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STRATIGRAPHIC RECORD OF TRIASSIC-JURASSIC COLLISIONAL TECTONICS IN THE BLUE MOUNTAINS PROVINCE, NORTHEASTERN OREGON

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ABSTRACT. Sedimentary and volcanic rocks in the Blue Mountains province (BMP) of northeastern Oregon preserve a well studied record of Triassic–Jurassic magmatism, basin evolution, and terrane accretion. Terranes of the BMP represent two magmatic arcs (Wallowa and Olds Ferry terranes), an intervening oceanic subduction and accretionary complex (Baker terrane), and a complex thick succession of sedimentary rocks commonly known as the Izee terrane. We divide volcanic and sedimentary rocks into two regionally correlative, unconformity-bounded megasequences: (1) MS-1, Late Triassic to Early Jurassic deposits that change up section from (1a) older volcanic and volcaniclastic deposits of the Wallowa and Olds Ferry arcs to (1b) marine turbidites, shale, and argillite with chert-clast conglomerate and olistostromes derived from the emergent Baker terrane; and (2) MS-2, Early to Late Jurassic marine deposits that overlap older rocks and structures and record ~20 to 40 m.y. of deep crustal subsidence in a large marine basin. Many of the known stratigraphic relationships in the Blue Mountains cannot be explained using the existing model for a Middle Triassic to Late Jurassic west-facing, non-collisional volcanic arc and forearc basin.

We propose a new tectonic model for the BMP based on prior studies and comparison to modern analogues, which includes: (1) Middle Triassic magmatism in the Wallowa and Olds Ferry arcs during subduction and progressive closure of an ocean basin; (2) Late Triassic collision between facing accretionary wedges of the Wallowa and Olds Ferry arcs, and growth of marine basins on both sides of the emergent Baker terrane thrust belt; (3) Early to Middle Jurassic terrane-continent collision which resulted in closure of a wide back-arc basin, crustal thickening and loading in Nevada, and growth of a large marine collisional basin in the BMP; and (4) Late Jurassic thrusting, regional shortening, and final accretion of the basin and underlying terranes to western North America. This analysis suggests that collisional tectonics may have played a significant role in plate interactions that drove Triassic–Jurassic crustal thickening, mountain building, and basin development in the western North American Cordillera.

INTRODUCTION

Our understanding of tectonic controls on Mesozoic crustal deformation and basin formation in western North America has improved significantly during the past ~30 years of research on this topic. There is general agreement that, from Early Cretaceous to Eocene time, the western Cordillera was an Andean-type convergent margin characterized by east-dipping subduction of oceanic crust, a west-facing magmatic arc and forearc basin, and an east-vergent thrust belt and foreland basin (Jordan, 1981; Oldow and others, 1989; Heller and Paola, 1989; Burchfiel and others, 1992; Cowan and Bruhn, 1992; Dickinson, 2004; DeCelles, 2004). Uncertainty persists, however, regarding plate interactions that controlled earlier development of the Cordilleran margin. For example, two contrasting tectonic mechanisms have been proposed to explain widespread Jurassic contractile deformation, crustal thickening and metamorphism: (1) collision and accretion of oceanic arc terranes to the continental margin (Monger and others, 1982, 1992; Silver and Smith, 1983; Schweickert and others, 1984; Ingersoll and Schweickert, 1986; Mortimer, 1986; Edelman, 1991; Wyld and others, 1996); or (2) strong coupling between subducting oceanic lithosphere and North America at a non-collisional margin (Oldow and others, 1989; Burchfiel and others, 1992; Smith and others, 1993; Dickinson, 2004). Some studies have suggested a complex setting in which short-lived accretion events alternated with periods of subduction, magmatism, and creation of marginal basins (Wright and Fahan, 1988; Saleeby and Busby-Spera, 1992). Thus the role and distribution of collisional plate interactions as a driver of Jurassic orogenesis in the western U.S. remains uncertain.

The term "collision" is defined as occurring when a large or buoyant plate margin is drawn into a trench and resists subduction because of buoyancy forces, resulting in protracted crustal shortening, thickening, metamorphism, and uplift (Cloos, 1993). Collisional orogenesis often results in delamination or breakoff of subducted lithosphere, upwelling and decompression melting of asthenosphere, and a wide range of geochemically diverse magmatic products. In modern settings such as southeast Alaska, Taiwan, Timor, and Papua New Guinea, arc and terrane collision is recognized as a major force that drives crustal thickening and construction of large orogenic mountain belts and flanking sedimentary basins (Cooper and Taylor, 1987; Plafker and others, 1994; Galewski and Silver, 1997; Lallemand and others, 2001; Mazzotti and Hyndman, 2002; Byrne and Liu, 2002; Clift and others, 2003; Audley-Charles, 2004; Cloos and others, 2005). These settings provide potential modern analogs for Triassic-Jurassic crustal deformation and basin evolution in western North America (Silver and Smith, 1983).

The Blue Mountains province (BMP) of northeastern Oregon (fig. 1) is a belt of Paleozoic to Mesozoic oceanic terranes that record a complex history of subduction, magmatism, basin formation, and accretion. According to most models for the BMP, a thick succession of Triassic-Jurassic marine sedimentary rocks accumulated in a long-lived forearc basin between a non-collisional east-dipping subduction zone in the west and a west-facing magmatic arc in the east (Dickinson and Thayer, 1978; Dickinson, 1979, 2004; Brooks and Vallier, 1978; Vallier, 1995). Two large volcanic provinces, the Wallowa and Olds Ferry terranes, are interpreted to either be built on a single plate that underwent a reversal in subduction polarity (Vallier, 1995), or tectonic juxtaposition of the two arcs is inferred to be post-basinal and recorded only in latest Jurassic compressional structures and metamorphic fabrics (Dickinson and Thayer, 1978; Dickinson, 1979, 2004; Avé Lallemant, 1995). We question these interpretations because some critical existing data sets appear to be incompatible with the predictions of a model for non-collisional subduction during Late Triassic and Jurassic time.

In this paper we summarize previous studies of Triassic-Jurassic sedimentary and volcanic rocks in the BMP, with a focus on regional stratigraphic correlations, provenance links, unconformities, and a widespread Jurassic marine overlap assemblage. Based on this synthesis we identify limitations of existing tectonic models and propose a new model that involves Late Triassic collision of two facing accretionary wedges followed by Jurassic terrane-continent collision and related formation of a large marine basin. A key component of this hypothesis is the reconstruction of Wyld and Wright (2001), which proposes that the BMP was located outboard of NW Nevada during Triassic and Jurassic time and was later translated ~400 km into its present position during Cretaceous offset on a regional dextral strike-slip fault system (fig. 1). By integrating the tectonic evolution of the Blue Mountains with events documented elsewhere in western Idaho and Nevada, we highlight the likely role of collisional tectonics in growth of the western U.S. Cordillera during Late Triassic and Jurassic time.

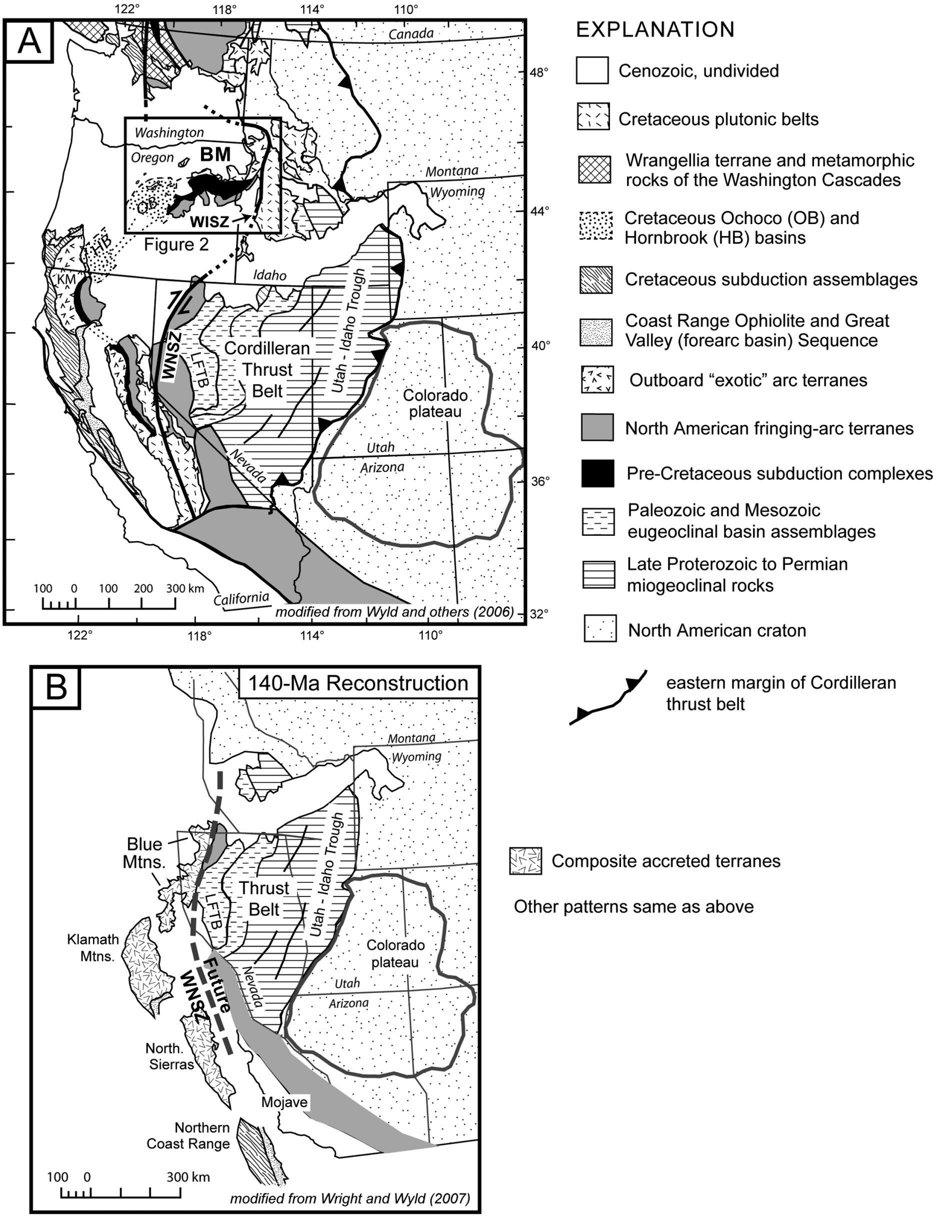


Fig. 1. (A) Simplified pre-Tertiary geology of the western United States, modified from Wyld and others (2006). BM, Blue Mountains province; LFTB, Luning Fencemaker thrust belt; WISZ, western Idaho shear zone; WNSZ, western Nevada shear zone. (B) Pre-Cretaceous reconstruction for accreted terranes in the western U.S., modified from Wright and Wyld (2007).

REGIONAL GEOLOGY AND TECTONICS

Terranes of the Blue Mountains Province

Mesozoic and Paleozoic rocks of the Blue Mountains province (BMP) are divided into four terranes – Wallowa, Baker, Izee and Olds Ferry terranes – that trend east and

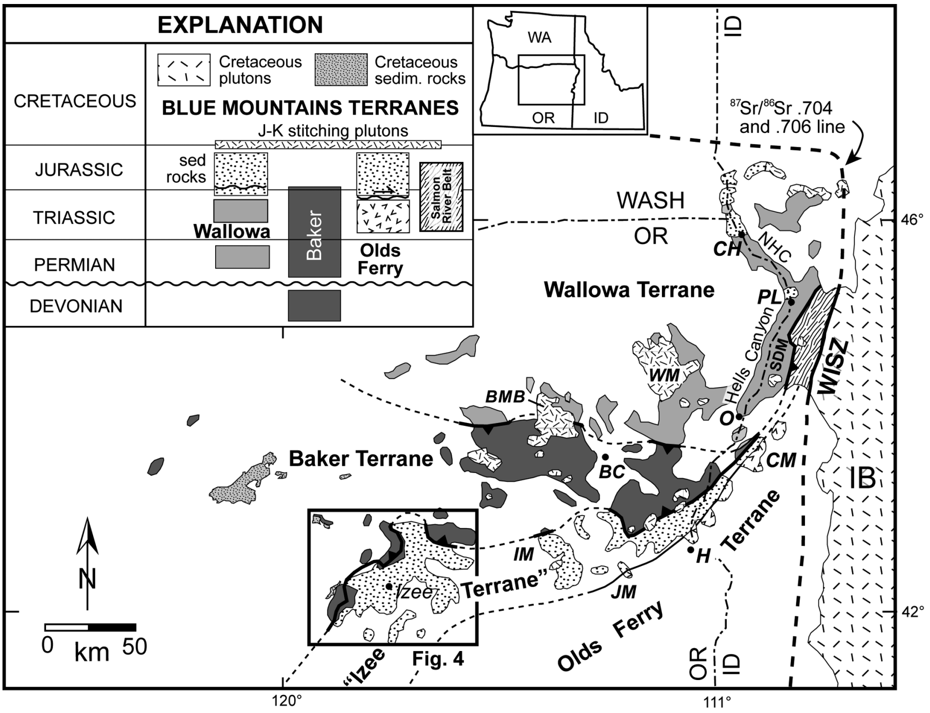


Fig. 2. Generalized terrane map of the Blue Mountains Province (BMP), modified from Dickinson (1979), Mann (1989), Follo (1992), Vallier (1995), and Gray and Oldow (2005). BC, Baker City; BMB, Bald Mountain batholith; H, Huntington; IB, Idaho Batholith; IM, Ironside Mountain; JM, Juniper Mountain; O, Oxbow; PL, Pittsburg Landing; CM, Cuddy Mountains; CH, Coon Hollow; NHC, northern Hells Canyon; SDM, Seven Devils Mountains; WM, Wallowa Mountains and Wallowa batholith; WISZ, Western Idaho Shear Zone.

northeast across NE Oregon (fig. 2; Vallier and others, 1977; Dickinson and Thayer, 1978; Brooks and Vallier, 1978; Dickinson, 1979; Silberling and others, 1984). The Wallowa and Olds Ferry terranes contain Permian to Triassic plutonic, volcanic and volcaniclastic rocks that formed in subduction-related magmatic arcs and sedimentary basins (Vallier, 1977, 1995; Brooks and Vallier, 1978; Dickinson, 1979, 2004; Mortimer, 1986; Kays and others, 2006). The Wallowa terrane occupies the most outboard position in the BMP, and has been correlated to either the Wrangellia terrane (Wernicke and Klepacki, 1988; Dickinson, 2004) or the Stikine terrane in British Columbia (Mortimer, 1986; Oldow and others, 1989; Yancey and Stanley, 1999). The Middle to Late Triassic Olds Ferry arc is commonly correlated to the Quesnel terrane in British Columbia (Oldow and others, 1989; Saleeby and Busby-Spera, 1992) and the Cordilleran fringing arc system in western Nevada and eastern California (Oldow and others, 1989; Wyld and Wright, 2001; Gray and Oldow, 2005).

The Baker terrane is a wide belt of sheared Permian to Jurassic argillite and chert, olistostromal blocks of Devonian to Triassic limestone, serpentinized forearc and oceanic crustal fragments, mafic to ultramafic igneous rocks, and locally developed blueschist facies that were deformed in a long-lived subduction zone accretionary complex (Hotz and others, 1977; Morris and Wardlaw, 1986; Carpenter and Walker, 1992; Bishop, 1995a, 1995b; Ferns and Brooks, 1995; Vallier, 1995). The Baker terrane is bounded on both margins by large thrust faults that dip north on the south side and south on the north side (fig. 2), defining a doubly vergent thrust belt that experienced multiple episodes of shortening from Triassic to Jurassic time (Ferns and Brooks, 1995). The Baker terrane has been correlated to similar subduction complexes in the Cache Creek terrane of British Columbia and the Stuart Fork and central metamorphic terranes in the Klamath Mountains (Saleeby, 1983; Oldow and others, 1989; Hacker and Goodge, 1990; Burchfiel and others, 1992). When corrected for post-Jurassic clockwise rotation, all belts in the BMP restore to an approximately N-S orientation, consistent with the overall trend of the Mesozoic Cordilleran margin (Wilson and Cox, 1980; Hillhouse and others, 1982; Oldow and others, 1984, 1989; Housen, 2007).

The term "Izee terrane" refers to a thick succession of Triassic and Jurassic sedimentary rocks that occupy a belt extending from Izee eastward to Huntington and into western Idaho (fig. 2; Dickinson, 1979; Silberling and others, 1984; Vallier, 1995). The ages and stratigraphy of these deposits are well known from pioneering studies in the Izee and Huntington areas (Dickinson and Vigrass, 1964, 1965; Brown and Thayer, 1977; Dickinson and Thayer, 1978; Brooks and Vallier, 1978; Dickinson, 1979; Brooks, 1979; Imlay, 1986). While use of terrane terminology for these rocks was appropriate in earlier work, more recent studies have shown that Jurassic deposits in the Izee area correlate to similar Jurassic marine strata around the BMP that overlie older rocks of the other terranes along a time-transgressive angular unconformity (fig. 3; White and others, 1992; White and Vallier, 1994; White, 1994; Goldstrand, 1994; Vallier, 1995, 1998). Thus all Jurassic deposits above this unconformity belong to a regional overlap assemblage, recognition of which is essential for interpreting the tectonic evolution of the BMP. We suggest that the term "Izee terrane" be abandoned because the Jurassic part of this thick succession depositionally overlaps and links the other terranes of the BMP.

Mesozoic Magmatism

A major phase of magmatic activity is recorded in Triassic plutonic and volcanic rocks of the Wallowa and Olds Ferry terranes, where ages range from ~249 to 215 Ma. Crystallization ages for plutons are known from U-Pb dating of zircon (Walker, ms 1986, 1995; Vallier, 1995) and ^{40}Ar-^{39}Ar ages on hornblende and biotite (Avé Lallemant and others, 1980; Snee and others, 1995). Only a small number of U-Pb ages have been published for the region, and ^{40}Ar-^{39}Ar ages record cooling which can significantly postdate emplacement. Ages of volcanic rocks are based primarily on fossil ages obtained from interbedded sedimentary units (for example, Vallier, 1977, 1995; Brooks, 1979), which are subject to uncertainties in correlating biozones to the global time scale (Gradstein and others, 2004), especially for the Late Triassic. Despite these limitations, there is strong evidence for widespread emplacement of mafic to intermediate plutons and volcanic rocks during Middle to Late Triassic (mainly ~237 – 215 Ma) magmatism in both the Wallowa and Olds Ferry terranes. The Middle to Late Triassic was also a time of regional metamorphism (Coward, ms, 1983; Ashley, 1995; Avé Lallemant, 1995; Evans, 1995; Ferns and Brooks, 1995), sinistral mylonitic deformation in shear zones exposed along the Snake River (Avé Lallemant and others, 1985; Avé Lallemant, 1995; Vallier, 1995), cooling of white micas in blueschist of the Baker terrane west of John Day (Hotz and others, 1977), and widespread thrusting and folding (Dickinson and Thayer, 1978; Avé Lallemant and others, 1980).

Latest Jurassic to Early Cretaceous (~150 – 135 Ma) granodiorite and tonalite plutons form numerous intrusions, including the Wallowa and Bald Mountain batholiths, which cross-cut Late Jurassic regional thrust faults and deformation fabrics throughout the BMP and western Idaho (fig. 2; Armstrong and others, 1977; Brooks and Vallier, 1978; Walker, ms, 1986; Vallier, 1995; Gray and Oldow, 2005). These intrusions may be related to initial subduction of an oceanic plate shortly after accretion of terranes in the BMP to western North America (Manduca and others,

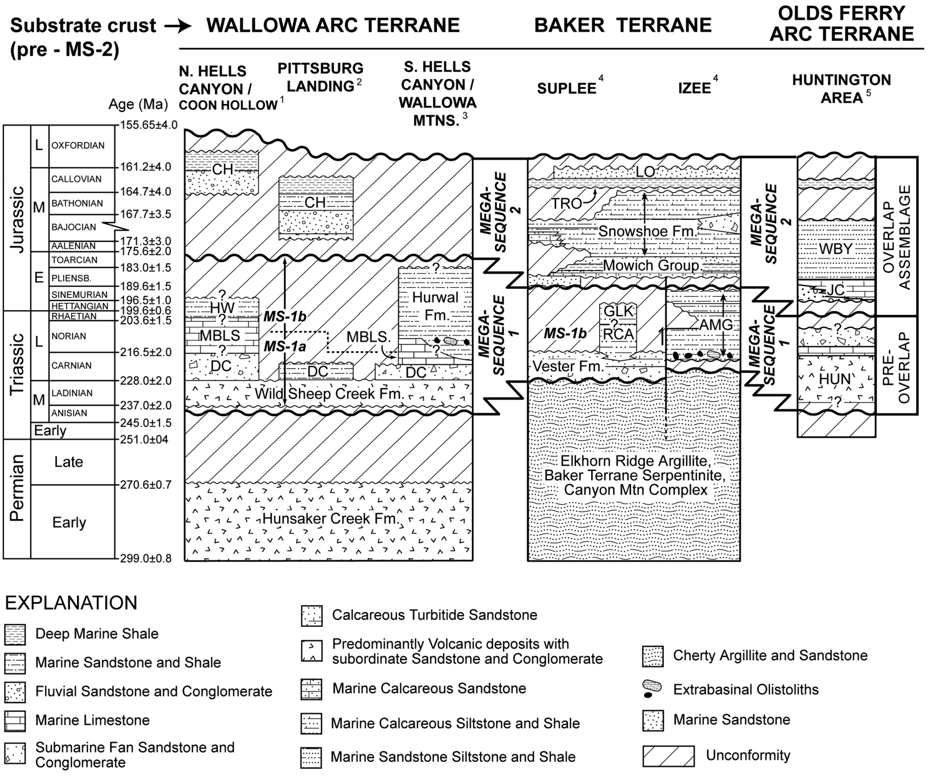


Fig. 3. Chronostratigraphic correlation chart for sedimentary and volcanic rocks in the Blue Mountains. Data are from (see headers): **(1)** Goldstrand (1994), Morrison (ms, 1963), Nützel and Erwin (2004), and Vallier, (1974, 1977); **(2)** Vallier (1974, 1977), White (1994), White and others (1992), and White and Vallier (1994); **(3)** Follo, (1992, 1994), Newton (1986), Nolf (1966), Stanley (1986), Vallier (1974, 1977), Whalen (1988), and Zhang and others (2000); **(4)** Blome and others (1986), Brown and Thayer (1977), Dickinson and Vigrass (1965), Dickinson and Thayer (1978), Dickinson (1979), Imlay (1986), Smith (1980), Taylor (1982), Taylor and Guex (2002), and Pessagno and Blome (1986); **(5)** Brooks (1979), Brooks and others (1976), Imlay (1986), Collins and others (2000a, 2000b), Lund (2004) and Mann (1989). Abbreviations: CH, Coon Hollow Formation; HW, Hurwal Fm.; DC, Doyle Creek Formation; MBLS, Martin Bridge Limestone; LO, Lonesome Formation; TRO, Trowbridge Formation; AMG, Aldrich Mountains Group; GLK, Graylock Formation; RCA, Rail Cabin Argillite; WBY, Weatherby Formation; JC, Jet Creek Member of Weatherby Formation; HUN, Huntington Formation. Ages of stage boundaries from Gradstein and others (2004).

1992, 1993), and they place an important age constraint on Late Jurassic deformation. A few intermediate ages have been obtained from plutons at Cuddy Mountain (220 – 190 Ma; Hendricksen and others, 1972), the Oxbow complex (227 – 197 Ma; Avé Lallemant and others, 1980, 1985; Balcer, ms, 1980), and elsewhere in the region (160 – 115 Ma; Armstrong and others, 1977), leading some workers to infer that the Olds Ferry magmatic arc was active during Early and Middle Jurassic time (Brooks and Vallier, 1978; Dickinson and Thayer, 1978; Dickinson, 1979; Pessagno and Blome, 1986; Blome and others, 1986). However, ages in this group are suspect because they were obtained with K-Ar or ^{40}Ar-^{39}Ar methods and likely reflect partial resetting of older ages due to argon loss during Late Jurassic metamorphism (Vallier, 1995).

Adjacent and Related Regions

To the northeast, the BMP merges with metamorphic rocks of the Salmon River belt (fig. 2) that represent the metamorphosed equivalents of rocks of the BMP, though protolith ages and terrane affinities remain incompletely understood (Lund and Snee, 1988; Selverstone and others, 1992; Lund, 2004; Gray and Oldow, 2005). Rocks in the Salmon River belt underwent Late Jurassic, west-vergent contractile deformation and greenschist to amphibolite grade metamorphism that also affected the Mesozoic fringing-arc complex in western Nevada and elsewhere along the North American Cordillera (Snee and others, 1995; Lund, 2004; Gray and Oldow, 2005). Penetratively deformed rocks in the western Salmon River belt are intruded by undeformed tonalite dated at 145 ± 1.5 Ma (^{40}Ar/^{39}Ar cooling age on hornblende; Snee and others, 1995). The Salmon River Belt is bounded on the east by the western Idaho shear zone, a profound tectonic boundary along which rocks of oceanic affinity and isotopic composition are juxtaposed directly against the truncated western margin of cratonal North America (Armstrong and others, 1977; Fleck and Criss, 1985; Lund and Snee, 1988; Manduca and others, 1992; Selverstone and others, 1992). Dextral transpressive shear along this boundary accommodated mid to Late Cretaceous northward translation of crust west of the fault zone (McClelland and others, 2000; Tikoff and others, 2001; Wyld and Wright, 2001; Giorgis and others, 2005).

Wyld and Wright (2001) proposed a reconstruction that restores the BMP to the latitude of northwestern Nevada during Triassic and Jurassic time (fig. 1B). This model is based on comparison of geologic and structural histories in different areas, reconciliation of compositional trends in magmatic belts, and correlation of major strike-slip faults in the western U.S. They concluded that a regionally integrated strike-slip fault system, including the western Idaho shear zone and western Nevada shear zone, accommodated ~400 km of dextral offset during Early Cretaceous time and translated rocks of the BMP north into their present position (Wyld and Wright, 2001). New detrital zircon ages and analysis of structural trends in California suggest that the Cordilleran arc-trench system included one or more large strike-slip faults that contributed to dextral translation in the western U.S. during Cretaceous time (Wright and Wyld, 2007). Based on growing support for these ideas, we use the reconstruction in figure 1B (from Wright and Wyld, 2007) as the basis for a tectonic model developed later in this paper. While it is important to continue testing and refining this reconstruction, we believe it provides a reasonable paleogeography that is better than keeping the BMP in its present position relative to cratonal North America prior to Cretaceous time. Jurassic crustal shortening produced a large orogenic mountain range (Cordilleran thrust belt, includes the Luning-Fencemaker thrust belt) that occupied much of present-day Nevada and drove eastward migration of the Utah-Idaho Trough foreland basin (fig. 1; Oldow, 1984; Jordan, 1985; Bjerrum and Dorsey, 1995; Wyld and others, 1996, 2003; Allen and others, 2000; Wyld, 2002).

STRATIGRAPHY OF THE BLUE MOUNTAINS PROVINCE

Overview

In this section we synthesize information about the distribution, ages, and lithologies of volcanic and sedimentary rocks in the BMP, providing the basis for later interpretations. Figure 3 is a time-stratigraphic diagram in which data from many previous studies are compiled in a standard format that facilitates correlation and comparison of deposits across the region. Volcanic and sedimentary rocks in the BMP can be divided into two regionally correlative, unconformity-bounded units that resemble stratigraphic sequences documented in other tectonically active settings (for example, Martin-Chilvelet, 1995; Roca and Nadon, 2007). Based on their thick composite nature, we recognize these units as megasequences (MS-1 and MS-2) (fig. 3). Megasequences are large-scale (100's to 1000's of m thick; 10's of m.y.) stratal units that accumulate during a distinct phase of basin evolution, and are bounded by unconformities that mark a change in basin-controlling processes (Phinney and others, 1999; Burton-Ferguson and others, 2005; Krézsek and Bally, 2006). They often coincide with second-order cycles in traditional sequence stratigraphy (Vail and others, 1977), and typically are formed by changes in tectonic boundary conditions that control basin development. As with traditional applications of sequence stratigraphy, megasequence subdivisions provide a useful tool for visualizing and interpreting genetically related stratal packages and their bounding unconformities.

Megasequence 1 consists of Late Triassic to Early Jurassic deposits (ca. 220 – 195 Ma) that include (1a) arc-related volcanic and volcaniclastic rocks of the Wallowa and Olds Ferry terranes, and (1b) marine turbidites, shale, and argillite with locally abundant chert-clast conglomerate and olistostromes derived from the Baker terrane (fig. 3). While most workers agree that Triassic to Early Jurassic rocks in the Wallowa and Olds Ferry terranes formed on different plates separated by two or more intervening subduction zones, we use the term "megasequence 1" for rocks of this age in both terranes because of their broadly similar ages and lithologies (with notable differences described below). Megasequence 2 is a regional overlap assemblage of Early to early-Late Jurassic marine deposits that rest on older rocks along a time-transgressive angular unconformity. Basal deposits of MS-2 young from ~196 to 190 Ma in the Huntington area (where they rest on Olds Ferry terrane substrate), to ~190 to 180 Ma in the Izee area (Baker terrane substrate), to ~167 to 164 Ma at Pittsburgh Landing and Coon Hollow (Wallowa terrane substrate) (fig. 3). Based on regional correlation of MS-2 strata over a large region, it is well established that most of the BMP was covered by a single large marine basin by Middle Jurassic time (Brooks and Vallier, 1978; Follo, ms 1986, 1992, 1994; White and others, 1992; Goldstrand, 1994).

Izee Area

Triassic and Jurassic strata in the Izee area make up a very thick succession (~12 – 15 km) that nonconformably overlies older rocks of the Baker terrane (figs. 3 and 4; Dickinson and Thayer, 1978; Dickinson, 1979). The Baker terrane in this area consists of two main lithologic associations that are tectonically intercalated at map scale: Permian mafic to ultramafic intrusive rocks and sheared serpentinite (Walker, 1995; Bishop, 1995b); and sheared Paleozoic and Mesozoic chert, argillite and metavolcanic rocks (Brown and Thayer, 1966; Thayer and Brown, 1966). Megasequence 1 includes the Late Triassic Vester and Fields Creek formations, which contain marine argillite, turbidites, chert-clast sandstone and conglomerate, and large chaotic slide breccias and olistostromes derived from nearby Baker terrane sources. These deposits record mass-flow deposition and slope instability in thrust-fault-bounded marine basins that were progressively deformed during thrusting, uplift and erosion in the emergent Baker terrane (Dickinson and Thayer, 1978; Dickinson, 1979). Because marine deposits of megasequence 1 correlate to volcanic and volcaniclastic rocks in the Huntington area (figs. 2 and 3), and rocks in both areas lie southeast of the Baker terrane, megasequence 1 in the Izee area is inferred to have accumulated in the forearc region of the Olds Ferry arc (Dickinson, 1979).

Jurassic strata of Megasequence 2 overlie MS-1 along an angular unconformity (figs. 3 and 4). The basal Mowich Group (Pliensbachian) fines up from fossiliferous shallow marine sandstone and calcarenite to offshore volcaniclastic turbidites and shale (Dickinson and Vigrass, 1965; Dickinson and Thayer, 1978). The Mowich Group is overlain by dominantly thin-bedded turbidites of the Snowshoe Formation and shale of the Trowbridge Formation, which in turn coarsens up into sandy turbidites of the Lonesome Formation (Dickinson and Thayer, 1978) (fig. 4). Sandstone compositions in the Izee area show an up-section change from chert-rich in the Carnian Vester Formation (MS-1), to volcanic-rich in the Pliensbachian to Bathonian Mowich Group

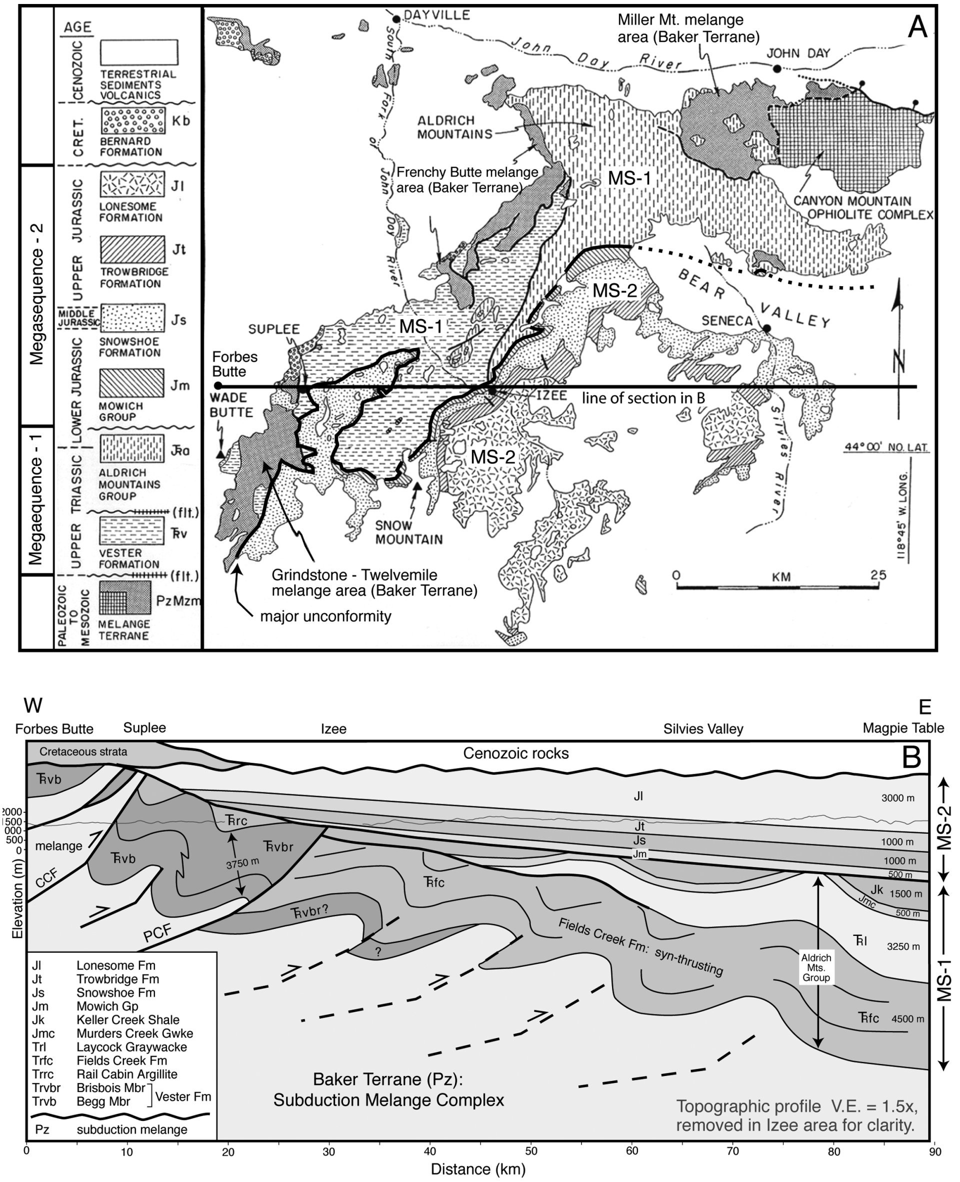


Fig. 4. (A) Geologic map of the Izee area, modified from Dickinson and Thayer (1978). Location of map is shown in figure 1. (B) Stratigraphic reconstruction of Izee area, projected into E-W line of section (in A) using maps and data from Dickinson and Thayer (1978), Dickinson and Vigrass (1965), and Brown and Thayer (1966). Total structural relief of east- to SE-vergent thrust belt is ~10 to 15 km based on thickness of Triassic-Jurassic syn- to post-thrusting stratigraphic section. CCF, Camp Creek fault; PCF, Poison Creek fault.

and Snowshoe Formation (lower MS-2), to meta-sedimentary and meta-volcanic lithic arenites of the Callovian Lonesome Formation (upper MS-2) (Dickinson and others, 1979). Paleocurrent indicators record a change from overall SE-directed in megasequence 1 to NW-directed in megasequence 2 (present-day coordinates; Dickinson and Thayer, 1978).

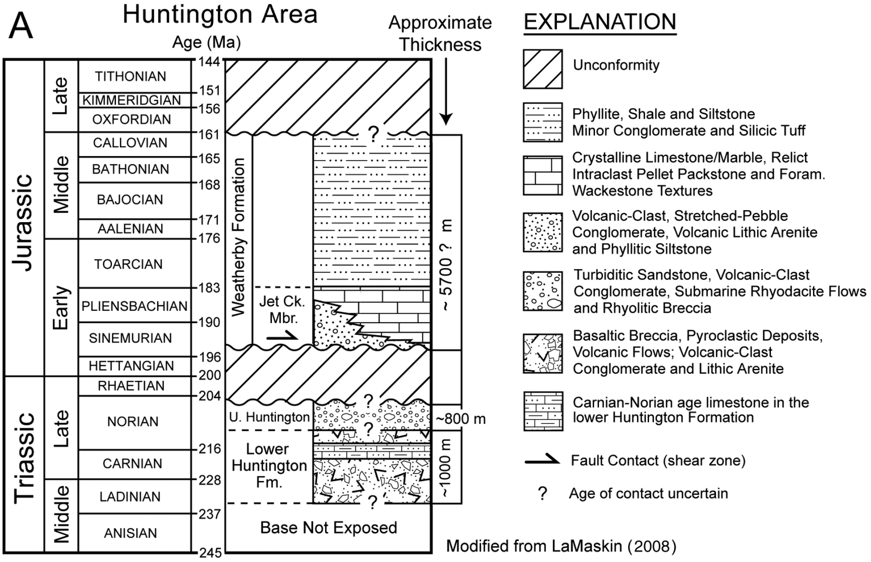
Huntington Area

Rocks in the Huntington area provide the best exposures of Olds Ferry terrane in the BMP (figs. 3 and 5A). Megasequence 1 consists of the Middle to Upper Triassic Huntington Formation, which includes a lower member of mafic to intermediate volcanic flows, breccias, shallow intrusions, and volcaniclastic rocks (Wagner and Brooks, 1962; Wagner and others, 1963; Vallier, 1977; Brooks and Vallier, 1978; Brooks, 1979; Vallier, 1995), and an upper member of volcaniclastic sandstone, turbidites, conglomerate, and abundant rhyodacite flows and subaqueous rhyolitic breccias that record a pronounced shift to explosive silicic volcanism in a marine environment (fig. 5A; Collins and others, 2000a, 2000b; San Filippo, ms, 2006). A laterally extensive limestone unit within the lower Huntington Formation records a short-lived hiatus in volcanic activity and contains ammonite and bivalve fossils that indicate a late Carnian to early Norian age (Brooks, 1979; LaMaskin, 2005, 2008). The Brownlee pluton consists of trondjemite that was dated at 234 +/- 1 Ma by Walker (ms, 1986) and has been suggested as possible basement for volcanic rocks of the Huntington Formation (Vallier, 1995). Detailed mapping and observations of contact relations suggest that it intrudes rocks as young as upper Huntington Formation (Juras, ms, 1973; Brooks and others, 1976; San Filippo, ms, 2006), which would make it younger than ~215 Ma. This problem is unresolved and requires additional mapping and dating of the pluton.

Megasequence 2 in the Huntington area consists of the Jurassic Weatherby Formation, which includes a basal member of nonmarine conglomerate and shallow marine limestone, and an overlying thick succession of Lower to Middle Jurassic marine shale and thin-bedded turbidites (Brooks and others, 1976; Brooks, 1979; Avé Lallemant, 1983; Imlay, 1986). The basal contact of the Weatherby Formation was first interpreted as an angular unconformity (Brooks, 1979), but later was recognized as a tectonized NW-dipping fault zone with SE-verging (thrust-sense) shear indicators inferred to offset an original depositional contact (Avé Lallemant, 1983; Payne and Northrup, 2003; Wright, ms, 2005). The thickness of the Weatherby Formation was estimated at ~7,000 m by Brooks (1979); map and structural data of Avé Lallemant (1983) suggest a possible total thickness of ~5,700 m. These rocks were metamorphosed to lower greenschist facies slate and phyllite by Late Jurassic regional metamorphism. The Weatherby Formation is truncated on the northwest by the Connor Creek fault, a large reverse fault that marks a major post-basinal tectonic boundary between the Baker terrane and Middle Jurassic sedimentary rocks (Brooks and others, 1976; Avé Lallemant, 1983).

Wallowa Mountains - Hells Canyon

In the Wallowa Mountains and Hells Canyon (fig. 2), megasequence 1 unconformably overlies Permian volcanic rocks and includes the Wild Sheep Creek, Doyle Creek, Martin Bridge and Hurwal formations (figs. 3 and 5B; Vallier, 1977, 1995). The Ladinian to Carnian Wild Sheep Creek Formation is over 2,000 m thick and contains basaltic to andesitic flow rocks, breccias, welded tuffs and volcanic-clast conglomerate (Vallier, 1977; White and Vallier, 1994). It interfingers with and is overlain by the Carnian Doyle Creek Formation (~750 m thick), a dominantly sedimentary succession of volcaniclastic turbiditic sandstone, conglomerate and minor tuffs and flow rocks that accumulated in a forearc or intra-arc basin during active or waning magmatism in the Wallowa arc (Vallier, 1977, 1995; Brooks and Vallier, 1978; Follo, ms 1986, 1992, 1994). The transition to the Martin Bridge Limestone (Carnian-Norian) is gradational in most places. It is a lithologically diverse, regionally extensive Late Triassic unit that includes fossiliferous shallow-marine platform carbonates and deeper marine graded grainstone and carbonate-clast conglomerate that accumulated on a platform-flanking



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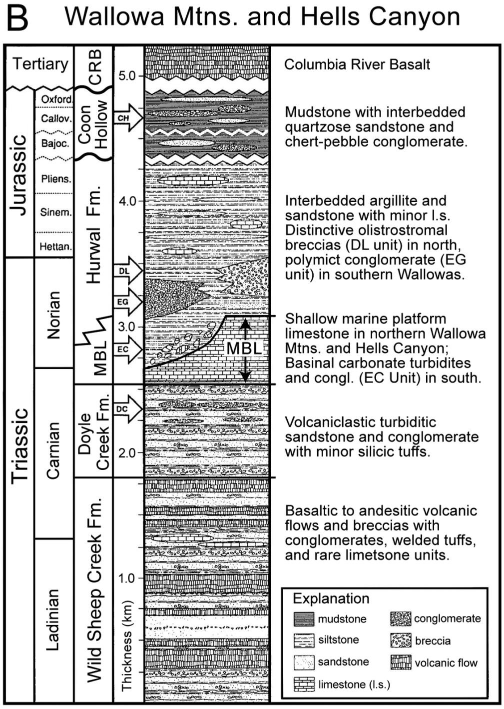

Modified from Follo (1992)

Fig. 5. (A) Stratigraphy of the Huntington area, modified from LaMaskin (2008). (B) Stratigraphy of the Wallowa Mountains and Hells Canyon area, modified from Follo (1992). Arrows indicate conglomerate intervals: CH, conglomerates in Coon Hollow Formation; DC, conglomerates in Doyle Creek Formation; DL, Deadman Lake unit; EC, Eagle Creek conglomerates; EG, Excelsior Gulch unit. Other abbreviations: CRB, Columbia River Basalt; MBL, Martin Bridge Limestone.

slope (Nolf, 1966; Follo, ms 1986, 1992, 1994; Newton, 1986; Stanley, 1986; Whalen, 1988; McRoberts, 1993). The Martin Bridge Limestone youngs from south to north in present-day coordinates (Nolf, 1966; Newton, 1986; Stanley, 1986; Whalen, 1988; McRoberts, 1993; Nutzel and Erwin, 2004), a trend that we interpret to reflect migrating tectonic elements (see below). The Martin Bridge Limestone is overlain along a regionally diachronous marine flooding surface by the Late Triassic to Early Jurassic Hurwal Formation (~1500 m), which contains siliciclastic marine turbidites and shale with locally abundant carbonate- and chert-clast conglomerate (Excelsior Gulch unit; fig. 5B) and sedimentary breccia (Deadman Lake breccia) (Nolf, 1966; Follo, ms 1986, 1992, 1994). These deposits accumulated in a marine basin and base-of-slope setting that received input of chert, limestone and plutonic clasts from the Baker terrane (Follo, 1992).

Along the Snake River at Pittsburgh Landing and Coon Hollow, sedimentary rocks of the Middle to Late Jurassic Coon Hollow Formation (megasequence 2) overlie the Wild Sheep Creek and Doyle Creek formations along an angular unconformity that cuts out the Hurwal and Martin Bridge formations (figs. 2 and 3; Morrison, ms, 1963; Goldstrand, ms 1987, 1994; White and others, 1992; White and Vallier, 1994; White, 1994). The preserved thickness of the Coon Hollow Formation in the type locality is approximately 600 meters (Goldstrand, 1994). It includes a lower unit of locally derived conglomerate and shallow-marine sandstone, and an upper flysch facies of Oxfordian marine shale and turbidites (White and others, 1992; White and Vallier, 1994; White, 1994; Goldstrand, 1994). In the Coon Hollow area, the upper flysch facies coarsens and thickens up section into channelized sandstone and conglomerate that were deposited by coarse-grained turbidity currents and debris flows on a prograding marine slope (Follo, ms 1986; Goldstrand, ms 1987, 1994). These deposits contain abundant chert and metasedimentary clasts, with paleocurrent indicators that record transport to the northwest and input from an orogenic highland to the southeast (present coordinates) (Goldstrand, 1994).

PREVIOUS TECTONIC MODELS

Previous tectonic models for the BMP fall into two main groups. In the first set of models, the Wallowa and Olds Ferry terranes are inferred to represent a composite, *single island-arc complex* that experienced a change in subduction polarity in Late Triassic time (fig. 6A; Vallier, 1977; Brooks and Vallier, 1978; Pessagno and Blome, 1986; White and others, 1992; Vallier, 1995). According to this model, the Wallowa portion of the arc system – represented by the Wild Sheep Creek and Doyle Creek formations – was active during Middle Triassic time, and the Olds Ferry portion of the arc became active at ~ 225 Ma when the Wallowa portion was abandoned due to a reversal of subduction polarity. This resembles the history of polarity reversal that has been documented for the Solomon Islands in the SW Pacific (Vallier, 1995). Evidence cited to support this idea includes similar composition of the Wallowa and Olds Ferry volcanic rocks, correlation of Middle Jurassic strata that unconformably overlie these two terranes, and northeastward narrowing of the Baker terrane with close spatial association of the Wallowa and Olds Ferry terranes (fig. 2; Brooks and Vallier, 1978). However, this model is inconsistent with available age data, which show that the lower Huntington Formation overlaps in age with the Wild Sheep Creek and Doyle Creek formations (Carnian; Brooks, 1979), indicating that the Wallowa and Olds Ferry arcs were active concurrently during Late Triassic time.

A second group of models postulates that the Wallowa and Olds Ferry terranes originated as *two distinct and separate magmatic arcs* that converged toward each other across a closing ocean basin during Triassic and Jurassic time (Dickinson and Thayer, 1978; Dickinson, 1979; Avé Lallemant and others, 1980, 1985; Mortimer, 1986; Follo, 1992; Avé Lallemant, 1995). According to this hypothesis, Late Triassic through

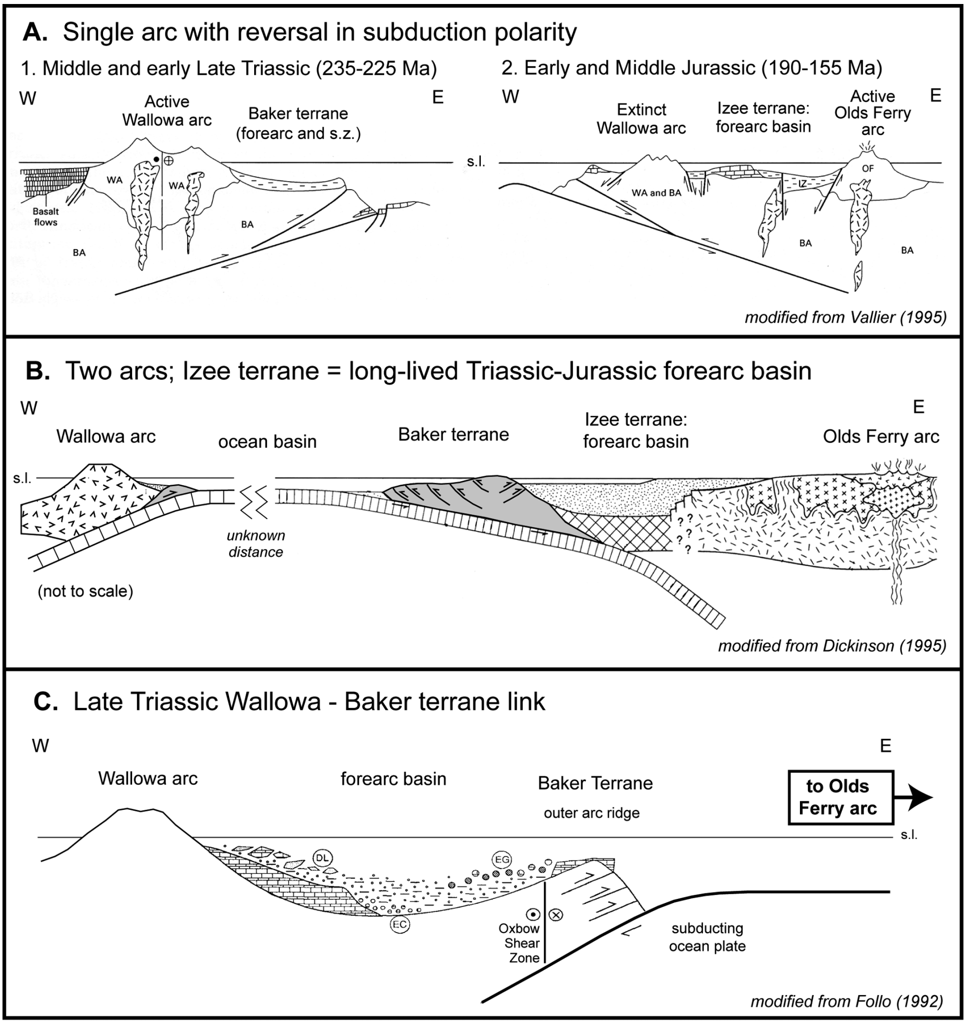

Fig. 6. Previous tectonic models for the Blue Mountains province. (A) Single-arc model, modified from Vallier (1995). s.z. = subduction zone. (B) Two-arc model, with a long-lived, west-facing forearc basin represented by marine deposits in the Izee area, modified from Dickinson (1995). (C) Triassic uplift and erosion of the Baker terrane in response to oblique convergence and strike-slip deformation in the Oxbow complex, modified from Follo (1992). In all diagrams, s.l. = sea level. See text for discussion.

Middle Jurassic marine sedimentary rocks of the Izee terrane (as originally defined) accumulated in a long-lived, west-facing forearc basin between the Olds Ferry volcanic arc to the east and an east-dipping subduction zone (Baker terrane) to the west (fig. 6B). Late Triassic east-vergent thrusts and marine olistostromes in the Izee area are inferred to reflect back-thrusting on the inboard flank of the accretionary wedge, and later stratigraphic onlap and submergence of the Baker terrane records expansion of the same west-facing forearc basin (Dickinson, 1979). Sinistral shear zones in the Wallowa and Baker terranes record strike-slip faulting in the arc root and accretionary wedge, and are attributed to left-oblique plate convergence during Late Triassic and Jurassic time (Oldow and others, 1984; Avé Lallemant and others, 1985; Avé Lallemant, 1995). According to this group of models, collision of the two arcs did not occur until

Late Jurassic strong regional shortening, penetrative deformation, and regional metamorphism (for example, Dickinson, 1979; Avé Lallemant, 1995).

Follo (1992, 1994) recognized the significance of Baker terrane-derived chert- and limestone-clast conglomerates in the Hurwal Formation, and proposed that Late Triassic uplift and erosion in the Baker terrane was related to oblique convergence and strike-slip shearing in the Oxbow complex, dated at ~ 228 to 219 Ma (Avé Lallemant and others, 1985; Avé Lallemant and Oldow, 1988), similar to deformation seen in outer-arc ridges of modern obliquely convergent arc-trench systems (fig. 6C). He suggested that west-dipping subduction beneath the Wallowa arc led to closure of a marginal basin and initial interaction with the Olds Ferry terrane by Middle Jurassic time, to explain input of chert-clast conglomerate in the Coon Hollow Formation (Follo, 1992, 1994). However, Follo did not elaborate on the correlation of Late Triassic Baker-terrane-derived conglomerates to similar deposits in the Izee area, or the significance of that correlation for regional tectonic reconstructions.

In all of the above models, plate convergence and subduction played a major role in Triassic volcanism in the Wallowa and Olds Ferry terranes, the Baker terrane is correctly identified as a long-lived subduction complex, and volcaniclastic sandstones in Middle Jurassic strata of the Izee area are recognized as recording input from a volcanic arc source. However, most existing models fail to explain Late Triassic demise of the Wallowa arc. Jurassic subsidence is often attributed to expansion of the Olds Ferry forearc basin, but lack of well dated Jurassic volcanic or plutonic rocks in the BMP suggests a need to consider other tectonic processes. We believe that any successful tectonic model for the Blue Mountains has to explain: (1) simultaneous deposition of Late Triassic submarine conglomerates and olistostromes in syntectonic basins that formed on opposite margins of an emergent Baker terrane thrust belt; (2) a major angular unconformity along which regionally correlable Jurassic strata of megasequence 2 overlap all older rocks; and (3) subsequent Jurassic subsidence of the Baker, Wallowa and Olds Ferry terranes to depths of up to ~10 km below sea level.

NEW MODEL: COLLISIONAL TECTONICS AND SEDIMENTATION

Overview

Below we outline a new hypothesis for Triassic-Jurassic tectonic evolution of the BMP that is based on the preceding synthesis of previous studies, and includes a history of: (1) Middle Triassic magmatism in the Wallowa and Olds Ferry arcs during subduction and progressive closure of a former ocean basin (fig. 7A); (2) Late Triassic collision between accretionary wedges of the converging arcs, growth of an emergent thrust belt in the Baker terrane, and related growth of marine foredeep basins on both sides of the thrust belt (fig. 7B); (3) Jurassic collision of the previously amalgamated terranes with the North American margin and resultant growth of a large marine collisional basin in the BMP (fig. 7C); and (4) thrusting and accretion of the basin and underlying terranes to the western margin of North America at the end of the Jurassic (fig. 7D). We propose that two major phases of synorogenic mountain building and subsidence in flanking sedimentary basins (stages 2 and 3, above) resulted in deposition of megasequences 1 and 2, and that deformation related to the first of these episodes produced the intervening angular unconformity. Some details of this working hypothesis are presented below.

Our hypothesis includes tectonic closure of a backarc basin between the Cordilleran fringing arc and the North American craton during Jurassic time, with concomitant growth of a large orogenic mountain belt in the former backarc basin, consistent with restoration of NE Oregon to the latitude of NW Nevada (fig. 1B; Wyld and Wright, 2001) and prior studies in Nevada (Oldow, 1984; Smith and others, 1993; Wyld, 2000, 2002; Wyld and others, 2003). A backarc basin may also have existed at the present

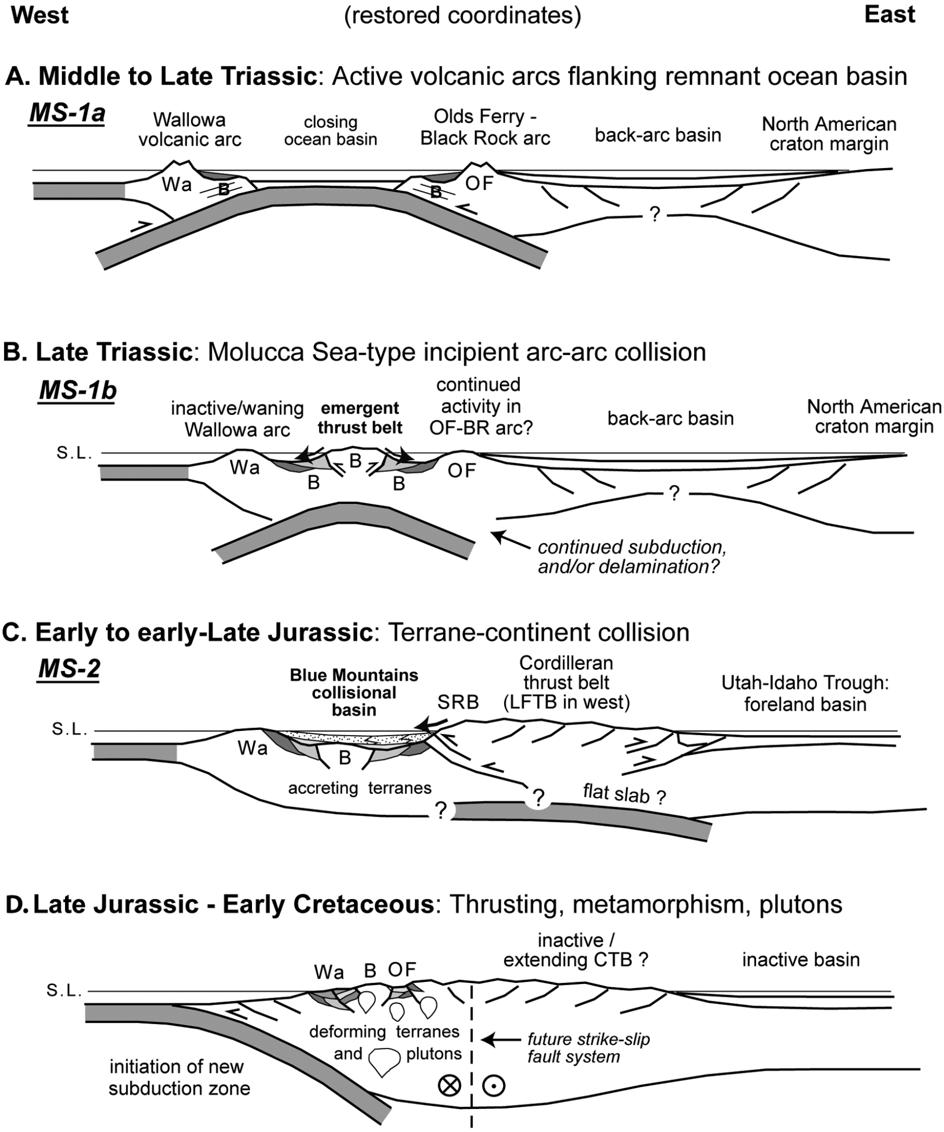

Fig. 7. Schematic diagrams of working hypothesis for Late Triassic to Late Jurassic arc-arc and arc-continent collision in the Blue Mountains Province (BMP) and related collisional basin evolution. Restoration of ~400 km of post-Jurassic dextral translation places the BMP outboard of the Black Rock arc and Cordilleran thrust belt in NW Nevada (fig. 1B; Wyld and Wright, 2001). (A) Pre-collisional Wallowa and Olds Ferry arcs; (B) Doubly-vergent Molucca Sea-type arc-arc collisional complex with coarse olistostromes and gravel shed into flanking marine basins (arrows). C) Early to Late Jurassic terrane-continent collision and growth of Blue Mountains collisional basin. Deep basin subsidence and onlap of sediments onto older rocks and structures may record a flexural response to thrust loading in the Codilleran thrust belt to the east. Flat-slab subduction is speculative and based on comparison to modern collisional orogens in Papua New Guinea and SE Alaska. (D) Thrusting, uplift, and post-kinematic pluton emplacement inferred to be related to initiation of new subduction zone to the west. MS-1a, 1b, 2 indicate megasequences. See text for discussion. Abbreviations: B, Baker terrane; BR, Black Rock terrane (NW Nevada); CTB, Cordilleran thrust belt; OF, Olds Ferry terrane; LFTB, Luning-Fencemaker thrust belt; Wa, Wallowa terrane.

latitude of Oregon, or farther south, and/or it may have been incorporated into the North American margin and subsequently truncated along the western Idaho shear zone (McClelland and others, 2000; Tikoff and others, 2001; Giorgis and others, 2005; Gray and Oldow, 2005). Our model is therefore consistent with a wide range of possible post-Jurassic translation scenarios and does not depend on any particular reconstruction.

Middle Triassic: Subduction and Arc Magmatism

Middle Triassic plutonic and volcanic rocks in the Wallowa and Olds Ferry terranes (megasequence 1a) record voluminous magmatism related to plate convergence and subduction of oceanic crust in the BMP. One set of models, above, assigns these rocks to different stages of a single-arc system, but this seems unlikely based on overlapping ages of volcanism and the wide area occupied by an intervening subduction complex (Baker terrane) (fig. 2). We therefore concur with other models, summarized above, that assign the Wallowa and Olds Ferry terranes to two distinct and separate magmatic arcs that formed above oppositely-dipping subduction zones and approached each other during Triassic consumption of the intervening oceanic plate (fig. 7A). Our model assumes that megasequence 1 in the Izee area is a lateral equivalent of arc-proximal volcanic and volcaniclastic rocks exposed in the Huntington area, and that strata in the Izee area formed in the tectonically disrupted distal forearc of the Olds Ferry terrane. The fate of the facing arcs and accretionary prisms as they approached each other is discussed below.

Late Triassic – Early Jurassic: Initial Arc-Arc Collision

Most previous models for the BMP infer that collision of the Wallowa and Olds Ferry arcs did not occur until the end of Jurassic time, during a period of strong crustal shortening and regional metamorphism. No prior studies that we're aware of have attempted to explain simultaneous deposition of submarine conglomerates and olistostromes in syntectonic basins on opposite sides of the Baker terrane – Izee area on the east, southern Wallowa Mountains on the west – during Late Triassic time. We believe this correlation provides a critical, previously overlooked provenance link that records tectonic interactions between the Wallowa, Baker, and Olds Ferry terranes by late Carnian time (~216 Ma; fig. 3). We suggest that Late Triassic structural interaction and deformation of the facing accretionary wedges of the Wallowa and Olds Ferry arcs resulted in crustal thickening, uplift, and growth of a doubly-vergent thrust belt in the Baker terrane subduction complex that propagated into and disrupted the flanking forearc basins (fig. 7B). Tectonically controlled uplift on both margins of the thrust belt created steep marine slopes that were affected by mass wasting and deposition of olistostromes and coarse debris flows derived from eroding highlands in the Baker terrane thrust belt. The inferred reversal of thrust vergence and advance of a growing accretionary wedge into adjacent forearc basins is similar to structural patterns observed for early stages of arc-arc collision documented in the modern Molucca Sea region (Silver and Smith, 1983; Hamilton, 1988; Bader and others, 1999; Pubellier and others, 1999; Hall, 2000; Lallemand and others, 2001).

We further propose that the change from volcaniclastic arc-related sedimentation (MS-1a, Doyle Creek Formation) to carbonate platform deposition (Martin Bridge Limestone) and subsequent shift to deeper marine deposition of Hurwal Formation flysch with direct input from the Baker terrane (MS-1b) (figs. 3 and 7) records migration of a flexural foredeep basin. According to this hypothesis, carbonate deposition of the Martin Bridge Limestone resulted from development and migration of an outer flexural bulge through the Wallowa terrane, and subsequent deepening into the Hurwal basin records accelerated subsidence in the migrating foredeep depozone (for example, DeCelles and Giles, 1996; Giles, 1996). We consider the Late

Triassic decline of arc-related magmatic output from the Wallowa arc to be a consequence of the onset of arc-arc collision and cessation of normal subduction, a genetic relationship that is often observed in modern zones of arc-arc and arc-continent collision (Suppe, 1984, 1987; Audley-Charles and Harris, 1990; Huang and others, 2000; Sajona and others, 2000). The angular unconformity between Middle Triassic volcanic rocks and overlying Middle Jurassic sedimentary rocks exposed along the Snake River in NE Oregon (White and Vallier, 1994; White, 1994; Goldstrand, 1994) records tilting and erosion in the Wallowa terrane that we infer resulted from Late Triassic to Early Jurassic collision of the facing accretionary wedges (now preserved in the Baker terrane) of the Wallowa and Olds Ferry arcs (fig. 7B).

Middle to Late Jurassic: Terrane-Continent Collision

Middle to Late Jurassic deep subsidence of previously amalgamated terranes in the BMP requires a regional-scale mechanism to drive the vertical crustal motion. Based on the above synthesis, we propose that Jurassic subsidence resulted from westward migration of a flexural foredeep basin in response to crustal loading and advance of the Salmon River belt in western Idaho and Luning-Fencemaker thrust belt in Nevada (fig. 7C). According to this hypothesis, protracted oblique collision of the previously amalgamated Wallowa-Baker-Olds Ferry terranes with the North American margin resulted in Jurassic crustal shortening, closing of the former backarc basin, mountain building, lithospheric loading, and growth of syntectonic basins in the NW U.S. Cordillera. The Jurassic marine basin in the BMP was similar in many respects to other large marine basins known as "successor" or "collisional" basins, which form on the outboard margins of large thrust belts produced by collisional orogenesis (Kleinspehn, 1985; Lundberg and Dorsey, 1988; Garver and others, 1990; Dorsey, 1992; Graham and others, 1993; Galewski and Silver, 1997; Brown and others, 2001; Clift and others, 2003). Flexural subsidence in these basins produces deep accommodation and thick successions of marine turbidites and shale that are later incorporated into accreted terranes. Progradation of easterly-derived sandstone and conglomerate rich in low-grade metavolcanic and metasedimentary lithic fragments is consistent with the predictions of this hypothesis. While existing paleocurrent data do not require long-distance transport along the basin axis, as is seen in many collisional basins, axial sediment dispersal is expected for collisional margins and may be revealed in future work.

Sedimentation and subsidence in the Jurassic collisional basin was coeval with strong west-vergent thrusting and metamorphism to the east in the Salmon River Belt (Gray and Oldow, 2005) and protracted crustal shortening, oblique-sinistral transpression, metamorphism, and mountain building in the Cordilleran thrust belt of Nevada (fig. 7C; Oldow, 1984; Oldow and others, 1984; Smith and others, 1993; Wyld and others, 1996, 2003; Wyld and Wright, 2001; Wyld, 2002). While most of the Cordilleran thrust belt is a wide east-vergent thrust system, it includes a zone of west-vergent deformation in the west that is similar to the west-vergent Salmon River belt (as summarized by Gray and Oldow, 2005). We therefore infer that the Salmon River belt and western Luning-Fencemaker thrust belt represent a relatively narrow, west-vergent "retro-wedge" zone (for example, Willett and others, 1993; Naylor and Sinclair, 2007) that formed in the western part of an asymmetric doubly-vergent orogenic thrust belt. Our reconstruction resembles Late Cenozoic oblique collision of amalgamated oceanic arc terranes with the northern margin of Australia in Papua New Guinea (Cooper and Taylor, 1987; Pigram and Davies, 1987; Pigram and Symonds, 1991; Abbott and others, 1994; Abbott, 1995; Klootwijk and others, 2003a, 2003b; Cloos and others, 2005). The Papuan example is somewhat different because it involves collision of an oceanic terrane complex with a trailing/passive continental margin (northern Australia) rather than a continent-fringing magmatic arc and backarc basin. However, the fundamental driving processes in which previously amalgamated terranes are buttressed against a continental margin, and large flexural foredeep basins form in response to regional-scale mountain building and crustal loading, are the same.

Late Jurassic: Regional Deformation

Rocks of the BMP experienced widespread Late Jurassic, post-basinal contractile deformation and regional metamorphism that was followed by intrusion of Late Jurassic to Early Cretaceous (~145 – 135 Ma) plutons (fig. 7D; Armstrong and others, 1977; Brooks and Vallier, 1978; Walker, ms 1986, 1995; Vallier, 1995; Avé Lallemant, 1995; Gray and Oldow, 2005). This phase of deformation coincided with the Late Jurassic Nevadan orogeny recognized elsewhere in the western U.S. Cordillera (Schweickert and others, 1984; Oldow and others, 1989; Burchfiel and others, 1992; Saleeby and Busby-Spera, 1992), and occurred during final accretion of arc terranes in the BMP to western North America (McClelland and others, 2000; Gray and Oldow, 2005). Intrusion of Late Jurassic to Early Cretaceous plutons may record reorganization of the plate margin and initial subduction of an outboard oceanic plate at the end of the terrane-accretion phase (Manduca and others, 1992, 1993).

In summary, we suggest that east-west convergence between the North America craton and the ocean plate carrying the Wallowa arc was accommodated by different regional-scale processes at different stages during evolution of the BMP: (1) Middle to Late Triassic (~235 –220 Ma) subduction of oceanic crust prior to the onset of arc-arc collision; (2) Late Triassic to Early Jurassic (~220 – 195 Ma) shortening and thrusting within and at the margins of the collisional Baker terrane thrust belt; (3) Early to Late Jurassic (~195 – 155 Ma) shortening and tectonic closure of the backarc basin in Nevada and western Idaho; and (4) tectonic closure of the Blue Mountains collisional basin and initiation of east-dipping subduction and related magmatism in latest Jurassic to earliest Cretaceous time (~145 – 135 Ma).

DISCUSSION

Historical use of a terrane-analysis approach that emphasizes the different histories of adjacent lithotectonic blocks (for example, Howell and others, 1985; Hamilton, 1990; Sengor and Dewey, 1990), while useful for understanding the evolution of mobile blocks in orogenic belts, also has the potential to obscure similarities and related histories of neighboring crustal provinces. In the Blue Mountains for example, an important Late Triassic provenance link between the Baker, Wallowa and Olds Ferry terranes appears to have been overlooked in most previous studies. Grouping of Late Triassic to Late Jurassic marine deposits into a single "Izee terrane" has minimized the significance of a regional angular unconformity that separates two megasequences and records a period of Late Triassic shortening, uplift and erosion. The synthesis presented above illustrates how tectonic models can be significantly improved through compilation of regional stratigraphic data and application of established principles in basin analysis to interpret tectonic controls on crustal subsidence.

The new model developed here is based on a synthesis of many different data types and observation scales, and it builds on comparison to processes documented in a variety of Tertiary and modern active margins. This model is also predictive and testable. For example, the sediment fill of a pre-collisional forearc basin that formed in an oceanic island-arc system should reveal a juvenile, depleted-mantle signature in isotopic and REE compositions, and contain detrital-zircon ages that reflect the age of arc volcanism. The sediment fill of a collisional basin derived from a complex source that includes fragments of continental crust should trend toward more evolved continental signatures with populations of detrital zircons representing older, cratonal sources. Any effort to apply such tests will have to include assessment of long-distance axial sediment transport, evolution of river catchments through time, and possible inherited crustal structure such as rifted continental blocks and subducted slabs. Future work of this type will improve our understanding of Triassic-Jurassic tectonic evolution in the Blue Mountains.

Some aspects of Triassic volcanism in the BMP and western Nevada at first appear inconsistent with our proposed model for Middle Triassic subduction and related volcanism followed by Late Triassic collision of facing accretionary wedges (figs. 7A and 7B). In the Huntington area (Olds Ferry arc), volcanism did not stop during Late Triassic arc-arc collision, but instead continued into Norian time, producing voluminous rhyodacite flows and rhyolitic breccias interbedded with volcaniclastic marine deposits (Collins and others, 2000a, 2000b; San Filippo, ms, 2006). In northwestern Nevada, which may lie east of the Olds Ferry arc in the pre-Cretaceous reconstruction, volcanism was limited or nonexistent during Middle Triassic time and became very active in the Late Triassic (Quinn and others, 1997; Wyld, 2000), a time when a simple model might predict that volcanism should end as a result of arc-arc collision. However, patterns of volcanism at collisional margins are extremely complex because slab delamination and breakoff commonly generates voluminous and variable magmatic activity. Volcanism related to slab breakoff is documented from a number of Tertiary to modern collisional settings, including northwest Turkey (Altunkaynak, 2007), eastern Anatolia (Keskin, 2003), eastern Carpathians (Chalot-Prat and Girbacea, 2000), Apennines (Wortel and Spakman, 2000), Kamchatka (Levin and others, 2002), Papua New Guinea (Cloos and others, 2005), and the Molucca Sea (Hall and others, 1988; MacPherson and others, 2003). The abundance and chemical diversity of magmatically active collisional margins indicates that the complex patterns of magmatism seen in Triassic to early Jurassic rocks of northeastern Oregon and northwestern Nevada can be expected for an evolving collision zone. Geochemical data from Mesozoic rocks could be compared to those of modern collisional margins to test this model in future work.

The multi-stage collisional hypothesis has significant implications for understanding plate interactions that drove Triassic–Jurassic mountain building and basin development in this and other parts of the NW U.S. Cordillera. In particular, it addresses the question of whether collision of oceanic terranes with North America was a primary driver of continental deformation during Jurassic time (Monger and others, 1982, 1992; Schweickert and others, 1984; Ingersoll and Schweickert, 1986; Edelman, 1991; Wyld and others, 1996) or a relatively small-scale, short-lived and unimportant process (Oldow and others, 1989; Burchfiel and others, 1992; Smith and others, 1993). Subduction of ocean crust clearly took place in the southwestern U.S. during Late Triassic and Jurassic time (for example, Saleeby and Busby-Spera, 1992), suggesting a southward change from collisional plate interactions to oceanic subduction. Spatial complexity of this kind is similar to the intricate pattern of subduction, collision, and strike-slip tectonics seen in present-day Southeast Asia and southwest Pacific region (Silver and Smith, 1983). Jurassic subsidence in the Blue Mountains collisional basin coincided with growth of a large thrust belt in Nevada and related eastward migration of the Utah-Idaho Trough, a foreland basin that formed in response to thrust loading in Nevada (Jordan, 1985; Bjerrum and Dorsey, 1995; Allen and others, 2000; Wyld, 2000; Wyld and others, 2003; Dorsey and Wyld, 2007). The Jurassic was also a time of significantly reduced arc-related magmatism in eastern Oregon and Nevada (Quinn and others, 1997; Wyld, 2002). We suggest that the similar timing of these events is not mere coincidence, and instead reveals a set of related orogenic processes that profoundly deformed and shaped the western Cordilleran margin during much of Jurassic time. Our synthesis of previous studies in the BMP, integrated with the pre-Cretaceous reconstruction of Wyld and Wright (2001), suggests that collisional tectonics may have played a significant role in Triassic-Jurassic growth of the northwestern U.S. Cordillera.

CONCLUSIONS

A synthesis of previous studies in the Blue Mountains reveals evidence for two major phases of Triassic – Jurassic basin development that prompt us to suggest a new tectonic model for convergent and collisional tectonics in this region. According to this model, Middle Triassic convergence between the facing Wallowa and Olds Ferry magmatic arcs took place by consumption of an intervening oceanic plate along oppositely dipping subduction zones. Late Triassic collision between the facing accretionary prisms of the Wallowa and Olds Ferry arcs produced a large doubly-vergent thrust belt in the Baker terrane, which shed sediment into flanking syntectonic basins formed on forearc crust of the Wallowa and Olds Ferry terranes.

During Early to early-Late Jurassic time, a large marine basin formed and subsided deeply on crust of the previously amalgamated terranes. Using a reconstruction that places the Blue Mountains at the latitude of central to northern Nevada in Jurassic time (Wyld and Wright, 2001), we suggest this was a collisional basin that formed during protracted collision of the previously amalgamated Wallowa, Baker, and Olds Ferry terranes with western North America. According to this hypothesis, terrane-continent collision resulted in tectonic closure of a large backarc basin, growth of the Cordilleran thrust belt, regional metamorphism, and widespread crustal thickening and mountain building in western Idaho and Nevada. We infer that flexural subsidence in flanking basins on both sides of the doubly-vergent orogen produced the Jurassic Utah-Idaho Trough (foreland basin) in the east and the Blue Mountains collisional basin in the west. We therefore suggest that collisional tectonics may have played a significant role in plate interactions and regional-scale lithospheric processes that drove mountain building and basin evolution in the northwestern U.S. Cordillera during Late Triassic and Jurassic time.

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References

Abbott, L. D., 1995, Neogene tectonic reconstruction of the Adelbert–Finisterre–New Britain collision, northern Papua New Guinea: Journal of Southeast Asian Earth Science, v. 11, p. 33–51.

Abbott, L. D., Silver, E. A., Thompson, P. R., Filewicz, M. V., Schneider, C., and Abdoerrias, 1994, Stratigraphic constraints on the development and timing of arc-continent collision in northern Papua New Guinea: Journal of Sedimentary Research, v. B64 (2), p. 169–183.

Allen, P. A., Verlander, J. E., Burgess, P. M., and Audet, D. M., 2000, Jurassic giant erg deposits, flexure of the United States continental interior, and timing of the onset of Cordilleran shortening: Geology, v. 28, p. 159–162.

Altunkaynak, S., 2007, Collision-Driven Slab Breakoff Magmatism in Northwestern Anatolia, Turkey: Journal of Geology, v. 115, p. 63–82.

Armstrong, R. L., Taubeneck, W. H., and Hales, P. O., 1977, Rb-Sr and K-Ar geochronometry of Mesozoic granitic rocks and their Sr isotopic composition, Oregon, Washington, and Idaho: Geological Society of America Bulletin, v. 88, p. 397–411.

Ashley, R. P., 1995, Petrology and deformation history of the Burst River Schist and associated plutonic rocks in the Burst River Canyon area, northeastern Oregon, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington: petrology and tectonic evolution of pre-Tertiary rocks of the Blue Mountains region: U.S. Geological Survey Professional Paper 1438, p. 457–496.

Audley-Charles, M. G., 2004, Ocean trench blocked and obliterated by Banda forearc collision with Australian proximal continental slope: Tectonophysics, v. 389, p. 65–79.

Audley-Charles, M. G., and Harris, R. A., 1990, Allochthonous terranes of the Southwest Pacific and Indonesia, *in* Dewey, J. F., Gass, I. G., Curry, G. B., Harris, N. B. W., and Sengor, A. M. C., editors, Allochthonous terranes: Philosophical Transactions of the Royal Society of London, Series A, v. 331, p. 571–587.

Avé Lallemant, H. G., 1983, The kinematic insignificance of mineral lineations in a Late Jurassic thrust and fold belt in eastern Oreogn: Tectonophysics, v. 100, p. 389–404.

——— 1995, Pre-Cretaceous tectonic evolution of the Blue Mountains Province, northeastern Oregon, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington: petrology and tectonic evolution of pre-Tertiary rocks of the Blue Mountains region: U.S. Geological Survey Professional Paper 1438, p. 271–304.

Avé Lallemant, H. G., and Oldow, J. S., 1988, Early Mesozoic southward migration of Cordilleran transpressional terranes: Tectonics, v. 7, p. 1057–1075.

Avé Lallemant, H. G., Phelps, D. W., and Sutter, J. F., 1980, 40Ar/39Ar ages of some pre-Tertiary plutonic and metamorphic rocks of eastern Oregon and their geologic relationships: Geology, v. 8, p. 371–374.

Avé Lallemant, H. G., Schmidt, W. J., and Kraft, J. L., 1985, Major Late-Triassic strike-slip displacement in the Seven Devils Terrane, Oregon and Idaho: a result of left-oblique plate convergence: Tectonophysics, v. 119, p. 299–328.

Bader, A. G., Pubellier, M., Rangin, C., Deplus, C., and Louat, R., 1999, Active slivering of oceanic crust along the Molucca Ridge (Indonesia-Philippine); implication for ophiolite incorporation in a subduction wedge?: Tectonics, v. 18, p. 606–620.

Balcer, D. E., ms, 1980, 40Ar/39Ar ages and REE geochemistry of basement terranes in the Snake River Canyon, northeastern Oregon-western Idaho: Columbus, Ohio, The Ohio State University, M. S. Thesis, 111 p.

Bishop, E. M., 1995a, High-pressure, low-temperature schistose rocks of the Baker Terrane, northeastern Oregon, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington: petrology and tectonic evolution of pre-Tertiary rocks of the Blue Mountains region: U.S. Geological Survey Professional Paper 1438, p. 211–220.

——— 1995b, Mafic and ultramafic rocks of the Baker Terrane, eastern Oregon, and their implications for terrane origin, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington: petrology and tectonic evolution of pre-Tertiary rocks of the Blue Mountains region: U.S. Geological Survey Professional Paper 1438, p. 221–246.

Bjerrum, C. J., and Dorsey, R. J., 1995, Tectonic controls on deposition of Middle Jurassic strata in a retroarc foreland basin, Utah-Idaho Trough, Western Interior, United States: Tectonics, v. 14, p. 962–978.

Blome, C. D., Jones, D. L., Murchey, B. L., and Liniecki, M., 1986, Geologic implications of radiolarian-bearing Paleozoic and Mesozoic rocks from the Blue Mountains Province, eastern Oregon, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington: geologic implications of Paleozoic and Mesozoic paleontology and biostratigraphy, Blue Mountains Province, Oregon and Idaho: U.S. Geological Survey Professional Paper 1435, p. 79–101.

Brooks, H. C., 1979, Geologic Map of Huntington and Part of Olds Ferry Quadrangles, Oregon: State of Oregon, Oregon Department of Geology and Mineral Industries, Geologic Map Series, GMS-13, Scale 1:62,500.

Brooks, H. C., and Vallier, T. L., 1978, Mesozoic rocks and tectonic evolution of eastern Oregon and western Idaho, *in* Howell, D. G., and McDougall, K. A., editors, Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Paleogeography Symposium 2, p. 133–145.

Brooks, H. C., McIntyre, J. R., and Walker, G. W., 1976, Geology of the Oregon Part of the Baker 1-degree by 2-degree Quadrangle: State of Oregon, Oregon Department of Geology and Mineral Industries, Geologic Map Series, GMS-7, Scale 1:250,000.

Brown, C. E., and Thayer, T. P., 1966, Geologic Quadrangle Map, Mount Vernon Quadrangle, Oregon: United States Geological Survey, GQ-548, Scale 1:62,500.

——— 1977, Geologic map of pre-Tertiary rocks in the eastern Aldrich Mountains and adjacent areas to the south, Grant County, Oregon: U. S. Geological Survey, Miscellaneous Investigations Series I-1021, Scale 1:62,500.

Brown, D., Alvarez-Marron, J., Perez-Estaun, A., Puchkov, V., Ayarza, P., and Gorozhanina, Y., 2001, Structure and evolution of the Magnitogorsk forearc basin: identifying upper crustal processes during arc-continent collision in the Southern Urals: Tectonics, v. 20, p. 364–375.

Burchfiel, B. C., Cowan, D. S., and Davis, G. A., 1992, Tectonic overview of the Cordilleran orogen in the western U. S., *in* Burchfiel, B. C., Lipman, P. W., and Zoback, M. L., editors, The Cordilleran Orogen: Conterminous U. S.: The Geology of North America: Geological Society of America, Volume G-3, p. 407–480.

Burton-Ferguson, R., Aksu, A. E., Calon, T. J., and Hall, J., 2005, Seismic stratigraphy and structural evolution of the Adana Basin, eastern Mediterranean: Marine Geology, v. 221, p. 189–222.

Byrne, T. B., and Liu, C. S., editors, 2002, Geology and geophysics of an arc-continent collision, Taiwan: Geological Society of America Special Paper 358, 211 p.

Carpenter, P. S., and Walker, N. W., 1992, Origin and tectonic significance of the Aldrich Mountains serpentinite matrix melange, northeastern Oregon: Tectonics, v. 11, p. 690–708.

Chalot-Prat, F., and Girbacea, R., 2000, Partial delamination of continental mantle lithosphere, uplift-related crust-mantle decoupling, volcanism and basin formation: a new model for the Pliocene-Quaternary evolution of the southern East-Carpathians, Romania: Tectonophysics, v. 327, p. 83–107.

Clift, P. D., Schouten, H., and Draut, A. E., 2003, A general model of arc-continent collision and subduction polarity reversal from Taiwan and the Irish Caledonides, *in* Larter, R. D., and Leat, P. T., editors, Intra-oceanic subduction systems: tectonic and magmatic processes: London, Geological Society Special Publication, v. 219, p. 81–98.

Cloos, M., 1993 Lithospheric buoyancy and collisional orogenesis; subduction of oceanic plateaus, continental margins, island arcs, spreading ridges, and seamounts: Geological Society of America, v. 105, p. 715–737.

Cloos, M., Sapiie, B., Quarles van Ufford, A., Weiland, R. J., Warren, P. Q., and McMahon, T. P., 2005, Collisional delamination in New Guinea: The geotectonics of subducting slab breakoff: Geological Society of America, Special Paper 400, 51 p.

Collins, A. Q., Northrup, C. J., and White, C. M., 2000a, Lithologic definition and geologic mapping of the Huntington Formation, Olds Ferry Terrane, Baker County, Oregon (abstract): Geological Society of America Abstracts with Programs, v. 32, n. 5, p. 6.

——— 2000b, Petrogenesis of the Huntington Formation, Olds Ferry Terrane, Baker County, Oregon (abstract): Geological Society of America Abstracts with Programs, v. 32, n. 6, p. 7.

Cooper, P., and Taylor, B., 1987, Seismotectonics of New Guinea; a model for arc reversal following arc-continent collision: Tectonics, v. 6, p. 53–67.

Cowan, D. S., and Bruhn, R. L., 1992, Late Jurassic to early Late Cretaceous geology of the U.S. Cordillera, *in* Burchfiel, B. C., Lipman, P. W., and Zoback, M. L., editors, The Cordilleran Orogen: Conterminous U.S.: Geological Society of America, The Geology of North America, Volume G-3, p. 169–203.

Coward, R. I., ms, 1983, Structural geology, stratigraphy, and petrology of the Elkhorn Ridge Argillite in the Sumpter area, northeastern Oregon: Houston, Texas, Rice University, Ph. D. thesis, 144 p.

DeCelles, P. G., 2004, Late Jurassic to Eocene evolution of the Cordilleran thrust belt and foreland basin system, western U.S.A.: American Journal of Science, v. 304, p. 105–168.

DeCelles, P. G., and Coogan, J. C., 2006, Regional structure and kinematic history of the Sevier fold-and-thrust belt, central Utah: Geological Society of America Bulletin, v. 118, p. 864–875.

DeCelles, P. G., and Giles, K. A., 1996, Foreland basin systems: Basin Research, v. 8, p. 105–123.

Dickinson, W. R., 1979, Mesozoic forearc basin in central Oregon: Geology, v. 7, n. 4, p. 166–170.

——— 1995, Forearc basins, *in* Busby, C. J., and Ingersoll, R. V., editors, Tectonics of sedimentary basins: Oxford, England, Blackwell, p. 221–261.

——— 2004, Evolution of the Western Cordillera of North America: Annual Review of Earth and Planetary Sciences, v. 32, p. 13–45.

Dickinson, W. R., and Vigrass, L. W., 1964, Pre-Cenozoic history of Supplee-Izee District, Oregon: implications for geosynclinal theory: Geological Society of America Bulletin, v. 75, p. 1037–1044.

——— 1965, Geology of the Suplee-Izee area, Crook, Grant, and Harney counties, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 58, 109 p.

Dickinson, W. R., and Thayer, T. P., 1978, Paleogeographic and paleotectonic implications of Mesozoic stratigraphy and structure in the John Day inlier of central Oregon, *in* Howell, D. G., and McDougall, K. A., editors, Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Paleogeography Symposium 2, p. 147–161.

Dickinson, W. R., Helmold, K. P., and Stein, J. A., 1979, Mesozoic Lithic Sandstones in Central Oregon: Journal of Sedimentary Petrology, v. 49, p. 501–516.

Dorsey, R. J., 1992, Collapse of the Luzon volcanic arc during onset of arc-continent collision: Evidence from a Mio-Pliocene unconformity, eastern Taiwan: Tectonics, v. 11, p. 177–191.

Dorsey, R. J., and Wyld, S. J., 2007, Jurassic collisional tectonics in the northwestern U.S. Cordillera, and paired growth of the Luning-Fencemaker thrust belt and Utah-Idaho Trough: Geological Society of America Abstracts with Programs, v. 39, n. 4, p. 80.

Edelman, S. H., 1991, Relationships between kinematics of arc-continent collision and kinematics of thrust faults, folds, shear zones, and foliations in the Nevadan Orogen, northern Sierra Nevada, California: Tectonophysics, v. 191, p. 223–236.

Evans, J. G., 1995, Pre-Tertiary deformation in the Desolation Butte quadrangle, northeastern Oregon, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains Region of Oregon, Idaho and Washington: Petrology and Tectonic Evolution of Pre-Tertiary Rocks of the Blue Mountains Region: U. S. Geological Survey Professional Paper 1438, p. 305–330.

Ferns, M. L., and Brooks, H. C., 1995, The Bourne and Greenhorn subterranes of the Baker Terrane, northeastern Oregon; implications for the evolution of the Blue Mountains island-arc system, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains Region of Oregon, Idaho and Washington: Petrology and Tectonic Evolution of Pre-Tertiary Rocks of the Blue Mountains Region: U. S. Geological Survey Professional Paper 1438, p. 331–358.

Fleck, R. J., and Criss, R. E., 1985, Strontium and oxygen isotopic variations in Mesozoic and Tertiary plutons of central Idaho: Contributions to Mineralogy and Petrology, v. 90, p. 291–308.

Follo, M. F., ms, 1986, Sedimentology of the Wallowa Terrane, Northeastern Oregon: Cambridge, Massachusets, Harvard University, Ph. D. thesis, 292 p.

——— 1992, Conglomerates as clues to the sedimentary and tectonic evolution of a suspect terrane: Wallowa Mountains, Oregon: Geological Society of America Bulletin, v. 104, p. 1561–1576.

——— 1994, Sedimentology and stratigraphy of the Martin Bridge Limestone and Hurwal Formation (Upper Triassic to Lower Jurassic) from the Wallowa Terrane, Oregon, *in* Vallier, T. L., and Brooks, H. C., editors, Stratigraphy, Physiography, and Mineral Resources of the Blue Mountains Region: U.S. Geological Survey Professional Paper 1439, p. 1–27.

Galewsky, J., and Silver, E. A., 1997, Tectonic controls on facies transitions in an oblique collision: The western Solomon Sea, Papua New Guinea: Geological Society of America Bulletin, v. 109, p. 1266–1278.

Garver, J. I., Umhoefer, P. J., McGroder, M. F., and Bourgeois, J., 1990, Pre- to syncollisional sedimentation in the Middle Jurassic to Cretaceous Methow-Tyaughton Basin, northern Washington, southwestern British Columbia (abstract): AAPG Bulletin, v. 74, p. 660.

Giles, K. A., 1996, Tectonically forced retrogradation of the Lower Mississippian Joana Limestone, Nevada and Utah, *in* Longman, M. W., and Sonnenfeld, M. D., editors, Paleozoic systems of the Rocky Mountain region: SEPM, Rocky Mountain Section, p. 145–164.

Giorgis, S., Tikoff, B., and McClelland, W., 2005, Missing Idaho arc: Transpressional modification of the 87Sr/86Sr transition on the western edge of the Idaho batholith: Geology, v. 33, p. 469–472.

Goldstrand, P. M., ms, 1987, The Mesozoic stratigraphy, depositional environments, and tectonic evolution of the northern portion of the Wallowa terrane, northeastern Oregon and western Idaho: Bellingham, Washington, Western Washington University, Masters thesis, 200 p.

——— 1994, The Mesozoic geologic evolution of the northern Wallowa Terrane, northeastern Oregon and western Idaho, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington; stratigraphy, physiography, and mineral resources of the Blue Mountains region: U.S. Geological Survey Professional Paper 1439, p. 29–53.

Gradstein, F. M., Ogg, J. G., and Smith, A. G., 2004, A Geologic Time Scale 2004: Cambridge, United Kingdom, Cambridge University Press, 589 p.

Graham, S. A., Hendrix, M. S., Wang, L. B., and Carroll, A. R., 1993, Collisional successor basins of western China: impact of tectonic inheritance on sand composition: Geological Society of America Bulletin, v. 105, p. 323–344.

Gray, K. D., and Oldow, J. S., 2005, Contrasting structural histories of the Salmon River belt and Wallowa terrane: Implications for terrane accretion in northeastern Oregon and west-central Idaho: Geological Society of America Bulletin, v. 117, p. 687–706.

Hacker, B. R., and Goodge, J. W., 1990, Comparison of early Mesozoic high-pressure rocks in the Klamath Mountains and Sierra Nevada, *in* Harwood, D. S., and Miller, M. M., editors, Paleozoic and early Mesozoic paleogeographic relations; Sierra Nevada, Klamath Mountains, and related terranes: Boulder, Colorado, Geological Society of America Special Paper 255, p. 277–295.

Hall, R., 2000, Neogene history of collision in the Halmahera region, Indonesia: Proceedings of the Indonesian Petroleum Association 27th Annual Convention, 487–493.

Hall, R., Audley-Charles, M. G., Banner, F. T., Hidayat, S., and Tobing, S. L., 1988. Late Palaeogene-Quaternary geology of Halmahera, eastern Indonesia: initiation of a volcanic island arc: London, Journal of the Geological Society, v. 145, p. 577–590.

Hamilton, W. B., 1988, Plate tectonics and island arcs: Geological Society of America Bulletin, v. 100, p. 1503–1527.

——— 1990, On terrane analysis: Philosophical Transactions of the Royal Society of London, Series A, v. 331, p. 511–522.

Heller, P. L., and Paola, C., 1989, The paradox of Lower Cretaceous gravels and the initiation of thrusting in the Sevier orogenic belt, United States Western Interior: Geological Society of America Bulletin, v. 101, p. 864–875.

Hendricksen, T. A., Skurla, S. J., and Field, C. W., 1972, K-Ar dates for plutons from the Iron Mountain and Sturgill Peak areas of western Idaho: Isochron/West, v. 5, p. 13–16.

Hillhouse, J. W., Gromme, C. S., and Vallier, T. L., 1982, Paleomagnetism and Mesozoic tectonics of the Seven Devils volcanic arc in northeastern Oregon: Journal of Geophysical Research, B, v. 87, p. 3777–3794.

Hotz, P. E., Lanphere, M. A., and Swanson, D. A., 1977, Triassic blueschist from northern California and North-central Oregon: Geology, v. 5, p. 659–663.

Housen, B. A., 2007, Paleomagnetism of Mesozoic-Cenozoic rocks of the Blue Mountains, Oregon: Geological Society of America Abstracts with Programs, v. 39.

Housen, B. A., and Dorsey, R. J., 2005, Paleomagnetism and tectonic significance of Albian and Cenomanian turbidites, Ochoco basin, Mitchell Inlier, central Oregon: Journal of Geophysical Research, v. 110, B07102, doi:10.1029/2004JB003458.

Howell, D. G., Jones, D. L., and Schermer, E. R., 1985, Tectonostratigraphic terranes of the Circum-Pacific region, *in* Howell, D. G., editor, Tectonostratigraphic terranes of the Circum-Pacific region: Houston, Circum-Pacific Council for Energy and Mineral Resources Earth Science Series, v. 1, p. 3–30.

Huang, C. Y., Yuan, P. B., