





Origins of the Black Hills Terrane in the Eastern Wyoming Craton An atypical supergiant orogenic gold province within supercontinent Nuna

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Generalized Tectonostratigraphy

Little Elk

Parautochthon

Allochthon

Roberts Draw Fmn.

Central Plains

Dakota Orogen at 1850 Ma

Trans Hudson /

Revised Geologic Map Black Hills

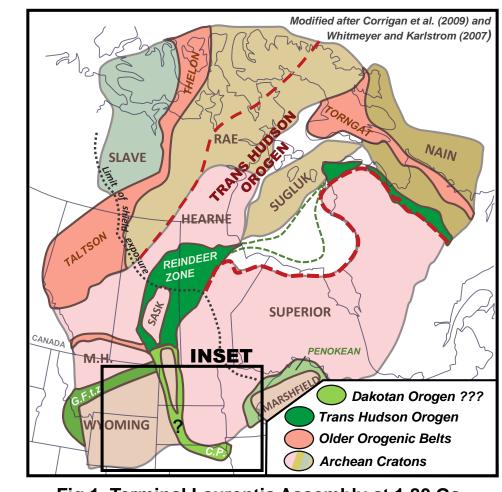


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Abstract

The Black Hills Terrane (BHT) marks the eastern margin of the Archean Wyoming craton and contains the largest Paleoproterozoic orogenic gold province in North America, including a supergiant deposit at Homestake that contains >62 Moz Au in known resources. Despite this phenomenal gold endowment the BHT remains remarkably unstudied and stands out as the only significant orogenic gold province formed during the terminal stages of the Nuna supercontinent assembly. This study presents a tectonic synthesis of the Precambrian evolution of the BHT based on U-Pb geochronology and paired Lu-Hf analyses of detrital zircons within 72 metasedimentary units and igneous zircons within twelve granitoids. The BHT is underlain by Mesoarchean greenstone basement with geologic links to the gold-endowed Vaalbara supercraton that may have imposed an underlying fertility to BHT crust. Auriferous conglomerates correlative with the basal Transvaal Supergroup of the Kaapvaal craton (Black Reef) are present in the Black Hills, providing a spatial and temporal link between the Transvaal and Huronian Supergroups in the Kenorland supercontinent. The exposed portion of the BHT is dominated by Paleoproterozoic passive margin miogeoclinal sequences deposited between 2.15-1.96 Ga that were subsequently overthrust by 1860-1820 Ma parautochthonous greywacke successions transposed over the margin during arc collision and ocean closure <1820 Ma. A flexural foreland accommodated thick greywacke sedimentation shed from the adjoining thrust highlands. With our expanded dataset, the gold resources of the BHT can be placed in a proper Paleoproterozoic tectonic framework during the assembly of Nuna. From 1.9 to 1.82 Ga the Wyoming craton was rapidly rotated during oroclinal development initiated by the failed subduction of the Dakota block beneath the Minnesota River Valley subprovince of the Superior craton, culminating in a soft collision of the Wyoming and Superior cratons at 1.82 Ga in a dominantly strike-slip setting that trapped the intervening Dakota block and extruded Paleoproterozoic arc crust south of the Wyoming craton to form the controversial Central Plains Orogen. This event placed the Black Hills near the south-facing margin of a mega-subduction system extending across the entire southern boundary of Laurentia after 1.8 Ga associated with Yavapai accretionary orogenesis. Stalled subduction, intense compression and foreland fold-thrust belt development, and eruption of komatiitic lavas with OIB compositions in the Black Hills section of this margin after 1.78 Ga mark the arrival and failed subduction of a large fragment of circum-Manikewan LIP plateau crust tentatively associated with the Dawes terrane. Tectonic readjustments after 1.77 Ga produced an environment favorable for the development of orogenic gold deposits in the BHT, including a switch from dextral to sinistral transpression that led to differential block uplift, synorogenic clastic basin deposition, dilation of the mantle-tapping transverse basement faults, largescale hydrothermal fluid release and the development of supergiant orogenic gold deposits in the older passive margin sedimentary rocks. We view the BHT as an atypical orogenic gold province where deposits are hosted in miogeoclinal successions deposited several hundred m.y. before gold deposit formation and underlain by ancient attenuated lithosphere along a long-lived plate margin that experienced repeated gold refertilization through subduction modification. The remarkable first-order similarities with the Paleozoic tectonic history of both the Altaids and the Great Basin argue that the BHT may mark a transitional form of gold province linking classic Archean greenstone orogenic gold deposits with the sediment-hosted deposits that would dominant the Phanerozoic.

