A Transect Across an Island Arc-Continent Boundary in West-Central Idaho

Elaine A. Aliberti¹
Cathryn Allen Manduca²

INTRODUCTION

One of the most striking paleogeographic anomalies of the western U. S. Cordillera is exposed in west-central Idaho where Permian and Triassic island arc volcanics of the Wallowa Terrane are juxtaposed against rocks with cratonic affinities, across a narrow transition zone of metamorphic and plutonic rocks. In this area much or all of the Paleozoic miogeoclinal section present elsewhere along the western edge of the craton is missing, as are commonly intervening belts of melange and eugeoclinal sedimentary rocks of mixed provenance between the oceanic arc terrane and the cratonic margin (Davis and others, 1978; Hamilton, 1978; Lund, 1984). The preserved transition zone records an early to middle Cretaceous period of compressional deformation. This event appears to postdate the truncation of the Paleozoic miogeoclinal section and the removal of transitional assemblages between the arc and cratonic margin.

The original nature of the boundary between accreted arc material and the cratonic margin has been obscured by Cretaceous compressional deformation and by the emplacement of voluminous intrusives. No evidence of the event that truncated the cratonic margin and removed the transitional assemblages is preserved. The boundary is recognized by an abrupt change in the lithology of metamorphic pendants within the plutonic rocks. Pendants of metavolcanic and volcaniclastic schists and gneisses give way to quartzites and metapelites of continental affinity, suggesting that the plutons were emplaced across a steeply dipping boundary between arc and continent (Lund, 1984; Manduca and Kunz, 1987). Geochemical studies in this area have revealed a rapid change in the strontium and oxygen isotopic ratios of the rocks, which generally corresponds with the change in pendants (Armstrong and others, 1977; Fleck and Criss, 1985; Manduca and others, 1986).

The transition zone between rocks of the Wallowa Terrane and the continental margin as preserved within the Cretaceous intrusives of the Idaho batholith is illustrated schematically in Figure 1. The transition zone consists of a series of lithotectonic packages which are, from west to east: the Wallowa Terrane, the Rapid River thrust plate, the Pollock Mountain plate, the Little Goose Creek Complex and the Payette River Complex. The Wallowa Terrane consists of Permian and Triassic Seven Devils Group arc volcanics, and overlying limestone of the Martin Bridge Formation and slate of the Lucile or Hurwal Formation. These rocks have been relatively unaffected by deformation and metamorphism along the transition zone. The Rapid River thrust system emplaces Riggins Group schists and lesser amounts of Martin Bridge, Lucile and Seven Devils lithologies over the Wallowa Terrane. The Riggins Group is an assemblage of metavolcanic and volcaniclastic schists thought

¹ Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138
² Department of Earth and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125
to represent a portion of an island arc terrane. These schists have been correlated with either the Wallowa Terrane or the Olds Ferry Terrane and adjacent flysch and melange sequences in eastern Oregon (Hamilton, 1978; Brooks and Vallier, 1978; Lund, 1984, Silberling and others, 1984). The Rapid River thrust plate increases in metamorphic grade from lower greenschist facies in the west to uppermost greenschist or lower amphibolite facies in the east, and is penetratively deformed throughout. The Pollock Mountain fault emplaces the Pollock Mountain Amphibolite and the Hazard Creek Complex over the Rapid River thrust plate. Both the Rapid River thrust system and Pollock Mountain fault are shallowly dipping, northwest-directed thrusts at high structural levels, which steepen into vertical shear zones at depth.

The Hazard Creek Complex, Little Goose Creek Complex and Payette River Complex are all composed primarily of Cretaceous plutonic rocks. The Hazard Creek Complex consists of variably deformed epidote-bearing intrusives and gneissic country rocks emplaced during the early to middle Cretaceous compressional deformation. The westernmost plutons in the Hazard Creek Complex intrude metamorphosed island arc volcanics of the Pollock Mountain Amphibolite. The Little Goose Creek Complex consists primarily of strongly mylonitized porphyritic granodiorite gneissness. This mylonitization is the youngest penetrative deformation in the area, postdating the emplacement of all three intrusive complexes. It affects the eastern margin of the Hazard Creek Complex and the western margin of the Payette River Complex, obscuring the original nature of these contacts. The transition in wall rocks from arc-related to continentally derived material and the rapid change in strontium and oxygen isotopic ratios occur within the Little Goose Creek Complex. The Payette River Complex consists primarily of undeformed tonalite, containing abundant quartz and inclusions of continentally derived metamorphosed sedimentary rocks.

This field trip traverses the transition zone from west to east, beginning in rocks of the Wallowa Terrane and ending in rocks of the continental margin preserved as pendants within the Cretaceous Payette River Complex (Fig. 2). Although the transition occurs within a 25 mile (40 km) wide zone, roads that are nearly parallel to the strike of the transition zone require a longer trip.

### ROAD LOG

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>Begin at the Salmon River Inn, U.S. Highway 95, Riggins, Idaho. Drive 4.4 miles south on Highway 95 to Rapid River turnoff. Outcrops along the highway comprise the type section of the Squaw Creek Schist of the Riggins Group. The Squaw Creek Schist is a gray, compositionally layered schist which typically weathers rusty brown. The schists are dominantly composed of sodic plagioclase and quartz with abundant carbonate, biotite, muscovite, and carbon dust with minor amounts of epidote, clinozoisite, garnet, hornblende, and chlorite. Compositional layering of the schists has been transposed by pervasive deformation of this unit. Hamilton (1963) described the schists as marine sediments with a volcanic provenance.</td>
</tr>
<tr>
<td>4.1</td>
<td>This ultramafic pod is typical of those found along the contact between Squaw Creek Schist and Lightning Creek Schist.</td>
</tr>
<tr>
<td>4.4</td>
<td>Turn right and head west on Rapid River Road. Outcrops along the road expose the Lightning Creek Schist member of the Riggins Group, unconformably overlain by Quaternary gravels.</td>
</tr>
<tr>
<td>5.2</td>
<td>Junction; continue straight on dirt road.</td>
</tr>
<tr>
<td>6.6</td>
<td>Junction; stay left on main Rapid River Road.</td>
</tr>
<tr>
<td>7.0</td>
<td>Stop 1. Park near the Rapid River fish hatchery dam. At this locality we will look at a portion of</td>
</tr>
</tbody>
</table>
the Rapid River thrust system. The Rapid River thrust was originally mapped by Hamilton (1963, 1969) as a major post-metamorphic thrust which emplaces Riggins Group schists over the Seven Devils Group volcanics and the overlying Martin Bridge Formation and Lucile Slate. The Rapid River thrust actually consists of a system of faults which dip shallowly to the east at high structural levels, but steepen rapidly into a vertical shear zone with depth (Aliberti and Wemicke, 1986a). Here the basal thrust of the Rapid River thrust system emplaces Riggins Group schists, as well as blue-grey calcite marbles of the Martin Bridge Formation and black phyllites of the Lucile Slate, over Seven Devils Group volcanics.

Walk up the Rapid River trail to look at the basal thrust of the Rapid River thrust system. Rattlesnakes, poison ivy, and steelhead salmon are seasonally abundant along this trail and stream. Steep outcrops in the canyon consist of pervasively deformed marbles of the Martin Bridge Formation above the basal Rapid River thrust. Approximately 0.25 mile (0.4 km) up the trail on the right side there is a shallow cave in blue marble. The lower slab of marble shows excellent calcite stretching lineations (Fig. 3a). Mineral stretching lineations collected above the Rapid River thrust south of Riggins indicate northwest movement along the Rapid River thrust system (Fig. 3c; Aliberti and Wemicke, 1986a). Martin Bridge Formation and Lucile Slate intercalated with Riggins Group schists above the thrust suggest that all three units were tectonically interleaved before or during thrusting.

Continue west along the Rapid River trail to an unsigned trail junction; bear left on lower trail. Small-scale duplexing in the Martin Bridge Formation is observed in the cliff face across the river. Seven Devils Group metavolcanic tuffs and breccias crop out at the top of the next small hill approximately 0.5 mile (0.8 km) from the car. The mottled green and red colors are characteristic of these volcanics below the thrust. Steep foliations typical of the lower plate volcanics are locally present. Locally, tectonic slivers of Seven Devils Group volcanics are incorporated along the basal thrust. Looking back down river, the low-angle thrust contact between the Martin Bridge Formation and the Seven Devils Group is clearly visible as it crosses the Rapid River.

Return to car. Along the edge of the pool above the dam there are a few boulders of deformed volcanic breccias. These are typical of the Seven Devils Group volcanics, deformed in the root zone of the Rapid River thrust system upstream. Strain analysis of oriented breccias within the root zone shows that they have been flattened by pure shear and pressure solution along vertical foliation planes, which strike approximately N. 15°E. The subparallel attitude of the plane of flattening to the arc-continent boundary at this latitude suggests that the maximum shortening direction was at a high
10.25 Stop 2. Quaternary river gravels unconformably overlie pyrite-bearing, black phyllite of the Lucile Slate above the Rapid River thrust system. The Lucile Slate is correlated with the Hurwal Formation in Oregon (Brooks and Vallier, 1978), which stratigraphically overlies limestone of the Martin Bridge Formation, in turn resting conformably on Seven Devils Group volcanics of the Wallowa Terrane. At this locality, excellent mineral stretching lineations indicating west-northwest thrust movement are readily observed (Fig. 3b).

7.4 Stop 3. Intersection of Shingle Creek and Rapid River Roads. A silicified talc schist tectonite pod is present on the contact between the Lucile Slate and the Lightning Creek Schist. Such pods are volumetrically very minor, but they are the only material within the transition zone that may represent ocean floor.

9.4 Stop 4. The Lightning Creek Schist of the Riggins Group is a green to grayish green schist composed of chlorite, sodic plagioclase, quartz, actinolite and epidote with local occurrences of biotite, hornblende, garnet, clinozoisite, and carbonate. Here the chlorite schists are dipping gently eastward, with east-plunging mineral stretching lineations. Hamilton (1963) recognized this unit as a sequence of metavolcanic tuffs and flows with local agglomerate horizons. However, specific correlation of these schists with either the Olds Ferry Terrane or the Wallowa Terrane remains unresolved.

9.5 Highway 95; turn right and continue south.

11.8 Stop 5. Rest stop. Riggins Group Squaw Creek Schist is exposed in the roadcuts on the opposite side of the highway. The rock is typically a banded quartz-rich biotite schist or phyllite with variable amounts of carbonate. The metamorphic grade of Riggins Group schists increases eastward from the Rapid River thrust fault, where rocks are metamorphosed to lower greenschist facies, to the Pollock Mountain fault, where rocks reach upper greenschist to lower amphibolite facies. This increase in grade is interpreted to reflect a vertical section of the crust that was brought up along the steeply dipping Rapid River thrust system.

16.9 Turn right on Whitebird Ridge Road.

17.0 Junction; bear right and head up Whitebird Ridge Road.

17.4 Junction; bear left uphill.

19.2 Junction; bear left uphill.

19.7 Stop 6. This stop affords a good view of the Pollock Mountain fault on the hillside across the Little Salmon River. The trace of this low-angle fault cuts below resistant outcrops on the hilltops and down through upper terraces. It is offset slightly by a high-angle fault and then steepens into the river. The Pollock Mountain fault separates high-grade, garnet-bearing amphibolite gneisses of the Pollock Mountain plate above, from lower grade Riggins Group schists of the the Rapid River thrust plate below. These two plates record radically different metamorphic histories. Two-stage garnets within the amphibolites suggest burial of the Pollock Mountain plate to pressures of 8 to 10 kb and temperatures of 600 to 650° C (Selverstone and others, 1987). In contrast, single-
22.7 Stop 8. The Pollock Mountain Amphibolite is a metamorphosed pile of Triassic island arc volcanics. A preliminary garnet-whole rock isochron from single-stage synkinematic garnets within the Pollock Mountain Amphibolite near Pollock Mountain gives a metamorphic age of 144 Ma, interpreted to be the earliest stage of metamorphism and deformation associated with the arc-continent collision (Aliberti and others, 1988). Early deformation of the Pollock Mountain Amphibolite was followed by synkinematic intrusion of the Hazard Creek Complex to the east. $^{40}$Ar/$^{39}$Ar ages ranging from 118 to 95 Ma (Snec and others, 1987) may be related to deformation and uplift along the Pollock Mountain fault and Rapid River thrust system, as well as increased magmatic activity.

