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PRECAMBRIAN CRYSTALLINE BASEMENT MAP OF IDAHO—AN INTERPRETATION OF AEROMAGNETIC ANOMALIES

By
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Lambert conformal conic projection
1927 North American datum

SCALE 1:1 000 000

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INTRODUCTION

Idaho lies within the northern sector of the U.S. Cordillera (fig. 1) astride the boundary between the Proterozoic continent (Laurentia) to the east and the Permian to Jurassic accreted terranes to the west. The continental basement is mostly covered by relatively undeformed Mesoproterozoic metasedimentary rocks and intruded or covered by Phanerozoic igneous rocks; accordingly, knowledge of the basement geology is poorly constrained.

Incremental knowledge gained since the pioneering studies by W. Lindgren, C.P. Ross, A.L. Anderson, A. Hietanen, and others during the early- and mid-1900's has greatly advanced our understanding of the general geology of Idaho. However, knowledge of the basement geology remains relatively poor, partly because of the remoteness of much of the region plus the lack of a stimulus to decipher the complex assemblage of high-grade gneisses and migmatite of central Idaho.

The availability of an updated aeromagnetic anomaly map of Idaho (North American Magnetic Anomaly Group, 2002) provides a means to determine the regional

Precambrian geologic framework of the State. The combined geologic and aeromagnetic data permit identification of previously unrecognized crystalline basement terranes, assigned to Archean and Paleoproterozoic ages, and the delineation of major shear zones, which are expressed in the aeromagnetic data as linear negative anomalies (Finn and Sims, 2004).

Limited geochronologic data on exposed crystalline basement aided by isotopic studies of zircon inheritance, particularly Bickford and others (1981) and Mueller and others (1995), provide much of the geologic background for our interpretation of the basement geology.

In the northwestern United States, inhomogeneities in the basement inherited from Precambrian tectogenesis controlled many large-scale tectonic features that developed during the Phanerozoic. Two basement structures, in particular, provided zones of weakness that were repeatedly rejuvenated: (1) northeast-trending ductile shear zones developed on the northwest margin of the Archean Wyoming province during the Paleoproterozoic Trans-Montana orogeny (Sims and others, 2004), and (2) northwest-trending intra-continental faults of the Mesoproterozoic Trans-Rocky Mountain strike-slip fault system (Sims, unpub. data, 2003).

In this report, geologic ages are reported in millions of years (Ma) and generalized ages are given in billions of years (Ga). The subdivision of Precambrian rocks used herein is the time classification recommended by the International Union of Geological Sciences (Plumb, 1991).

MAP COMPILATION

The basement geologic map of Idaho was interpreted from the aeromagnetic anomaly map of the State (McCafferty and others, 1999), utilizing both published and unpublished geologic and isotopic data and comparative knowledge gained from basement studies in Montana (Sims and others, 2004). The aeromagnetic map provides a major tool for interpreting basement geology in the vast region of the State that lacks outcroppings of the basement rocks (fig. 2). Except for certain younger intrusive and volcanic rocks, large-scale magnetic anomalies are caused mainly by different levels of magnetization of the crystalline basement rocks and structures, principally shear zones and faults, that penetrate and transect the basement. (See Finn and Sims, 2004, for discussion).

The two major sets of basement structures in Idaho are manifested by steep magnetic gradients, commonly linear negative anomalies (fig. 2). The negative anomalies reflect the complete or partial destruction of magnetite in the basement rocks resulting from shearing and attendant thermal activity along the fault zones. The most prominent and persistent negative anomalies trend northeasterly across the State, into and through northern Montana (Sims and others, 2004); they delineate thrust faults, commonly containing mylonite, that were formed during collision of accreted Precambrian terranes, to the north, against the northwest margin of the Archean Wyoming craton, as discussed below. The suture zone is the Dillon shear zone (DSZ, fig. 2). The northwest-trending fault system is expressed by magnetic gradients that are more subtle than the northeast-trending anomalies. Strands of the well known Lewis and Clark fault system (Wallace and others, 1990, and references therein) yield distinct, generally narrow, northwest-trending negative magnetic anomalies (LC, fig. 2). The recognition of this correlation between anomalies and basement shear zones, which also has been observed throughout much of the western Cordillera (Sims, unpub. data, 2003), provides a means to confidently identify other major covered northwest-trending shear zones. Notably, the important Clearwater fault zone was identified during our study. A major north-striking transcurrent fault, interpreted as an antithetic or transfer fault that was formed between the Clearwater and Snake River strike-slip fault zones, is postulated as having influenced the location of the Salmon River suture zone. The magnetically quiet zone immediately east of the suture is interpreted as a highly tectonized zone in which magnetic minerals have been strongly altered.

GENERAL GEOLOGY

The northwestern U.S. Cordillera consists mainly of two fundamental crustal blocks—to the east, a western sector of the Proterozoic North American continent (Laurentia) and, to the west, composite Permian to Jurassic oceanic arc terranes (Brooks and Vallier, 1978; Silbering and others, 1992) that were accreted to the continent during the Cretaceous (Lund, 1988; Lund and Snee, 1988; Manduca and others, 1993). Much of the length of western Idaho straddles the boundary between the two disparate crustal blocks, which has a pronounced zig-zag pattern at the continental scale (fig. 1). This report mainly concerns the continental crust east of the Mesozoic accretionary belt and the delineation of pre-Mosozoic features in that continental crust.