Background and Geologic Setting



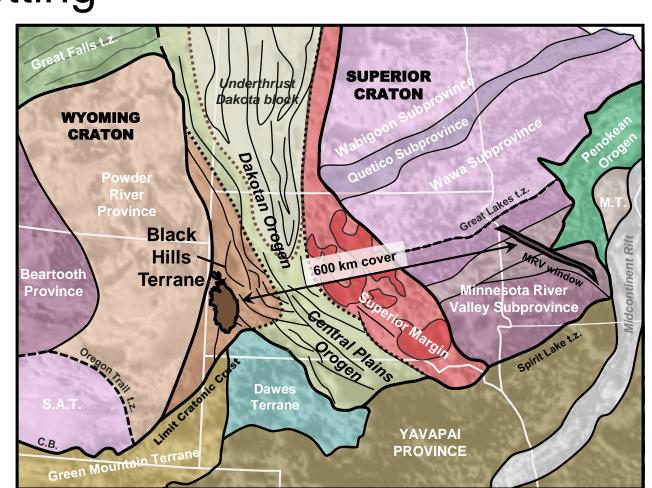
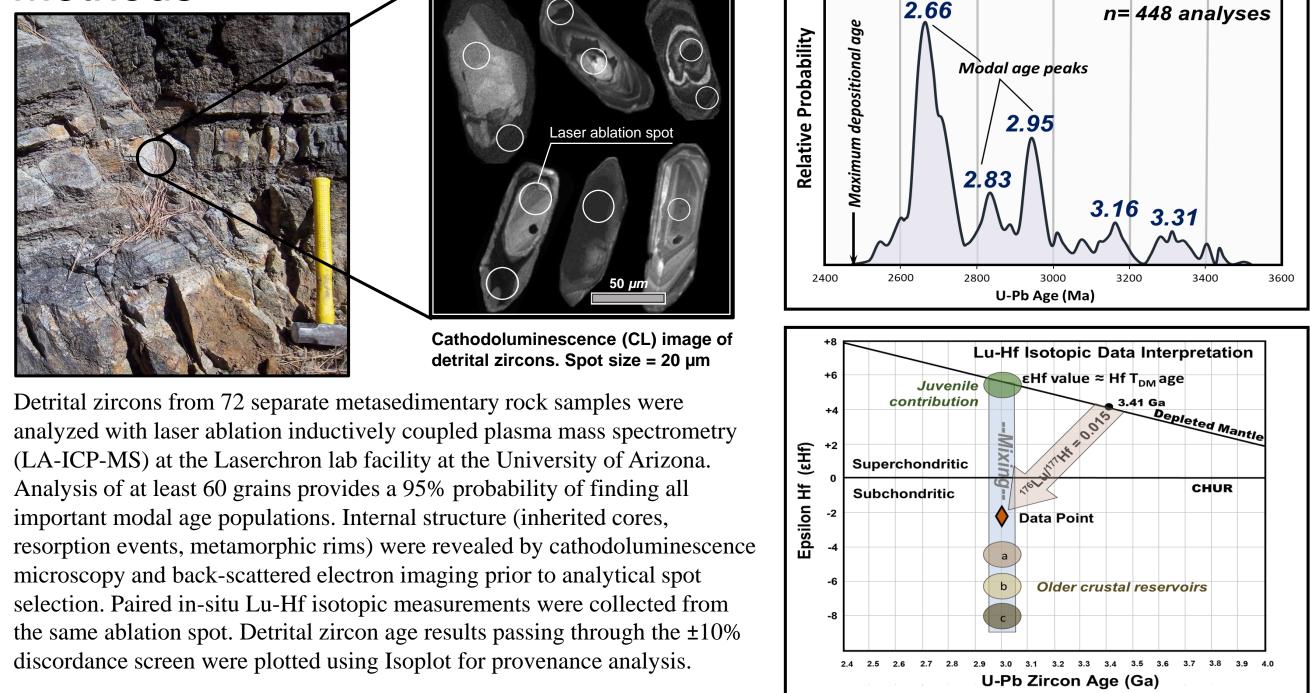


Fig 2. Aeromagnetic Interpr. of Wyoming-Superior craton boundary Fig 1. Terminal Laurentia Assembly at 1.80 Ga

The Black Hills represent a critical basement exposure in the American midcontinent near the intersection of the Wyoming and Superior cratons and the broad accretionary belts in the Yavapai Province. The affinity of the Black Hills for either craton is hotly debated as is the origin of the Powder River Province in the eastern Wyoming craton, which is interpreted by Worthington et al. (2016) as a Proterozoic accretionary collage but by Hrncir and Karlstrom (2018) as a Mesoarchean granite-greenstone domain. The timing and nature of the Dakotan Orogen relative to the broad Trans Hudson Orogen is also unclear. The Black Hills represent the key exposures for understanding many critical events in the history of southern Laurentia as the uplift preserves a remarkably complete archive of tectonic events in the detritus preserved in its numerous superimposed tectonosedimentary basins.

Methods

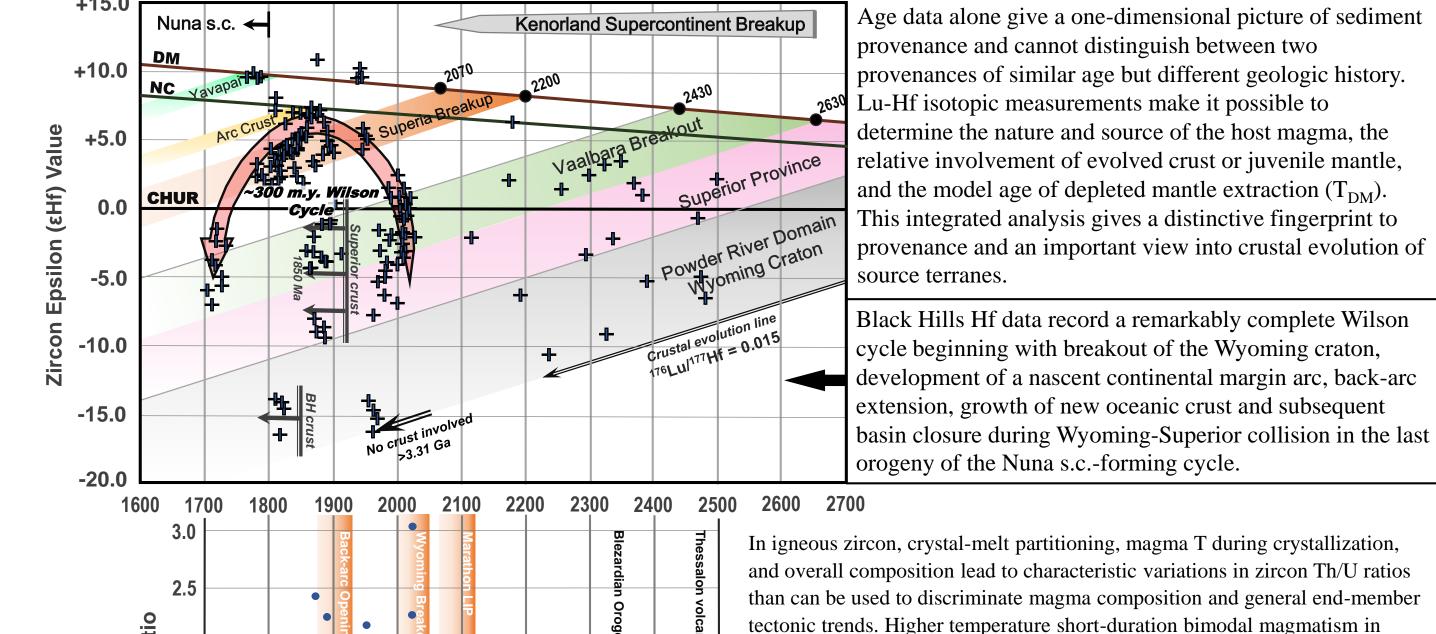


Sample Data Plots

Probability Density Plot Detrital Zircon Data

Paleoproterozoic Tectonic Setting of Black Hills

Zircon U-Pb ¹⁷⁷Pb/¹⁷⁶Pb Age (Ma)



extensional magmatic systems produces highly variable and elevated zircon Th/U ratios while long-lived convergent margin arcs are conducive to low Th/U zircon values.

0.5-1.0 Intermediate granitoid magmatism

>1.0 High-T fractionated extensional magmatism

Modeled after methodology of McKay et al. (2018)

Broad similarities between the Altaids and Black Hills include:

Tinton Window

Flag Rock Group

Lithologic mapping presented within is modified after the compilation map of Redden et al. (2008) and numerous USGS and SDGS 7.5

gold province in the world

geometry of the Altaid orogen.

movement along block margins

U-Pb ²⁰⁷Pb/²⁰⁶Pb Age (Ma)

South Laurentia Assembly: Altaids Analogue?

• The Altaid orogen of central Asia is the most important Phanerozoic

Particularly well-endowed in orogenic gold deposits (>500 Moz Au).

• The closure of the Paleozoic ocean basins between the Siberian and

East Europe cratons and Tarim microcontinent controlled the

• The clockwise rotation of Siberia led to oroclinal bending of an

intervening Cordilleran-style accretionary orogen involving

overthrusting of pericratonic and oceanic basins onto passive margin

sequences on the edges of discrete Precambrian ribbon continents.

• Deposits formed during multiple episodes of terminal transpressional

• Many parts of the orogen are spectacularly endowed with orogenic

gold resources hosted in the landward edges of miogeoclinal

successions that remained attached to their rear continents.

Minute quadrangles and unpublished graduate students maps.

First-order tectonic control of assembly through cratonic extraversion that traps external ocean arc crust and exposes passive margins to convergent margin tectonism ✓ Trapped arc terranes between two large cratonic blocks involving numerous microcontinent ribbons that produced pronounced arc curvature, rotation and oroclinal development.

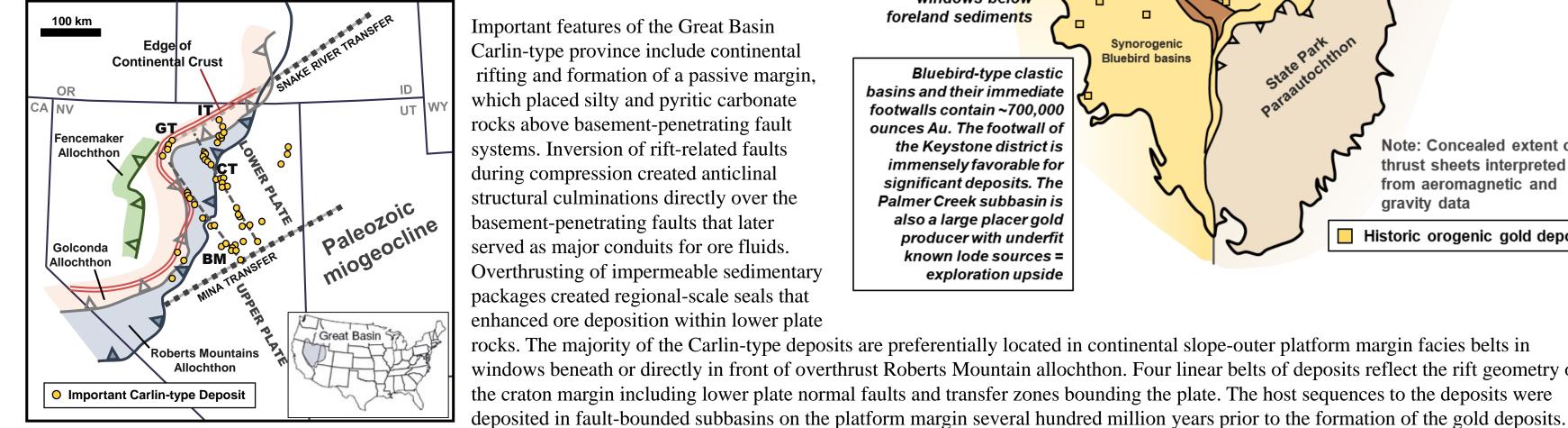
> European

- ✓ Dramatic rotation of one craton relative to another: rotation of the Wyoming craton is constrained with paleomagnetic poles to be 150° within 100 m.y. (Kilian et al. 2016) which is comparable in both rate and magnitude to the rotation of the Siberian craton of 130° in ~120 m.y.
- ✓ Ore deposits hosted within older passive margins sequences deposited >150 m.y. prior to gold deposit formation exposed as autochthonous windows beneath overthrust accretionary complexes.
- ✓ Ore deposits formed as a result of late-stage transpressional strike-slip movement
- ✓ Comparable spatial extent of BHT (~60,000 km²) with Altaids camps: Baikal-Patom (200 Moz Au) covers only 58,000 km² while the Southern Tien Shan (~320 Moz Au) at Kyzylkum and Zerafshan covers a combined area of only 93,000 km².

Uplift-scale orogenic Au exploration implications

- The supergiant Homestake deposit is hosted within a window into autochthonous miogeoclinal rocks along the easternmost of three parallel anticlinoria. Stratigraphic thickness changes, mafic intrusions, and structural style suggest each anticlinorium is cored by an original passive margin normal fault reactivated repeatedly during the Paleoproterozoic.
- Homestake is located near the intersection with the transverse Northern Black Hills transfer, marking the northern boundary of the miogeoclinal embayment into which the Black Hills Province developed during rift breakup of supercraton Superia.
- The vast majority of orogenic resources in the uplift are located in autochthonous rocks west of the overthrust domain while overthrust greywacke-basalt-gabbro-BIF and siliciclastic sequences in the allochthons are notably less productive for orogenic gold deposits.
- Exploration outside the Lead window to date has been remarkably unrewarding for major discoveries. The recognition that the southcentral Black Hills are dominated by overthrust allochthons and by an associated foredeep succession suggests that the most favorable earliest Paleoproterozoic stratigraphy for large deposits is present at depth, although possibly out of reach for exploration.
- In contrast an approx. 800 km² region beneath 50 to 1,000 feet of Phanerozoic cover along the Deadwood transfer remains virtually unexplored and likely contains broad exposures of favorable host rocks. This constitutes one of the most prospective exploration regions in the United States for major new
- Guides to major concealed orogenic gold deposits are provided by breached Eocambrian paleoplacers uplifted in small structural windows at East Tinton and Anchor, SD containing nearly 600,000 ounces of gold derived from unknown, but significant orogenic lode sources.

Comparisons With Great Basin Tectonic History



Important features of the Great Basin Carlin-type province include continental rifting and formation of a passive margin which placed silty and pyritic carbonate rocks above basement-penetrating fault systems. Inversion of rift-related faults during compression created anticlinal structural culminations directly over the pasement-penetrating faults that later served as major conduits for ore fluids. Overthrusting of impermeable sedimentary packages created regional-scale seals that enhanced ore deposition within lower plate

immensely favorable for significant deposits. The from aeromagnetic and Palmer Creek subbasin is also a large placer gold producer with underfit known lode sources = exploration upside rocks. The majority of the Carlin-type deposits are preferentially located in continental slope-outer platform margin facies belts in windows beneath or directly in front of overthrust Roberts Mountain allochthon. Four linear belts of deposits reflect the rift geometry of

Note: Concealed extent of

Conclusions

• The first detailed detrital zircon study has highlighted many inconsistencies with the current model for Black Hills Paleoproterozoic history, which has commonly been incorrectly ascribed to a juvenile greenstone belt similar to the internides of the Trans Hudson Orogen.

fault-anticlines;

parallel trend of

basement fault

foreland sedimen<mark>ts</mark>

Bluebird-type clastic

footwalls contain ~700,000

basins and their immediate

ounces Au. The footwall o

the Keystone district is

starved backbulge

- The unique history of the eastern Wyoming craton and the Dakotan Orogen is not characterized by the development of a wide external ocean but rather highly attenuated mature cratonic basement originating as a juvenile Mesoarchean granite-greenstone terrane covered by a miogeoclinal succession into which numerous Paleoproterozoic back-arc basins opened and were later inverted in a large-scale transpressional
- The Lu-Hf isotopic data argues for a persistent continental influence to these 1890-1830 Ma arcs switching from the Superior to Wyoming cratonic margins after 1860 Ma. Very little juvenile intra-oceanic arc material is present in Black Hills sedimentary basins, suggesting arcs were constructed on the trailing edges of cratons and ribbon continents in the intervening space between the Superior and Wyoming cratons.
- This assembly event is interpreted as an Altaids-style accretionary orogen involving development of accretionary collages around intra-oceanic continental fragments and later oroclinal bending and entrapment between the rapidly rotating Wyoming and Superior cratons that accommodated significant late-stage strike-slip faulting. This style of history is extremely favorable for the development of orogenic gold deposits in other orogens and can help explain the disparity in gold endowment between the Trans Hudson and Dakotan orogens.
- To reach their current location the Pactola and Little Elk allochthon strata were tectonically transported northward along the Wyoming craton margin in a sinistral transpressional fault system associated with the rapid rotation of the Wyoming craton in the Dakotan Ocean. Subsequent shortening during collision of the Wyoming and Superior cratons moved the allochthons up onto the craton margin in the Black Hills Terrane between 1820 and 1805 Ma. They contain almost no known gold resources although may be prospective for VMS deposits formed in the allochthonous oceanic domain.
- Without a constraining domain to the south between 1900-1800 Ma, extrusion of arc terranes may have occurred southeastward from the Wyoming craton along sinistral faults to form the controversial Central Plains orogen on the southern margin of the Superior craton and transported numerous older Paleoproterozoic continental fragments and detritus into the Yavapai oceanic domain. These would later form the substrate of the Dubois-character arcs in central Colorado. The presence of older Paleoproterozoic material >1.8 Ga south of the cratonic core of Laurentia is a persistent anomalous feature of the Yavapai terranes with competing and controversial models.
- The numerous similarities with the Altaids and Great Basin sedimentary-hosted gold provinces argue the Black Hills represents the earliest known passive margin-hosted gold province formed at the birth of supercontinent Nuna. Although classic orogenic gold provinces within oceanic-type crust still dominate the Neoarchean and Paleoproterozoic, the first recognition of this style of mineralization in the Paleoproterozoic opens up enormous areas for exploration within Nuna that have historically received little attention.
- Favorable terranes include not only the Black Hills but other passive margin sequences dominated by black shales, carbonates, and Superiorstyle BIF deposited on widespread passive margins during the breakup of supercontinent Kenorland and its constituent supercratons. Successions deposited on the trailing margins of cratons that experienced rotational extraversion would place these favorable lithologic successions on external oceanic convergent margins, where they could experience Altaids or Pacific-style retreating accretionary orogenic events characterized by subduction-driven SCLM refertilization and back-arc overthrusting thrusting, late in the Nuna supercontinent assembly.

