	6.50	n.a.	n.a.	n.a.	8.00	8.66	8.40
MgO	6.66	5.71	5.75	6.73	4.53	5.41	6.55	6.71	8.10	11.66	8.11	9.90
CaO	10.29	10.33	8.64	8.50	5.92	9.84	11.27	9.99	10.59	10.02	9.70	9.60
Na_2O	2.77	2.94	3.33	3.40	5.83	3.14	2.37	2.90	2.42	1.25	2.62	3.40
K_2O	0.27	0.38	0.19	0.65	0.35	0.26	0.22	0.24	0.32	0.62	0.52	0.23
TiO_2	1.92	1.74	1.45	1.69	1.86	1.71	1.69	1.37	0.75	0.91	1.46	0.96
P_2O_5	0.21	0.17	0.13	0.19	0.17	0.17	0.13	0.12	0.06	0.08	0.16	0.17
MnO	0.22	0.15	0.23	0.16	0.11	0.16	0.25	0.21	0.18	0.19	0.17	0.21
LOI	0.82	0.90	2.71	2.53	1.98	3.12	1.09	1.49	0.83	1.44	1.34	1.30
Total	100.49	100.6	100.84	100.27	100.95	99.29	100.58	98.93	99.3	98.51	99..82	101
Trace element analysis by X-ray fluorescence analysis (parts per million)												
Nb	10	6	9	8	8	5	10	11	3	3	6	n.a.
Zr	106	147	90	140	159	138	96	97	47	71	154	n.a.
Y	24	25	19	24	28	23	21	22	20	17	19	21
Sr	298	593	147	420	279	576	172	230	144	136	312	n.a.
Rb	5	4	2	9	3	4	5	5	8	12	26.3	n.a.
Zn	108	109	100	110	83	117	102	88	97	90	154	140
Cu	22	56	<5	<5	<5	86	86	78	54	19	n.a.	75
Trace element analysis by instrumental neutron activation analysis (parts per million)												
Co	53.9	68.9	57.8	51.3	38.4	56.7	54	50	44	62.5	42.9	39.4
Cr	163	60.5	10.3	120	43.5	56.9	21	50.7	236	1830	203	573
Hf	2.4	4.1	1.4	3	3.3	3.3	2.2	1.9	0.9	1.8	2.8	1.94
Ni	<50	120	<50	112	86	117	<50	<50	158	395	n.a.	n.a.
Sc	38.9	23.1	40.9	22.1	20.5	22.6	45.5	39.3	38.5	27.6	29.6	25.2
Ta	0.6	0.9	0.8	0.7	0.6	0.6	0.4	<0.3	0.3	0.4	0.414	0.27
Th	0.9	1.5	0.8	1.4	1.6	1.4	0.9	1	0.6	1.1	1.2	2.58
U	<0.1	0.5	<0.1	0.2	<0.1	0.4	<0.1	0.4	0.2	0.5	0.3	0.646
La	9.6	16.1	8.1	14.5	14	16.4	9.1	13.2	13.8	8.3	11.2	8.61
Ce	25	41	21	33	38	38	23	31	26	20	25.6	18.9
Nd	14	22	13	18	20	21	13	16	15	11	12.7	9.96
Sm	3.52	4.72	2.89	4.1	4.28	5.04	3.22	3.59	3.21	2.54	3.89	2.77
Eu	1.25	1.75	1.03	1.48	1.7	1.7	1.19	1.24	1.08	0.89	1.3	0.931
Gd	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	4.02	n.a.
Tb	0.7	0.8	0.7	0.7	0.9	0.8	0.7	0.6	0.5	0.5		0.518
Dy	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	3.9	3.35
Tm	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.375	0.26
Yb	2.25	1.98	1.72	1.7	1.89	1.95	1.89	1.71	1.57	1.55	2.18	1.54
Lu	0.32	0.3	0.23	0.23	0.26	0.29	0.26	0.26	0.23	0.23	0.346	0.235

Table 3. *Geochemistry of the Muskrat Canyon Metabasalt, Hartville uplift, Wyoming*—Continued

Field No.	2765	0016b	0019-MSC-1	0022-MSC-1	0307-3	0319A	0510r	0738R B	CU#3-378	HU-028	HU-035	TKHU 017A
Description	metabasalt massive	amphibolite	metabasalt mottled	metabasalt	metabasalt	metabasalt	metagabbro dike	amphibolite	metabasalt layered	metabasalt	metagabbro dike	metabasalt
Latitude N.	42.48941667	42.58098639	42.47810556	42.47810556	42.37563694	42.37692361	42.31120833	42.61618944	42.49005	42.56415	42.28031389	42.65166111
Longitude W.	104.6246	104.502737	104.587367	104.587367	104.66029	104.656234	104.707235	104.458265	104.616492	104.584817	104.72538	104.520011
Quadrangle	MS	RBW	MS	MS	HG	HG	G	RBE	MS	RBW	G	SS
Major element oxides by X-ray fluorescence analysis (weight percent)												
SiO_2	48.1	52.34	50.2	56.3	47.12	48.16	47.62	50.8	53.8	50.6	48.3	44.81
Al_2O_3	15.00	12.37	12.30	13.30	16.09	15.19	15.07	13.14	14.40	11.90	16.40	17.33
Fe_2O_3T	15.12	16.34	13.60	10.50	13.46	13.87	11.84	15.01	13.60	8.40	12.80	15.61
FeO	9.20	n.a.	10.90	8.67	6.00	n.a.	7.70	n.a.	8.06	7.56	8.66	9.80
MgO	5.30	4.37	8.96	6.23	5.78	5.89	7.31	6.57	13.60	7.89	6.73	10.15
CaO	9.00	6.88	10.60	7.99	11.05	8.73	9.06	8.99	4.07	10.90	9.47	7.49
Na_2O	2.70	1.85	1.73	3.22	2.24	2.56	3.20	2.10	<0.15	3.87	2.55	0.93
K2O	0.39	0.64	0.50	0.33	0.26	0.90	0.21	0.62	4.43	0.25	0.74	0.14
TiO_2	2.00	2.10	1.40	1.41	1.84	1.76	1.46	1.57	1.43	0.98	0.84	1.34
P_2O_5	0.33	0.28	0.15	0.16	0.18	0.19	0.11	0.16	0.08	0.14	0.25	0.12
MnO	0.21	0.26	0.20	0.14	0.14	0.16	0.29	0.20	0.11	0.18	0.18	0.18
LOI	2.10	0.53	0.64	0.51	2.69	2.64	1.98	0.74	1.01	n.a.	1.32	2.15
Total	99	97.96	99.11	99.39	100.83	100.05	98.14	99.9	97.9	98.49	98.62	100.24
Trace element analysis by X-ray fluorescence analysis (parts per million)												
Nb	n.a.	10	n.a.	n.a.	6	7	11	9	n.a.	6	5	7
Zr	n.a.	149	n.a.	n.a.	140	157	89	99	n.a.	67	74	77
Y	23	51	21	11	23	25	22	33	14	15	18	19
Sr	n.a.	199	n.a.	n.a.	587	686	268	188	n.a.	156	524	82
Rb	n.a.	34	n.a.	n.a.	6	17	3	13	n.a.	3	15.8	6
Zn	160	138	n.a.	n.a.	112	129	106	100	n.a.	124	74	117
Cu	49	63	n.a.	n.a.	54	43	157	70	n.a.	50	n.a.	<5
Trace element analysis by instrumental neutron activation analysis (parts per million)												
Co	49.9	45.2	48.3	36.1	54.2	61.7	67	47.9	37.9	39.4	48.6	61.7
Cr	30.1	17.6	556	316	54	49.6	77	75.9	98.6	665	143	159
Hf	4.79	3.8	2.86	2.74	3.3	3.9	2	2.6	2.71	2.09	1.85	1.7
Ni	n.a.	<50	n.a.	n.a.	176	<50	<35	<50	n.a.	n.a.	n.a.	<50
Sc	24.6	39.5	31.9	30.3	21.5	23.8	47	46.3	17.5	26.3	28.5	50.8
Ta	0.715	0.5	0.47	0.418	0.6	<0.3	<0.5	<0.3	0.415	0.291	0.234	0.3
Th	2.46	3.6	3.4	3.18	1.3	1.6	36	1.2	1.21	2.61	3.7	0.3
U	0.463	1.4	0.698	0.921	0.5	<0.1	<0.5	0.4	0.355	0.625	1.03	<0.1
La	25.2	26.3	16.9	12.3	15.1	18.6	8.7	10	7.11	7.62	39.3	4.6
Ce	59.2	53	37.4	28.9	36	42	15	25	25.3	17.3	83.4	13
Nd	31.5	29	17.8	16.5	21	26	5	16	16	10.3	32.7	8
Sm	7.26	6.65	4.75	3.9	4.67	5.53	2.3	4.06	4.32	2.73	5.49	2.39
Eu	2.02	2.3	1.36	1.2	1.73	1.86	0.7	1.38	1.38	3.08	1.46	0.71
Gd	6.37	n.a.	4.95	4.1	n.a.	n.a.	n.a.	n.a.	4.5	0.9333	4.13	n.a.
Tb	0.95	1.3	0.811	0.623	0.9	0.8	<0.5	0.9	0.7	0.5	0.601	0.5
Dy	6.05	n.a.	4.55	3.9	n.a.	n.a.	n.a.	n.a.	4.23	3.15	3.7	
Tm	0.485	n.a.	0.33	0.28	n.a.	n.a.	n.a.	n.a.	0.33	0.266	0.341	
Yb	2.58	4.51	1.94	1.67	1.8	2.21	1.6	3.41	1.95	1.6	2.03	1.57
Lu	0.385	0.68	0.297	0.244	0.25	0.32	0.21	0.51	0.269	0.241	0.283	0.22

Table 4. *Approximate modes of granitoid rocks and gneiss from outlying areas (percent by volume)*

[Tr, trace]

Sample No.	HU 18	HU 17	HU 15	HU 16	HU 34
Plagioclase	23	45	42	42	46.5
Quartz	37	38	23	18.5	26
Potassium feldspar.	33	10.5	24	33	19
Biotite	6	3.5	11	5	7.5
Muscovite	1	3	Tr	1.5	1
Accessory minerals.	Tr	Tr	Tr	Tr	Tr

SAMPLE DESCRIPTIONS

HU 18 Lone Tree Hill; foliated medium- to coarse-grained biotite granite. Some biotite altered to chlorite.
HU 17 Lone Tree Hill; medium-grained granodiorite gneiss. Some biotite altered to chlorite.
HU 15 Foliated fine-grained granodiorite. Cuts gneiss (HU 16).
HU 16 Granite gneiss.
HU 34 Granodiorite gneiss; associated with amphibolite.