The continental sector (fig. 3) consists of amalgamated Archean and Paleoproterozoic crystalline basement terranes that were joined during the Paleoproterozoic Trans-Montana orogeny (Sims and others, 2004), and are overlain discontinuously by sedimentary rocks of Mesoproterozoic, Neoproterozoic, and Paleozoic ages, and volcanic and sedimentary rocks of Eocene and Miocene ages. Voluminous tonalite to granite bodies of the Idaho batholith and granitic plutons of Eocene age intrude the older rocks (Bond, 1978). Major deformational episodes that have been superposed on the Precambrian basement include the regional Cretaceous Sevier orogeny (Armstrong, 1968), which mainly involved east-vergent thin-skinned thrusting (Cordilleran thrust belt; Powers, 1983); Eocene extensional deformation, which resulted in development of metamorphic core complexes (Coney, 1980); and basin and range-type faulting. More local deformations took place in mid-Mesoproterozoic time (discussed in a following section) and in late Paleozoic time (Skipp and Hall, 1980). The latter involved uplift of the northwest-trending Copper basin highland in southeastern Idaho (north of eastern Snake River Plain) and deposition of coarse detritus in adjacent basins in Des Moinesian time. The tectonism is closely similar in age, and perhaps origin, to the Ancestral Rocky Mountains orogenesis in the southern Rocky Mountains (Sims, unpub. data, 2003).

Mesoproterozoic metasedimentary rocks, generally of low metamorphic grade, overlie the crystalline basement rocks in the northern part of the State. The Belt Supergroup (Harrison, 1972) forms a 15- to 20-km-thick blanket in northern Idaho, and the approximate correlative Yellowjacket Formation and associated sedimentary rocks form a thinner cover over the basement in part of east-central Idaho (Evans and Green, 2003). The boundary between the two successions is a profound early Mesoproterozoic northwest-striking shear zone, named here the Clearwater zone. The Mesoproterozoic sedimentary rocks are not included as basement on the map.

Exposures of Precambrian crystalline basement rocks in Idaho occur chiefly in the cores of gneiss domes, which are components of the north-trending, linear belt of Cordilleran metamorphic core complexes in western North America (Coney, 1980; Crittenden and others, 1980; Rehrig and Reynolds, 1981). The belt lies along and near the western margin of the Proterozoic continent (Laurentia). Migmatitic gneisses, in the cores of the complexes, form an infrastructure beneath gently arched mylonite zones that separate gneiss from the overlying supracrustal succession of diverse ages. Identified metamorphic core complexes in Idaho include the Priest River complex in northern Idaho and adjacent Washington (Doughty and others, 1998); the Clearwater complex in north-central Idaho (Seyfert, 1984; Doughty and Buddington, 2002); the Bitterroot complex in eastern Idaho (Hyndman, 1980); the Pioneer complex in south-central Idaho (Dover, 1981, 1983); and the core complex in the Albion Range, southern Idaho (Miller, 1980; Miller and others, 2002). The ages of basement rocks, so far as known, is Archean in the Priest River complex (Doughty and others, 1998) and in the Albion Range (Miller and others, 2002) and Paleoproterozic in the Clearwater complex (Reid and others, 1973; Armstrong, 1976; Doughty and Buddington, 2002).
Interpretation of dynamothermally metamorphosed rocks in central and northern Idaho, adjacent to the Idaho batholith, has been controversial. Early workers (Ross and Forrester, 1947) considered these metamorphic rocks as products of intrusion of the batholith. Later field studies led to their interpretation as products of a Mesoproterozoic (Reid, 1959; Reid and Greenwood, 1968; Reid and others, 1970) or older (Reid and others, 1973, 1981; Hietanen, 1984) metamorphic event. The regionally metamorphosed rocks host small diorite and porphyritic granite (augen gneiss) intrusive rocks that have been dated at 1,370 Ma (Evans and Fischer, 1986; Evans and Zartman, 1990; Doughty and Chamberlain, 1996). The protolith age of the paragneisses in central Idaho has not been conclusively documented; however, we propose on the basis of regional geologic relationships, that the amphibolite is likely Paleoproterozoic, as shown on the map and discussed in a following section. This interpretation needs further study.

PRECAMBRIAN BASEMENT ROCKS

The Precambrian crystalline basement in Idaho is interpreted to consist of the southwestward extension of the Archean Wyoming province (Houston and others, 1993, and references therein) and a composite terrane accreted to the northwestern part of the Wyoming province during the Paleoproterozoic Trans-Montana orogeny (Sims and others, 2004). The composite terrane is postulated to consist of three conjoined crustal segments, from east to west, the Archean Medicine Hat block, the Paleoproterozoic Wallace terrane, and the Archean Pend Oreille domain. The Medicine Hat block does not extend westward into Idaho; it is discussed in the report on the basement geology of Montana (Sims and others, 2004). The accreted, composite terrane underlies northern Idaho and extends through east-central Idaho into west-central Montana (north of the Dillon shear (suture) zone); Wyoming province rocks are present south of the suture zone and underlie the Eastern Snake River Plain in southern Idaho.

WYOMING PROVINCE

Archean rocks of the Wyoming province are inferred to underlie the part of Idaho that lies south of the Dillon suture zone, but they are exposed only in the infrastructure of a metamorphic core complex (gneiss dome) in the Albion Range (Miller and others, 2002) in southeastern Idaho, and, probably, in the core of the Pioneer complex (Dover, 1981, 1983), as shown on the geologic map. Underlying Archean rocks are postulated from secondary Pb isochrons of Archean age derived from Cenozoic basaltic lavas in the Snake River Plain (Leeman, 1982; Leeman and others, 1985). Extrapolation from exposures in Montana (Sims and other, 2004) and Wyoming (Sims and others, 2001b) suggests that the Archean rocks consist mainly of granodiorite-granite plutons (2.8–2.7 Ga), generally foliated, and older (mainly middle Archean) amphibolite- or granulite-grade metavolcanic and metasedimentary rocks (Wooden and others, 1988; Houston and others, 1993). Granitic rocks in Wyoming have isotopic signatures indicating they formed by remelting of older Archean crust (Frost, 1993); rocks derived from juvenile sources are rare.

The core of the Wyoming province, where exposed in Wyoming and Montana, has a distinctive magnetic signature, expressed at the regional scale by a crudely ovoidal pattern (Sims and others, 2001b, 2004), which reflects a substantial contrast in the intensity of magnetization of the respective Archean granitoid and layered metamorphic rocks (Finn and Sims, 2004). The granitoid rocks yield strong positive magnetic anomalies, whereas the layered rocks have a neutral magnetic expression.

The northwest margin of the Wyoming province was reworked during collision and subsequent convergence with the conjoined accreted terranes during Paleoproterozoic time (discussed in the following section). As a result, the cratonic margin was modified by imbricate thrust faulting, folding, and development of a new northeast-trending ductile foliation, which nearly obliterated the older Archean regional fabric. This deformation imposed a pronounced northeast-trending magnetic fabric, mainly characterized by steep-gradient, elongate magnetic lows, which overlie major ductile thrust faults (Sims and others, 2004).

Judged from aeromagnetic data, the deformed northwest margin of the Wyoming province extends southwestward from Wyoming into Idaho. This tectonically shortened belt of southeast-vergent imbricate thrusts and folds strikes northeastward and extends from the Dillon suture southeastward at least to the Madison mylonite zone (Sims and others, 2004; Erslev and Sutter, 1990), exposed a short distance northwest of Yellowstone National Park in northwest Wyoming.

ACCRETED TERRANES

Two of the three conjoined terranes believed to have been accreted to the northwest margin of the Wyoming province during the Trans-Montana orogeny (figs. 2, 3) are present in Idaho—the Paleoproterozoic Wallace terrane (Sims and others, 2004) and the herein named Archean Pend Oreille domain. Recognition of these two terranes as distinct crustal entities is based substantially on extrapolation of previously obtained geologic and geochemical data. Doughty and others (1998) demonstrated through U-Pb zircon dating that gneisses in the Spokane dome, within the core of the Priest River complex, are partly Archean in age, and these rocks are assigned herein to the Pend Oreille domain (fig. 3). Bickford and others (1981), Toth and Stacey (1992), Mueller and others (1995), and Foster and Fanning (1997) have shown that xenocrystic zircon cores within the Late Cretaceous Bitterroot lobe of the Idaho batholith are Paleoproterozoic, indicating that Paleoproterozoic oceanic island-arc rocks (Mueller and others, 1995) were involved in the origin of the younger magmatism, and presumably underlie the Bitterroot lobe. These rocks are assigned to the Wallace terrane.

The mechanics and timing of assembly of the composite terrane accreted to the northwest margin of the Wyoming province are conjectural because of the nearly ubiquitous cover of younger rocks. Geophysical data, however, provide a basis for interpreting the meager geologic and isotopic data. These data indicate that the three involved terranes are attached along north- to north-northwest-oriented structures (sutures?). The boundary between the Pend Oreille domain and the Wallace terrane is obscured by the north-trending basement fault now occupied by the Purcell trench (Doughty and Price, 2000). The trench has been interpreted as a normal fault formed by extension in Eocene time, which separates high-grade metamorphic rocks of the Priest River core complex from low-grade Belt rocks (Doughty and Price, 2000). However, we interpret the normal fault to be a product of reactivation of a north-trending basement fault that developed during formation of the Mesoproterozoic strike-slip fault system. The boundary between the Wallace terrane and the Medicine Hat block, on the other hand, is reasonably well known from seismic reflection data (Lemieux and others, 2000). West-dipping seismic reflectors in the western part of the Medicine Hat block are interpreted as east-vergent thrusts (Lemieux and others, 2000). These authors suggested that the structures resulted from continent-continent collision. We reinterpret (Sims and others, 2004) these structures, however, as resulting from arc-continent collision. Assembly of the conjoined terranes must have occurred prior to 1.85 Ga, the approximate time of suturing of the composite terrane with the Wyoming province.

Wallace terrane

Delineation of the Wallace terrane, as shown on the geologic map, is based on three confluent factors: (1) occurrence of xenocrystic zircons of Paleoproterozoic age in the Cretaceous Bitterroot lobe of the Idaho batholith in east-central Idaho (Bickford and others, 1981; Toth and Stacey, 1992; Mueller and others, 1995; Foster and Fanning, 1997), (2) sparse outcroppings of amphibolite southeast of the Bitterroot lobe (Berg, 1977), and (3) north-northwest-trending fabric in the magnetic and gravity anomaly data (McCafferty and others, 1999; Bankey and Kleinkopf, 1988). Together, these data are interpreted to indicate a terrane of Paleoproterozoic age, herein named the Wallace terrane, that may be of oceanic island-arc origin and comprises a north-northwest-trending, 75- to 200-km-wide belt extending from east-central Idaho through the Bitterroot lobe at least to the Canadian border.

The inherited zircons in the Bitterroot lobe are interpreted to indicate a minimum age of about 1.73 Ga for the Wallace terrane rocks (Mueller and others, 1995). Presumably equivalent gneiss and amphibolite are exposed to the southeast of the Bitterroot lobe, along the Idaho-Montana border (Berg, 1977). They are interpreted as products of regional dynamothermal deformation of probable late Paleoproterozoic age. The regionally metamorphosed rocks host metagabbro-diorite and porphyritic granite (augen gneiss), confidently dated at 1,370 Ma (Evans and Zartman, 1990; Doughty and Chamberlain, 1996).

Pend Oreille domain

The Pend Oreille domain is named herein from exposures of Archean and younger metamorphic rocks adjacent to the Pend Oreille River in northern Idaho and adjacent Washington (Doughty and others, 1998). The exposures occur in the Middle Eocene Priest River metamorphic core complex, which comprises an infrastructure of Precambrian gneisses and Phanerozoic granitic plutons with Eocene and older K-Ar cooling ages, and a suprastructure composed of weakly metamorphosed Mesoproterozoic Belt-Purcell strata. Precambrian gneisses are exposed in the Spokane dome (geologic map) and have been dated (U-Pb zircon method) at about 2,651 and 1,576 Ma (Doughty and others, 1998). The gneisses underlie the Spokane dome mylonite zone, considered by these authors to be the basal decollement of the Cordilleran thrust belt; accordingly, the Precambrian gneisses are interpreted as autochthonous. Doughty and others (1998, fig. 9) suggested that the Pend Oreille basement rocks could (1) be the western extension of the Archean Hearne province (in Canada) or, alternatively, (2) be separated from the Hearne province (Medicine Hat block of this report) by Paleoproterozoic crust, which has been identified in southern Alberta (Ross, 1991) and eastern Idaho (Mueller and others, 1995). We have presented evidence supporting the latter interpretation. Because of the restricted areal occurrence of these Precambrian gneisses and their spatial association with magnetic Phanerozoic intrusions, their magnetic character is not known.

The Pend Oreille domain is inferred to include the infrastructure of the Kettle (Cheney, 1980) and Okanogan (Fox and others, 1976) core complexes (Rhodes and Hyndman, 1988) because of their similarities to the Priest River complex and lack of direct evidence that the rocks are allochthonous to the continent.

PALEOPROTEROZOIC TRANS-MONTANA OROGENY

The Trans-Montana orogeny, as defined and delineated in Montana and extended into Idaho (Sims and others, 2004), developed along the northwest margin of the Wyoming province in Paleoproterozoic time (1.9–1.8 Ga). It contains many features typical of better known Paleoproterozoic convergent terranes that surround Archean cratons in the Canadian shield (Hoffman, 1987, 1988)—major orogen-parallel, craton-vergent, ductile thrust faults and related folds, asymmetric structures indicative of transport direction, and imbricate juxtaposition of thrust wedges of Archean and Paleoproterozoic rocks. The fold-and-thrust belt of the Trans-Montana orogeny coincides in part with the Great Falls tectonic zone of O'Neill and Lopez (1985); this zone was distinguished by brittle structures and intrusions of Phanerozoic age due to upward propagation of strain and magmatism during reactivation of the basement structures, and interpreted as reflecting Paleoproterozoic convergent tectonism (O'Neill, 1999).

The Trans-Montana orogeny comprises a deformed, north-facing, passive continental margin and subsequent foredeep assemblages overlying an Archean basement that is juxtaposed with the accreted conjoined terranes (Sims and others, 2004). The juncture of the two disparate bodies is the linear deformed belt between the Great Falls and Dillon shear zones. Suturing of the conjoined terranes with the Wyoming province took place at about 1.85 Ga, as constrained by the age of magmatic arc rocks exposed in the Little Belt Mountains in north-central Montana (Mueller and others, 2002). The architecture and age of the suture zone are similar to that of the Paleoproterozoic Penokean orogeny on the south margin of the Archean Superior province (Sims, 1996), although the two regions are separated by the Trans-Hudson orogen.

The Trans-Montana orogeny involved southeast-vergent collision east of the Wallace oceanic terrane and accompanying Archean micro-continents—the Medicine Hat block and the Pend Oreille domain—with the Archean Wyoming province, during the approximate interval 1.9–1.8 Ga. Collision was accompanied by development of a convergent-margin magmatic arc within the suture zone (Mueller and others, 2002). The probable presence of Paleoproterozoic oceanic crust beneath the Medicine Hat block (in northern Montana) is indicated by seismic reflection data and xenoliths within the Eocene alkalic rocks of the Sweetwater Hills (Lemieux and others, 2000). These data imply that the Medicine Hat block is underlain by subducted Paleoproterozoic ocean basin.

Major, southeast-directed, ductile, orogen-parallel thrust faults are postulated in the foreland fold-and-thrust belt of the Trans-Montana orogeny in Idaho, mainly by extrapolation from Montana (Sims and others, 2004). In Montana, intervening zones between the major shears are imbricately deformed, resulting in interleaving of Archean gneisses and Paleoproterozoic rocks (O'Neill, 1999). A northeast-trending penetrative foliation that generally dips moderately northwestward is pervasive in known intervening thrust wedges; it is superposed on earlier (Archean-aged) tectonic structures in the Archean rocks.

The fold-and-thrust belt is interpreted from exposure in Montana (O'Neill and Christiansen, 2004) to include a Paleoproterozoic passive-margin metasedimentary succession, mainly quartzite and marble, and an overstepping foredeep sedimentary succession (O'Neill, 1999); both successions were deposited on and are now interleaved with Archean basement rocks (Sims and others, 2004). The passive-margin strata were deposited on the rifted margin of the craton prior to closing of the presumed ocean between the craton and the arc to the northwest, and the foreland-basin deposits formed on the craton margin in advance of southeast-directed convergence of the arc-continent (O'Neill, 1999). Deformation during collision and continued convergence intricately interleaved the supracrustal and cratonic rocks, commonly as duplex structures.

MESOPROTEROZOIC TRANS-ROCKY MOUNTAIN FAULT SYSTEM

Knowledge of the lithospheric structure in this broad region is greatly enhanced by recognition of a major, deep-seated, northwest-trending, intra-continental strike-slip fault system of Mesoproterozoic age, named the Trans-Rocky Mountain fault system from exposures in the mountain belt (Sims, unpub. data, 2003), and its continuation into the northern Cordillera (fig. 4). The fault system is inferred to have formed at about 1.5 Ga, or perhaps somewhat earlier, in a left-lateral regional tectonic regime. Steep, linear to curvilinear, partly en-echelon, ductile shears (and associated folds) striking northwestward cut indiscriminately across both Proterozoic and Archean basement terranes; these shear zones typically have large-scale strike-slip displacements. The faults are wrench zones that have undergone alternating zone-perpendicular shortening and extension, owing to the interplay between wrench motion and the rheologic layering of the crust, in a manner discussed by Dewey and others (1998).

In the northwestern U.S. Cordillera, the Trans-Rocky Mountain fault system consists principally of west-northwest-striking strike-slip faults (principal displacement zones), branching and en-echelon northwest-trending faults, and widely spaced, more local north-trending faults (fig. 4). The two northwest fault sets are interpreted to have originated as left-lateral (synthetic) faults, and the north-trending faults are interpreted as transfer (right-lateral) fractures (see Sylvester, 1988, for discussion of kinematics). West-northwest-striking basement faults of the Trans-Rocky Mountain fault system are abundant in a 120-km-wide belt extending from the Lewis and Clark line (latitude 47°39' N.) southward to the previously unrecognized Clearwater fault zone (new name), a principal transcurrent lithospheric structure in the northwestern United States. Another zone of numerous, closely spaced west-northwest-oriented faults exists within the Snake River fault zone in southwestern Idaho. North-striking antithetic (transfer) faults are commonly spaced several tens of kilometers apart and are particularly common in the wide zone between the transcurrent Lewis and Clark line and Snake River fault zone (see Lewis and others, 1990, 1992b; Fisher and others, 1992; Worl and Johnson, 1995; Tysdal, 2002; Lund, 2005; Lund and others, 2003b; Tysdal and others, 2003).

SALMON RIVER CULMINATION

The origin of the enigmatic Salmon River arch of Armstrong (1975) is clarified by this study. The belt that was used to define the "arch" is distinguished by foliated amphibolite-grade gneiss and amphibolite, of uncertain age, that are locally intruded by plutons of gabbro-diorite and porphyritic granite. The granite has a U-Pb zircon age of 1,370 Ma (Evans and Zartman, 1990), subsequently confirmed by Doughty and Chamberlain (1996). The metamorphic rocks could include strata of the Mesoproterozoic Lemhi Group as well as other undated Mesoproterozoic rocks. Further studies are needed. The belt comprises a 70-km-wide belt (here interpreted as a horst) between the Clearwater and Big Creek transcurrent zones (fig. 4) of the Trans-Rocky Mountain fault system.

The exposure of Mesoproterozoic igneous rocks and their colinearity with the mid-Proterozoic Clearwater shear zone strongly suggest that emplacement was focused near the Clearwater zone. We propose that the belt resulted from transpressional-transtensional deformation of the shear zone during reactivation since mid-Proterozoic time.

REJUVENATION OF PRECAMBRIAN BASEMENT STRUCTURES

The two prominent sets of Proterozoic basement structures that formed by ductile shearing have profoundly influenced subsequent geologic events in Idaho and adjacent regions. The structures were formed during two disparate tectonic events in Proterozoic time: (1) reworking of the northwest margin of the Wyoming province by southeast-vergent tectonism during the Trans-Montana orogeny (Sims and others, 2004) at about 1.85 Ga, and (2) continent-scale transcurrent shearing at about 1.5 Ga (or older) that shortly followed amalgamation of the North America Proterozoic continent (Laurentia).

Rejuvenation of these structures provided first-order controls on many aspects of subsequent sedimentation and igneous activity, provided structural sites for deposition of valuable magmatic-hydrothermal mineral deposits, and shaped a segment of the western continental margin.

PALEOPROTEROZOIC TRANS-MONTANA OROGENY

Rejuvenation of foreland structures within the Paleoproterozoic Trans-Montana orogeny provided loci for emplacement of granitic plutons and related mineral deposits in Late Cretaceous–Eocene time (O'Neill and others, 2002). In southern Idaho, the plutons and associated mineral deposits are mainly confined to a 60-km-wide belt between the Great Falls shear zone and the Dillon shear zone (Sims and others, 2004). This belt contains major mineral deposits; the source of metals may have been substantial volumes of Paleoproterozoic juvenile magmatic arc rocks in the underlying basement orogenic belt. The innermost parts of the fold-thrust belt adjacent to undeformed sectors of the Wyoming craton lack appreciable igneous intrusions and metallic mineral deposits.

The pronounced northeast alignment of Neogene volcanic and subvolcanic rocks in the eastern Snake River Plain (Bond, 1978) also is attributed to emplacement of the igneous rocks along inherited basement structures, possibly formed during the Trans-Montana orogeny (Finn and Sims, 2004). The blanket of predominantly basaltic lavas largely obscures the underlying basement structure, but Archean rocks are known from xenocrystic zircons to underlie the lava field (Leeman, 1982; Leeman and others, 1985), and the northeast orientation of the lava field is parallel to known basement structures in the Trans-Montana fold-and-thrust belt. This interpretation is supported by detailed aeromagnetic data from Yellowstone National Park, where Finn and Morgan (2002) have reported a northeast magnetic fabric from detailed studies of rocks in the caldera. Together, these data provide an alternative to a suggested plume origin for the Neogene volcanic rocks.

It can be noted here that the western Snake River Plain volcanic field is parallel to the northwest-striking Snake River fault zone (fig. 3), thus explaining the arcuate shape of the Snake River Plain (Bond, 1978) as the result of the intersection of two major basement fault sets. The Snake River fault zone is a major part of the Trans-Rocky Mountain fault system (discussed in the following section).

MESOPROTEROZOIC TRANS-ROCKY MOUNTAIN FAULT SYSTEM

The northwest-trending Mesoproterozoic strike-slip fault system (fig. 4) provided major zones of weakness that were repeatedly reactivated, at the expense of the development of new, pristine structures.

Transpressional-transtensional deformation along the newly formed fault system in the Mesoproterozoic provided depocenters for the Belt-Purcell Supergroup and coeval successions. The sedimentary successions were deposited across west-northwest-striking active growth structures (Winston, 1986; O'Neill, 1995), which are faults of the Trans-Rocky Mountain fault system. Sedimentation in the Belt and related basins took place during the approximate interval 1.47–1.40 Ga (Evans and others, 2000), providing age constraints for early movement on these basement structures. During deposition of the

Belt-Purcell and related succession, favorable environments existed for accumulation of valuable ore deposits (for example, base metal sulfide deposits at Sullivan, British Columbia, Lydon and others, 2000; the Coeur d' Alene district, Idaho, Leach and others, 1998; and Blackbird mine, east-central Idaho, Nash and Hahn, 1989). The locations of Coeur d' Alene and Blackbird deposits along major strands of the Trans-Rocky Mountain intra-continental fault system suggest a possible genetic relationship. Mesoproterozoic sedimentation must have terminated by 1.37 Ga (Evans and Zartman, 1990; Doughty and Chamberlain, 1996), the time of emplacement of porphyrytic granite and related mafic rocks.

The recently identified belt of Neoproterozoic Windermere Supergroup equivalent rocks (Lund and others, 2003a) and the lower Paleozoic facies belts that trend east-southeast across central Idaho (Stewart, 1972; Poole and others, 1992) lie parallel to and between the Clearwater fault zone and the Snake River Plain structures. This suggests that southwestward extension occurred across central Idaho during Neoproterozoic and Paleozoic time, which was likely localized along ancient northwest-striking faults of the Trans-Rocky Mountain intra-continent system. Abrupt left-lateral offset of these sedimentary rocks from their northerly trend in northeastern Washington and west-central Idaho outlines the position of the northwest-trending continental margin in this region. Faults of the Trans-Rocky Mountain system controlled the orientation and location of the Neoproterozoic sedimentary belt. Similarly, left-lateral apparent offset of accreted Paleozoic continental slope deposits, assigned to the Kootenay arc from Canada (Ross and Parrish, 1991) and northeastern Washington to southern Idaho and Nevada (Silberling and others, 1992), is probably related to displacement of the continental margin across these and related structures.

The northwest-trending Precambrian zones of weakness were further involved in sculpting the western margin of Laurentia. The zig-zag shape of the continental margin resulted in a variety of accretionary geometries along the belt. Right-lateral transpressional accretion occurred in western Idaho along the north-striking Salmon River suture (Lund and Snee, 1988), which probably mimics an older basement structure of the Trans-Rocky Mountain fault system. The Clearwater fault zone apparently acted as a transform fault during development of the accretionary margin, allowing basement rocks to be removed and "escape" as arc terranes were emplaced. Related east-vergent thrust faults of the Sevier orogeny (Armstrong, 1968) were partially guided by and ramped along inherited northwest-striking faults, as judged from the mutual northwest orientation of the two structural entities. Strain associated with the thrust faulting was partitioned along the inherited west-northwest transcurrent faults. For example, in Montana salients of the foreland fold-and-thrust belt (Scholten, 1981) were partly controlled by ancient west-northwest transcurrent faults. Reactivation of west-northwest-striking basement structures has also been demonstrated along many faults of the Lewis and Clark line (Sears, 1988; Wallace and others, 1990; Yin and others, 1997; White, 1997). Transpressional-transtensional deformation within the Lewis and Clark tectonic zone during the Mesozoic (Wallace and others, 1990) resulted in substantial right-lateral displacement. The geometry of northwest-trending thrust faults along the inherited St. Joe transcurrent fault suggests left-lateral reactivation of this structure during Cretaceous thrust faulting (Reid and Greenwood, 1968; Lewis and others, 1992a). Also, thrust faults in the newly defined east-central Idaho thrust belt (Lund and others, 2003b; Tysdal and others, 2003) and in west-central Idaho (Lund, 2005) trend northwest subparallel to the Clearwater zone. These thrust faults are segmented by inherited north- and north-northeast-trending faults that were reactivated and acted as tear faults during Cretaceous thrust faulting (Tysdal, 2002, Lund, 2005; Lund and others, 2003b; Tysdal and others, 2003).

The westward stepping of Mesozoic batholiths from west-central Idaho to northern Idaho and northeastern Washington, recognized by previous workers (for example, Yates, 1968; Armstrong and others, 1977), is not a consequence of post-magmatic strike-slip faulting; instead, it is attributed to large-scale left-lateral displacement of the continental margin along the Clearwater zone long before the magmatism, probably in late Mesoproterozoic or early Neoproterozoic time. Thus, Mesozoic magmatism took place at two widely separated continental margin segments.

The Mesoproterozoic strike-slip fault system had a significant role in development of metamorphic core complexes in the region. The gneiss domes in northern Idaho were formed in Eocene time, and the metamorphic core complex in the Albion Range, in extreme southern Idaho, formed in the Oligocene (about 29 Ma, Miller and others, 2002). The Mesoproterozoic transcurrent faults formed kinematic boundary zones that focused strain during extensional (transtensional) deformation. The core complexes occur locally between major west-northwest strike-slip faults and are bound on the east and west by inherited north-trending faults. The west-northwest-trending faults provided zones of weakness that accommodated differential extension within and outside the core complexes. The north-trending faults acted as maximum zones of extension during the deformation; they commonly separate high-grade gneisses in the infrastructure of the core complexes from low-grade rocks in the superstructure.

Detachment zones in this region are localized along rheological boundaries between Precambrian basement rocks and the overlying more competent rocks of the Belt Supergroup. A classic example of this structural framework is the Clearwater core complex in north-central Idaho, mapped by Hietanen (1963, 1984) and discussed by Doughty and Buddington (2002). The complex has an infrastructure of anorthosite and upper amphibolite-facies gneisses, probably Paleoproterozoic in age (Reid and others, 1973; Armstrong, 1976), separated from low-grade Mesoproterozoic Belt strata on the east by an east-dipping mylonitic normal fault.

Interestingly, the Bitterroot core is completely separated from a suprastructure of lower grade Mesoproterozoic Belt sedimentary rocks on the east by a thick north-striking mylonite zone (Hyndman, 1980; Foster and Fanning, 1997). The mylonite zone overlies a north-trending basement fault of the Trans-Rocky Mountain system (Sims and others, 2004), indicated by a pronounced negative linear magnetic anomaly extending from east-central Idaho through western Montana and nearly to the Canadian border. The infrastructure of the Pioneer core complex, in central Idaho, is composed of strongly deformed sillimanite-grade, possibly Mesoproterozoic, metasedimentary gneisses that are separated from a thrust-faulted sequence of low-grade younger Paleozoic rocks by mylonitic normal faults (Dover, 1981).

CONCLUSIONS

Principal results of this investigation are: (1) recognition and delineation for the first time of major regional basement terranes, particularly the Paleoproterozoic Wallace ocean-arc terrane, which is postulated to be present in east-central Idaho mainly from indirect isotopic data (for example, Mueller and others, 1995) and (2) delineation of several major northwest-striking strike-slip shear zones (fig. 5) of the previously identified early Mesoproterozoic Trans-Rocky Mountain fault system (Sims, unpub. data, 2003), which have profoundly influenced the tectonic framework of the State. Many of these faults have been recognized previously (for example, Wallace and others, 1990). Identification of the Paleoproterozoic Wallace terrane provides a basis, in particular, for new interpretations of the complex metamorphic geology in central Idaho. These ocean-arc rocks are probable hosts for the 1,370-Ma intrusive “augen gneiss,” recognized at several localities along the central Idaho disturbed belt (the Salmon River arch of Armstrong, 1975), and they are interpreted as basement to the Belt Supergroup in the western part of the Belt basin. Significantly, the Purcell trench and the Rocky Mountain trench overlie the western and eastern margins, respectively, of the Wallace terrane, indicating that the terrane margins had a role in localizing significant younger tectonism. The northwest-trending strike-slip faults of the Trans-Rocky Mountain fault system strongly influenced subsequent tectonism in the region, as indicated by the pronounced northwest-southeast grain of the geology, as shown on the State geologic map (Bond, 1978). The faults in the crystalline basement were preferentially reactivated from Mesoproterozoic time to the Recent, affecting sedimentary patterns, tectonism, and igneous activity.

The west-northwest-striking Clearwater fault zone has been especially important in the evolution of the region, both as an intracratonic structure and as a transform fault that produced the prominent northwest jog in the continent margin from western Idaho into central Washington (fig. 3). In Mesoproterozoic time, the Clearwater zone affected sedimentary patterns during deposition of the Belt Supergroup and time-equivalent sedimentary rocks to the south, indicating that it was tectonically active during sedimentation. After cessation of Belt sedimentation and before, or during, accumulation of Neoproterozoic Windermere-equivalent rocks (Lund and others, 2003a), the Clearwater zone apparently was reactivated in a left-lateral sense as a transform fault, offsetting the western continent margin (Burchfiel and others, 1992). This reconfiguration of the continent margin remained intact through the Devonian, as indicated by the sinuous pattern of continent-margin sedimentary facies from Neoproterozoic to Devonian time. This zig-zag continental margin also controlled the geometry of accreted exotic terranes in the Mesozoic and the respective bounding magmatic belts in Late Cretaceous time, thus attesting to the permanency of lithospheric mantle structures established in Proterozoic time (Karlstrom and Humphreys, 1998).

DISCUSSION

Knowledge of the Precambrian basement geology enhances understanding of the geologic history of the region, mainly because shear zones that formed early in the geologic history persisted as lithospheric zones of weakness and focused strain during subsequent deformation. In transpressional-transtensional deformation, kinematic boundary conditions between fault-bounded blocks are more important than the regional stress field in determining local tectonic structures, as discussed by Dewey and others (1998). The northeast-trending Paleoproterozoic ductile shears and the west-northwest-trending Mesoproterozoic shear-fault systems guided, to varying degrees, subsequent tectono-magmatic and stratigraphic evolution. Thus, these ancient structures can be useful guides to future geologic investigations and exploration for new mineral resources.

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Figure 1. Precambrian-cored uplifts (colored) of Rocky Mountain region.

Figure 2. Aeromagnetic anomaly map of northwestern United States showing major Precambrian terrane boundaries and principal Proterozoic faults and shear zones. CB, Cheyenne belt suture; CF, Cedar Creek fault; CZ, Clearwater zone; DSZ, Dillon shear (suture) zone; GFSZ, Great Falls shear zone; LC, Lewis and Clark fault zone; SF, Snake River fault zone; SR, Snake River Plain volcanic field. Aeromagnetic map prepared by North American Magnetic Anomaly Group (2002).

Figure 3. Generalized Precambrian basement geologic map of northwestern United States. Compiled from Sims and others (2001a—Colorado), Sims and others (2001b—Wyoming), and Sims and others, (2004—Montana). BC, Big Creek zone; CB, Cheyenne belt suture; CF, Cedar Creek fault; CZ, Clearwater zone; DSZ, Dillon shear (suture) zone; GFSZ, Great Falls shear zone; LC, Lewis and Clark fault zone; SF, Snake River fault zone; SR, Snake River Plain volcanic field.

Figure 4. Major strike-slip shear zones of the mid-Proterozoic Trans-Rocky Mountain fault system. Faults are confined to Precambrian continental rocks. Dot pattern indicates allochthonous Permian to Jurassic ocean-arc terranes. Arrows indicate relative horizontal displacement and the intra-continental faults. BC, Big Creek zone; CZ, Clearwater zone; LC, Lewis and Clark fault zone; SF, Snake River fault zone. Compiled from Sims and others (2001a—Colorado); Sims and others (2001b—Wyoming); Sims and others (2004—Montana); and map accompanying this report.