

Evolution of the Salmon River suture and continental delamination in the Syringa embayment

K.I. LUND¹, J.N. ALEINIKOFF¹, D.M. UNRUH¹,
E.Y. YACOB¹ AND C.M. FANNING²

¹US Geological Survey, MS 973 Denver, CO 80225, USA
(klund@usgs.gov)

²Research School of Earth Sciences, ANU, Canberra, ACT
0200, Australia

The geology of west-central Idaho is dominated by the Salmon River suture that formed during dextral-oblique plate motion in the Cretaceous (~130-85 Ma). It is an unusual suture because it (1) juxtaposes Mesozoic island-arc rocks directly against Proterozoic continental rocks; (2) is defined by abrupt changes in ⁸⁷Sr/⁸⁶Sr initial ratios, ages, and origins in nearby and stitching plutons; and (3) has an ~90-degree change in trend from NNE in Idaho to W into Washington (Syringa embayment). NE of the embayment, SHRIMP U-Pb dates on detrital zircon show that Cretaceous island arc rocks are intercalated with Proterozoic continental rocks; U-Pb dates on inherited zircon and Sr and Nd isotopic analyses indicate diverse plutonic sources; U-Pb intrusive ages limit events.

Sample	Age (Inheritance)	⁸⁷ Sr/ ⁸⁶ Sr _i	εNd _i
Paragneiss of Dutch Oven Cr	Y (~1350-2500 Ma)		
Quartzite of Wild Goose Camp	Z (~900-1450 Ma; few X, W)		
Orthogneiss of Apgar Cr	94 ± 1 Ma (X)	0.7083	-5.22
Orthogneiss of Andys Hump	73 ± 3 Ma (X, Y, J, K)	0.7102	-7.62
Paragneiss of Swiftwater Cr	110-91 Ma (100-300 Ma; few Z, Y)		
Coolwater orthogneiss	91 ± 2 Ma (93-230 Ma)	0.7066	-2.91

Cretaceous island arc-derived Coolwater orthogneiss and paragneiss of Swiftwater are exposed in a window through the crustal-scale top-to-the-west Lowell thrust. The arc rocks were inserted as a wedge into the continent, delaminating Meso- and Neoproterozoic rocks (paragneiss of Dutch Oven Creek and quartzite of Wild Goose Camp) and continent-derived orthogneiss of Apgar Creek from underlying basement. Orthogneiss of Andys Hump intruded the top of the wedge. The entire package was folded into an antiformal culmination and exposed by normal faults. Detrital zircon data delimit Neoproterozoic rift margin deposits, suggesting that the Syringa embayment is an inherited segment that underwent local Cretaceous orthogonal contraction within overall dextral transpressive accretion.

The western Idaho Suture Zone: Mesozoic crustal boundary

ROBERT J. FLECK¹ AND JOSEPH L. WOODEN²

¹U.S. Geological Survey MS937, 345 Middlefield Road,
Menlo Park, CA 94025. (fleck@usgs.gov)

²U.S. Geological Survey, Stanford—USGS Micro-Analytical
Center, Stanford University, Green Earth Sciences
Building, Stanford, CA 94305

A zone of highly strained and metamorphosed rocks, called the western Idaho suture zone (WISZ), represents the boundary between Proterozoic North American lithosphere and accreted Late Paleozoic and Mesozoic intraoceanic terranes. Cretaceous plutons intruded the WISZ and subsequently were deformed within the zone. Pronounced variations in Sr, Nd, and O isotope ratios and in major- and trace-element compositions occur in these plutons from west to east across the suture zone, reflecting an increased mixing of Proterozoic sialic components in the marginal arc magmas. The zone of most highly deformed rocks coincides with an abrupt west to east increase in initial ⁸⁷Sr/⁸⁶Sr ratios and whole-rock δ¹⁸O and a decrease in εNd. The WISZ and coincident isotopic variations are traceable for more than 300 km from eastern Washington to near Ola in southwestern Idaho, where Columbia River basalts conceal its extension to the south.

Differences between SHRIMP U-Pb zircon ages and K-Ar, ⁴⁰Ar/³⁹Ar, and Rb-Sr mineral ages in Early Cretaceous plutons in the WISZ document patterns of thermal disturbance caused by deformation, subsequent batholith intrusion, and uplift of the continental margin. Inherited Proterozoic zircons occur in 111-Ma plutons with initial ⁸⁷Sr/⁸⁶Sr ratios of 0.7048 to 0.7057 within the WISZ, but none are observed in similar-aged intrusions 7 km west of the zone that have initial ⁸⁷Sr/⁸⁶Sr ratios of 0.7037. The occurrence of Proterozoic zircons in plutons of the WISZ confirms that suturing was complete by 111 Ma and that mixing of components from both cratonal and accreted arc terranes was occurring within these magmas. Major crustal movements within the WISZ commenced after about 135 Ma, but much of the displacement may have been largely vertical, during and following emplacement of batholith-scale silicic magmas. Deformation continued until at least 85 Ma and probably until 74 Ma, but may not have been synchronous throughout the length of the suture zone.

Tectonics of the Salmon River Suture Zone near Orofino, Idaho

LAWRENCE W. SNEE, DANIEL M. UNRUH
AND MEL A. KUNTZ

U.S. Geological Survey, Box 25046, MS974, Denver, CO
80225 (lsnee@usgs.gov, dunruh@usgs.gov),
(mkuntz@usgs.gov)

In the late 1800s Waldemar Lindgren (1897, 1898, 1900) described a zone of metamorphism and deformation in western Idaho and eastern Oregon along the western margin of a huge granitic mass. He noticed distinct lithologic differences, even in strata apparently of the same age, on opposite sides of this deformed zone. Lindgren (1915) later correlated the volcanic rocks west of this zone to similar volcanic rocks that extend from California to Alaska. Lindgren described what we recognize today as a suture zone between accreted island-arc rocks and the pre-Late Cretaceous North American continent, and, in essence, he was the first to make the "Wrangellian" connection.

This zone of accretion, which Lund and Snee (1988) named the Salmon River Suture Zone (SRSZ), is well-defined by an abrupt geochemical change across the suture zone from island-arc signature on the west to continental affinity on the east. The change occurs over about a few kms and trends north-south through much of western Idaho. In the region of Orofino, the geochemical change, as well as the apparent suture zone, make a sharp turn to the west. The nature of this bend has been an enigma.

Detailed $^{40}\text{Ar}/^{39}\text{Ar}$ and U-Pb thermochronology along the Orofino segment of the SRSZ records a tectonic history that begins with preaccretion plutonism that ended at about 140 Ma. Lower-amphibolite-facies dynamothermal metamorphism began at 130 Ma and was likely associated with arc accretion to North America. Plutons were emplaced into the island-arc terrane between 122 and 115 Ma, and some were deformed within the suture zone. Post-accretion southwest-directed thrusting occurred in the Orofino area between 93 and 80 Ma and emplaced rocks from deeper crustal levels along the terrane boundary over rocks from progressively shallower levels toward the southwest thickening the crust over the beheaded suture zone. This thrust plate was terminated along its northern extreme by a zone of ductile left-lateral, west-trending, strike slip translation, which produced the west-trending boundary and bend. Uplift resulting from the thrusting caused cooling of the overthrust high-grade rocks. Uplift progressed to the northeast resulting in a northeasterly decrease in mineral cooling ages to as young as 54 Ma in biotite.

Age, chemical, and isotopic complexity in magmatic belts along the Orofino segment of the western Idaho suture zone (WISZ)

KEEGAN L. SCHMIDT¹ AND REED S. LEWIS²

¹Div. of Nat. Sci., Lewis-Clark State College, Lewiston, ID
83501 (klschmidt@lsc.edu)

²Idaho Geological Survey, Morrill Hall, University of Idaho,
Moscow, Idaho 83844-3014 (reedl@uidaho.edu)

The Jurassic-Cretaceous WISZ was one of the first regions in which a major tectonic boundary was recognized based on systematic and sharp variation over short distances in isotopic ratios, chemistry, and K-Ar ages among plutons that intrude across it. We have examined a broad transect across the Orofino segment of the WISZ, where it strikes NW along the Clearwater River. This segment is more complicated than the N-S striking part of the WISZ that has been more rigorously studied farther south. Sparse U/Pb zircon age data suggest that the Orofino segment consists of several magmatic belts that differ in intrusive age, in Sr isotopic ratios, and to some degree in trace element composition. From SW to NE, these belts include: (1) a broad region of ~220-150 Ma plutons with low (<0.704) initial Sr ratios and island-arc major- and trace-element signatures that intrude Permian(?)–Triassic greenstone of the Wallowa accreted terrane; (2) a <10 km wide belt that straddles the WISZ consisting of ~120 to 115 Ma plutons with initial Sr ratios that vary systematically with some exceptions from ~0.703 to ~0.705 NE across the WISZ, which intrude rocks of the Wallowa terrane and Orofino series, a high-grade volcano-sedimentary assemblage of uncertain age; and (3) a >10 km wide belt of ~95 to 90 Ma plutons with initial Sr ratios >0.707 that intrude high grade Proterozoic cratonic sedimentary sequences. Few differences are apparent in major element chemistry between these magmatic belts. However, significant differences occur for many trace elements such as Hf, Ta, Th, U, Nd, Sm, Zr, Cu, and Sc. Belts 1 and 3 are readily distinguishable using these elements; belt 2 shows the most variation and overlaps with the other two belts. The presence of distinct tectonic belts defined by host rock assemblage, age, and isotopic and chemical character along and straddling the NW striking part of WISZ indicates that processes were probably different there than along the N-S striking zone of the WISZ. Either this part of the suture zone is characterized by tectonic slivering or thrusting, or the basement source regions evolved with time to produce contrasts in belts of varying age along it.

Genesis of a tonalite-trondhjemite suite within the accreted terrane, north-central, Idaho

ROBERT G. LEE¹, PETER B. LARSON² AND
JEFFERY D. VERVOORT²

¹Oregon State University Corvallis OR 97331, USA
(rglee@geo.oregonstate.edu)

²Washington State University Pullman WA 99163, USA
(plarson@wsu.edu, vervoort@wsu.edu)

Permian to Jurassic oceanic island-arc rocks of the Wallowa-Seven Devils terrane in north-central Idaho were juxtaposed during the Cretaceous against the North American craton. Cretaceous tonalite-trondhjemite suites intrude the accreted terrane and their emplacement coincides with the end of the suturing event. A small body of tonalite-trondhjemite located seven miles south of Greer, Idaho, the Sixmile Creek Pluton (SMCP), intrudes an older quartz diorite. The tonalite-trondhjemites have high alumina (>15 wt. %) and low potassium concentrations (<1%), similar to high-Al tonalite-trondhjemite suites that occur in other accretion complexes. The SMCP is enriched in LREE and depleted in HREE and exhibits positive Eu anomalies, suggesting that these rocks accumulated plagioclase during their formation. Whole-rock oxygen isotope ratios show a small increase from tonalite to trondhjemite consistent with a fractionation trend. Quartz-feldspar fractionations are about 2 ‰ and indicate that the rocks have not been hydrothermally altered.

U-Pb laser ablation inductively coupled mass spectrometry was conducted on zircon grains from a biotite tonalite and a biotite-muscovite trondhjemite from the SMCP. Concordant ages indicate that the biotite tonalite crystallized at 119 Ma and the biotite-muscovite trondhjemite at 116 Ma, which is consistent with their whole-rock fractionation trends.

Major and trace element concentrations indicate that the SMCP was produced from the partial melting of a basaltic source with garnet in the residue. This crust included an oceanic island-arc that was produced by pre-accretion subduction west of the Blue Mountains. Petrologic evidence indicates that deformation was occurring during emplacement of the SMCP. Thus, accretion was still active during emplacement. Geochronology is consistent with this interpretation and the crystallization age of the SMCP most likely marks the boundary for the end of accretion.

Strontium and oxygen isotopic evidence for strike/slip motion along the continental margin in the Idaho Batholith

E.M. KING¹, B.L. BEARD², C.M. JOHNSON²,
AND J.W. VALLEY²

¹Illinois State University, Normal, IL 61790, USA,
(emking@ilstu.edu)

²Univ. of Wisconsin, Madison, WI 53706, USA,
(beardb@geology.wisc.edu, clarkj@geology.wisc.edu,
valley@geology.wisc.edu)

Strontium and oxygen isotope composition of granitic rocks on the western edge of the Idaho Batholith provide insight into the nature of the suture zone and subsequent shearing. Granitic rocks of the mid-Cretaceous Batholith intrude both sides of a major structural and geochemical crustal boundary. Early Cretaceous suturing juxtaposed Triassic/Jurassic accreted arc terranes and the Precambrian craton followed by Late Cretaceous shearing along the margin. The suture zone has previously been recognized as a nearly vertical structure containing imbricated sections of continental and oceanic mantle components. Imbrication would be apparent in transitional isotope values between oceanic and continental reservoirs. Late Cretaceous shearing would deform the isotopic trend representative of magmatic processes.

Isotopic ratios of granitic rocks intruded along a west-east transect in the Slate Creek area on the west side of the batholith appear to record a unique tectonic history. Initial ⁸⁷Sr/⁸⁶Sr ratios of granitic rocks along Slate Creek jump from less than 0.704 to greater than 0.707 in less than 1 km with no intermediate values. The $\delta^{18}\text{O}$ values of quartz and zircon increase gradually across the transect suggesting variability in the composition of the crust on either side of the suture zone.

The lack of intermediate initial ⁸⁷Sr/⁸⁶Sr ratios in granitic rocks presently exposed along the Slate Creek transect could have one of two tectonic implications. 1) The original suturing mechanism occurred with a transcurrent/transpressional motion resulting in a nearly vertical suture with no mixing of oceanic and continental lithosphere; or 2) subsequent shearing could have removed transitional units. Either process is highly unique for the Idaho Batholith as other transects indicate imbrication during suturing and significant contractional deformation during Late Cretaceous tectonic activity.

Temporal, compositional, and structural development of the Idaho Batholith near McCall, Idaho

MEL A. KUNTZ, LAWRENCE W. SNEE
AND DANIEL M. UNRUH

U. S. Geological Survey, Denver, CO 80225, USA
(mkuntz@usgs.gov, lsnee@usgs.gov, dunruh@usgs.gov)

The Idaho Batholith east of the Salmon River suture zone near McCall, Idaho, consists, from west to east, of elongated tonalite and granodiorite plutons and equant leucogranodiorite and monzogranite plutons. U-Pb and Ar/Ar ages indicate that the four plutonic units were formed in the same pulse of magmatism, uplift, and cooling. The emplacement ages are leucogranodiorite~94 Ma, tonalite~90Ma, and monzogranite~83 Ma. Granodiorite is undated.

The west to east transition from tonalite to monzogranite represents a spatial change in source rocks; from subducted Blue Mountains island-arc amphibolite/trondhjemite for tonalite, to a mixture of arc-volcanic and continental rocks at the arc-continent boundary for granodiorite, to Proterozoic gneisses/metasediments of the North American continent east of the arc-continent boundary for monzogranite. Tectonic compression resulting from plate interactions produced shortening and thickening of the crust, metamorphism, and magmatism. Experimental models suggest tonalite magma formed by dehydration melting of amphibolite/trondhjemite source rocks in a 45-60 km crust at a geothermal gradient of ~35°C/km. Extremely efficient partial melting of fertile Proterozoic rocks containing abundant muscovite and biotite resulted from crustal thickening and produced voluminous monzogranite magma that formed largely in place.

Foliations, lineations, dikes, and joints in the plutons record a tectonic history in which crustal strains changed in style, intensity, and orientation. Transpression existed at ~94 Ma for the leucogranodiorite pluton; NW-SE contraction occurred ~90-85 Ma for tonalite-granodiorite plutons; and SW-NE extension existed as early as 83 Ma for monzogranite plutons and certainly existed after ~80 Ma during formation of joints.

Sodic and potassic suites of the Cretaceous Idaho batholith

REED S. LEWIS

Idaho Geological Survey, University of Idaho, Moscow, ID
83844-3014 (reedl@uidaho.edu)

Cretaceous plutons of the southern lobe of the Idaho batholith are predominantly sodic (Na_2O typically $>\text{K}_2\text{O}$) and thus similar to the Boulder batholith "sodic series" to the east in Montana, first recognized by Tilling (1973). Only the southeast part of the southern lobe is potassic (Kiilsgaard *et al.*, 2001). This potassic suite resembles the potassic "main series" of the Boulder batholith and contains more MgO, Rb, Cs, U, Sc, Co, and Cr than the sodic suite to the northwest.

Recent mapping shows that the northern lobe is more complex than the southern lobe, in part because deep-seated Eocene (Challis event) plutons that are mineralogically and texturally similar to the Cretaceous batholith are widespread. Nevertheless, the northern lobe appears to be sodic (Hyndman, 1983) and has high Sr/Y ratios similar to "HiSY" magmas (Tulloch and Kimbrough, 2003) of inboard plutons in Baja-California and New Zealand. Eocene plutons that intrude the northern lobe differ in that they have subequal K_2O and Na_2O concentrations and have much lower Sr concentrations (average 300 ppm versus 800 ppm). Outlying Cretaceous plutons east of the Purcell Trench in northern Idaho are potassic and similar to the potassic suite in the southeast part of the batholith. They have low Sr/Y ratios like potassic rocks in the southern lobe and in "LoSY" plutons of Baja-California and New Zealand. At least some of the plutons of the potassic suite are 10-15 Ma older than the sodic suite and were emplaced at shallower levels. The potassic suite apparently originated from a relatively enriched but more mafic source, perhaps located at a different depth than the source for the sodic suite.

References

- Hyndman, D.W., (1983), *Geol. Soc. Am. Memoir* 159, 213-240.
Kiilsgaard, T.H., Lewis, R.S., and Bennett, E.H., (2001), *U.S. Geol. Survey Bull.* 2064-U, 1-18.
Tilling, R.I., (1973), *Geol. Soc. Am. Bull.* **220**, 3879-3900.
Tulloch, A.J., and Kimbrough, D.L., (2003), *Geol. Soc. Am. Special Paper* 374, 275-295.

Eocene plutonic rocks of North-Central Idaho

THOMAS P. FROST¹ AND REED S. LEWIS²

¹U.S. Geological Survey, 904 W. Riverside Ave, Spokane
WA, 99201, USA (tfrost@usgs.gov)

²Idaho Geological Survey, University of Idaho, Moscow, ID
83844-3014, USA (reedl@uidaho.edu)

Two distinct suites of Tertiary granitoid plutons are present between the drainages of the Salmon and North Fork of the Clearwater Rivers. The plutons are widely distributed and have sharp intrusive contacts with rocks of the Cretaceous Idaho batholith. The few published U-Pb age dates range from 57 to 46 Ma. Many of the most silicic plutons are part of the well-known "pink granites" that commonly are resistant to erosion and form prominent tors in the otherwise subdued landscape of the batholith. A second suite of Eocene granodiorite and granite plutons, some of which had been mapped as part of the Cretaceous biotite granodiorite of the Idaho batholith, are far more common than previously recognized.

Plutons of the Eocene pink granite suite are epizonal and range from very coarse- to fine-grained with prominent miarolitic cavities. Potassium feldspar commonly is bright pink, subhedral to euhedral perthite, while plagioclase is fine grained and interstitial. Biotite with or without hornblende is commonly present at a few percent. Silica contents are above 74%, the rocks are potassic with $K_2O/Na_2O > 1$, Rb/Sr is > 1.2 . Rb is 140-300 ppm, and Sr is < 130 ppm. Flat REE (La/Lu is 2-10) and large negative Eu anomalies are common ($Eu/Eu^* = 0.05-0.3$).

In the Eocene granodiorite to granite suite biotite, with or without hornblende, is the common mafic mineral. The K-feldspar content is variable and the crystals commonly, but not always, are pink. In addition to variable amounts of K-feldspar, the granodiorites are distinguished from the Cretaceous biotite granodiorites by being finer grained and having strongly zoned plagioclase. The Eocene granodiorite to granite suite has from 65-74% SiO_2 , $Rb/Sr < 1.2$, and $Rb < 180$ ppm. Strontium is 180-550 ppm and contrasts with otherwise similar rocks south of the Salmon River that have Sr of 400-850 ppm. The north-central Idaho rocks have higher REE and have steeper patterns than the pink granites with La/Lu of 10-30 and most have Eu/Eu^* of 0.4-1.0. In contrast, despite similar silica contents (67-74%) the Cretaceous biotite granodiorites of the Bitterroot lobe of the Idaho batholith have $Rb/Sr < 0.2$, $Sr > 500$ ppm, $Rb < 100$ ppm, and the rocks have a higher Na_2O/K_2O ratio than the Tertiary granodiorite-granite suite.

Basement influence on Phanerozoic tectono-magmatic history of the northern Rocky Mountains

DAVID A. FOSTER¹, PAUL A. MUELLER¹, JAMES VOGL¹,
DAVID MOGK², JOSEPH WOODEN³ AND
ANN HEATHERINGTON¹

¹Department of Geological Sciences, PO Box 112120,
University of Florida, Gainesville, Florida 32611,
dfoster@geology.ufl.edu

²Department of Earth Sciences, Montana State University,
Bozeman, MT 59717

³US Geological Survey, 345 Middlefield Road, Menlo Park,
CA 94025

The distribution of Precambrian structures and lithosphere strongly influenced the Phanerozoic evolution of the crust-mantle system of western North America. In particular, accretion of primitive elements and magmatism between 2.4 and 1.6 Ga is indicated in the western Great Falls tectonic zone (GFTZ) by: geochronologic and isotopic data from exposures of pre-Belt basement, isotopic (Nd, Pb, & Sr) signatures of Precambrian and Phanerozoic rocks, xenocrystic zircons from Cretaceous-Eocene granitoids, and detrital zircon ages in Mesoproterozoic metasedimentary rocks. These data suggest that this Paleoproterozoic lithosphere extends west to the Neoproterozoic rifted margin and consists largely of accreted, juvenile, Paleoproterozoic arcs, possibly combined with a Proterozoic mafic underplate. The Idaho batholith, for example, formed mainly over these Paleoproterozoic arc terranes, suggesting that the lithosphere was chemically enriched and more fertile for partial melting compared to areas underlain by Archean lithosphere. Similarly, the Cretaceous SW Montana granitic province (e.g., Boulder and Pioneer batholiths), and Eocene Challis volcanics, Absaroka volcanics, and Montana alkaline province are mainly restricted to the GFTZ or parts of the Wyoming province known to contain Paleoproterozoic lower crust. Spatial (e.g., orogen-orthogonal), temporal (Cretaceous and Tertiary), and compositional (ore-bearing and non ore-bearing) variations in magmatism, therefore, were related to the compositions of mantle-derived melts, depth of melting, and the relative fertility of the lithosphere, a characteristic which was established during the Proterozoic and modified during the Mesozoic and Tertiary.

First evidence for exhumation of UHP garnet peridotite in the North American Cordillera

D. CANIL¹, J. MACKENZIE, M. MIHALYNUK²,
C. CHARNELL, S. JOHNSTON AND J. ENGLISH

¹School of Earth and Ocean Sciences, University of Victoria,
Victoria, BC., Canada (dcanil@uvic.ca)

²British Columbia Ministry of Energy and Mines, Victoria,
B.C., Canada

The Cordillera of western North America is a youthful collisional orogen. Garnet peridotite and other ultrahigh pressure (UHP, > 2.8 GPa) rocks recognized in other orogens are suspiciously absent in this mountain belt. Only sparse occurrences of crust and mantle rocks derived from moderate depths (< 60 km) are recognized, favouring 'thin-skinned' accretion of crustal flakes over a fixed deeper substrate of the continent. In contrast, exhumation of mantle lithosphere requires 'thick-skinned' involvement of deeper parts of the crust and mantle. These contrasting mechanisms bear on the growth of the Cordillera, often used as a 'classic' actualistic example of continental growth by accretion. Here we show the first evidence for exhumation of UHP garnet peridotite and eclogite in the northern Cordillera and its deposition as detritus in an early Jurassic forearc basin (Laberge Group, NW B.C.). We use textural observations, major and trace element compositions of garnets and pyroxenes, and thermobarometry to show that mantle lithosphere likely of Proterozoic age and equilibrated at pressures greater than 2.8 GPa and temperatures of 850 to 1100 C, was exhumed and quickly deposited as fresh detritus during collision over a restricted time interval about 190 m.y. ago. Our results suggest collision in the northern Cordillera must have been thick-skinned, involving a Proterozoic continental mass with a lithosphere greater than 100 km (and possibly up to 150 km) thick. Our discovery also attests to the efficacy of denudation in nascent continental arcs.