This locality is typical of high-grade injection gneisses of the Pollock Mountain Amphibolite above the Pollock Mountain fault, with garnet-bearing amphibolites pervasively injected by tonalite. Folded concordant sills of hornblende-biotite tonalite are coarse grained and contain xenocrystic garnets from the amphibolites. Deformation is syn- to post-intrusive. Younger but compositionally similar dikes are discordant to foliation, and these intrusives may be correlative with the oldest members of the Hazard Creek Complex. Sets of post-Miocene high-angle faults and joints are superimposed on earlier structures. Return to Highway 95.

23.9 Highway 95; turn right and head south.

25.8 Pinchurst; south of Pinchurst the outcrops along the highway are dominantly Columbia River Basalt.

32.2 Roadcuts in the Hazard Creek Complex begin here. The Hazard Creek Complex is the westernmost unit, composed primarily of Cretaceous intrusive rocks. The major members of the complex are variably deformed and recrystallized epidote-bearing quartz diorite to trondhjemite orthogneisses. These orthogneisses, emplaced during ongoing deformation, are the oldest intrusives along the suture zone. The structural style of the Hazard Creek Complex is very asymmetric. On the east the complex has a steeply dipping, generally north to north-northwest striking foliation. Plutons are elongate bodies with pervasive ductile folding around their margins. On the west, as seen in the following outcrops, dips are generally more shallow with diverse strike directions. Plutons are relatively equant with stoped blocks of wallrocks abundant along their margins. This asymmetry suggests the intrusives were emplaced within and to the west of an active zone of flattening and vertical flow.

32.6 Stop 9. These layered mafic gneisses are a minor component of the Hazard Creek Complex and crop...
Figure 4. Plot of initial epsilon Nd versus initial epsilon Sr with data from the Pollock Mountain Amphibolite. The range in Nd values supports the hypothesis that these rocks are metamorphosed island arc volcanics. The range in Sr toward high positive values suggests the amphibolites reacted with sea water prior to or during metamorphism (Aliberti and others, 1987). The field for mid-ocean ridge basalts (MORBs) is shown for comparison.

The layered mafic gneisses are surrounded by intrusive material of the Hazard Creek Complex and are inferred to be a pendant within the intrusives. Smaller blocks of layered gneiss are common as inclusions within intrusives in this area. The presence of the gneisses as pendants and inclusions, as well as the irregular contact between the Pollock Mountain Amphibolite and the Hazard Creek Complex, suggest that the contact is intrusive rather than tectonic.

The most abundant gneisses are andesitic in composition, containing andesine, hornblende, biotite, quartz ± clinozoisite, epidote, garnet, diopside, and cummingtonite. Amphibolites, calcic salite and quartzofeldspathic gneisses are interlayered with andesitic gneisses on scales from tens of centimeters to tens of meters. Amphibolites locally contain pyroxene. Calcic salite gneisses contain varying proportions of hornblende, epidote, tremolite, plagioclase, quartz and sphene. These gneisses, interpreted as metamorphosed volcanics and volcaniclastics of an oceanic volcanic arc, strongly resemble the Pollock Mountain Amphibolite which crops out to the west of the Hazard Creek Complex. Quartzofeldspathic layers, composed of plagioclase, quartz, biotite, clinozoisite, muscovite and garnet, contain large relict, zoned plagioclase grains and are interpreted as metamorphosed tonalite or trondhjemite sills. Compositionally, they strongly resemble early intrusives from the Hazard Creek Complex. Younger cross-cutting biotite granodiorite dikes are probably related to younger intrusives in the Hazard Creek Complex.

34.4 Stop 10. The Hazard Creek Complex contains several generations of intrusives which have been variably deformed into gneisses. At this locality a variety of the older orthogneisses within the Hazard Creek Complex can be observed. The oldest orthogneiss is fine grained, of quartz diorite composition, and contains abundant folded leucocratic veins. It occurs both as blocks and as elongate pods within the epidote-biotite-hornblende tonalite orthogneiss which makes up most of the...
outcrop. The tonalite orthogneiss is interlayered and deformed, with minor amounts of epidote-biotite-trondhjemitic orthogneiss. Magmas of these compositions were injected throughout an ongoing deformational episode, since these lithologies occur as crystalloblastic gneisses, as gneissic intrusives and as little-deformed intrusives. Tonalite and trondhjemite dikes cross-cutting the orthogneisses represent one of the youngest intrusions in this series.

35.2 Stop 11. Rocks in this outcrop are primarily epidote-biotite tonalite and trondhjemite which form approximately half of the outcrop in the canyon. This body is one of the youngest intrusives in the complex and is only slightly deformed. At this locality the intrusive is strongly foliated and contains concordant pods of orthogneiss and layered mafic gneiss. The tonalite is cut by trondhjemite and granite dikes and pegmatites. The latter are related to the youngest intrusive in the area: a leucocratic two-mica granite which crops out in Round Valley to the south.

35.5 Stop 12. Turnout on left; rocks are composed primarily of the epidote-biotite tonalite seen at Stop 11. However, at this locality the tonalite has a weaker foliation and contains steeper blocks of orthogneiss. These blocks can be observed both directly across from and to the south of the turnout. In the large boulder to the south of the turnout, a contact between the epidote-biotite tonalite and the crosscutting garnet-biotite trondhjemite dikes can be examined. Small clots of pure biotite within the granite arc interpreted as restite fragments.

The contrast in deformation style between the rocks at Stops 11 and 12 is typical of the western Hazard Creek Complex, where intrusive and deformational styles vary locally. Structural data from the western Hazard Creek Complex show no consistent preferred orientation, in part due to rotation of steeper blocks. However, foliations within a single rock type at a single outcrop also vary significantly, suggesting they formed as undulating surfaces rather than as planar fabrics. This structural style contrasts with the pervasive, steeply dipping foliation observed in the eastern Hazard Creek Complex. Deformation in the eastern Hazard Creek Complex appears to have been largely synplutonic and records east-west compression and vertical flow. The presence of a strong, oriented fabric only on the east side of the complex is interpreted to reflect the emplacement of intrusives within and to the west of a narrow zone of deformation.

47.3 New Meadows; at the junction of Highways 55 and 95, turn left on Highway 55 toward McCall.

51.6 Stop 13. This epidote-biotite hornblende tonalite mylonite crops out along the eastern edge of the Hazard Creek Complex. The outcrop is representative of the larger bodies of older quartz diorite orthogneiss throughout the complex. These gneisses typically have crystalloblastic fabrics, but here the gneiss was deformed by a younger mylonitic event, centered on the Little Goose Creek Complex which crops out several hundred meters to the east. In this area the Little Goose Creek Complex and Hazard Creek Complex appear to be interlayered on a scale of tens to hundreds of meters. Mylonitization has obscured the original relationship between the units.

53.0 Stop 14. The Little Goose Creek Complex is comprised primarily of this distinctive mylonitic, porphyritic biotite granodiorite orthogneiss. The porphyritic orthogneiss is tectonically interlayered with other intrusives ranging in composition from granite to gabbro. Epidote-free tonalites similar to those in the western portions of this outcrop are the most abundant interlayers. A hornblende pod, inferred to have been a cumulate, is present on the corner to the east. Layered mafic gneisses similar to those seen in the Hazard Creek Complex are also intercalated with the porphyritic orthogneiss, and can be observed in the upper part of the canyon. In the eastern portion of the Little Goose Creek Complex, metamorphosed continentally derived sediments are interlayered with the porphyritic orthogneiss. Thus, the orthogneiss contains pendants of both arc-related and continentally derived material. Strontium and oxygen isotopes within this unit have been studied by Manduca and others (1987). The isotopic ratios change dramatically from west to east. Calculated initial 87Sr/86Sr values range from 0.7045 in the west to 0.7097 in the east; δ18O values range from 8.0 to 10.9 (Manduca and others, 1986). Ratios generally increase from west to east, with a step in the central part of the complex. This step does not coincide in detail with the change in composition of metamorphic pendants. The gradient is inferred to reflect an eastward-increasing contribution of evolved crustal material (with elevated 87Sr/86Sr and δ18O) to the melt which formed the porphyritic orthogneiss. The changes in both pendant compositions and isotopic ratios within the orthogneiss suggest it intruded a steeply dipping lithospheric boundary, along which cratonic and oceanic arc lithologies were juxtaposed.

The Little Goose Creek Complex has been pervasively deformed into a mylonitic gneiss. Mylonitization appears to have occurred under dry conditions at amphibolite facies, since amphibolite facies mineral assemblages have not been retrograded and oxygen isotope variations are
preserved. Mylonitization also affected the western margin of the Payette River Complex to the east, and the eastern margin of the Hazard Creek Complex to the west, as seen at Stop 13. Deformation postdates the emplacement of the Payette River tonalite, and is the youngest penetrative deformational event in the area. Mylonitic foliations strike north-south, and dips are steep to vertical. (Foliation at this outcrop dips more shallowly than average). A well developed mineral lineation plunges down dip, and fold axes generally parallel the lineation. Movement is inferred to have been vertical with a strong flattening component.

58.4 McCall; turn left on Warren Wagon Road and drive north along the west shore of Payette Lake through rocks of the Payette River Complex.

66.1 Junction; stay left on Warren Wagon Road.

72.7 Stop 15. Payette River Complex: the Payette River tonalite is part of a belt of tonalite which crops out on the west side of the Idaho batholith along much of its length. Here the body is approximately 6 miles (10 km) wide and has a strong north-striking igneous flow foliation that dips steeply to the east. A steeply northeast-plunging flow lineation is also commonly present. Mylonitization of the western margin is the only post-emplacement penetrative deformation observed in this body.

Concordant screens and pods of metasedimentary rocks, inferred to be metamorphosed continentally derived clastics, are present throughout the complex. In this outcrop they are calcilutic gneisses and biotite schists. Quartzite and sillimanite-bearing schist are also common. Metasedimentary pendants vary in size from a meter to several kilometers in width, and the largest body is greater than 6 miles (10 km) in length. The metasedimentary material is intimately associated with granitic to tonalitic material, suggesting partial melting and local assimilation occurred during intrusion of the tonalite. Structures and fabrics in the metasedimentary rocks are generally parallel to those in the tonalite, and appear to be due to transposition of the metasedimentary rocks during intrusion of the tonalites. Older structures and fabrics may have been obliterated. The cross-cutting granitic dikes at this outcrop are related to the two-mica granitic core of the Idaho batholith which crops out 4 miles (6.5 km) to the east.

ACKNOWLEDGMENTS

Aliberti's research has been supported by NSF grant EAR 84-51181 to B. P. Wernicke. Geological Society of America research grants 3379-85 and 3531-86, and Harvard University field research grants. Field work by Manduca has been supported by the U.S. Geological Survey in collaboration with M. A. Kuntz. This guide stems from Aliberti's Ph. D. dissertation at Harvard University and Manduca's Ph. D. dissertation at the California Institute of Technology under the direction of L. T. Silver. The manuscript was reviewed by D. W. Rodgers and V. E. Chamberlain.

REFERENCES

Aliberti, E. A., and Wernicke, B. P., 1986a, Late stage processes in the growth of new continental crust: observations from the eastern margin of the Seven Devils terrane, west-central Idaho: Geological Society of America Abstracts with Programs, v. 18, no. 6, p. 524-525.


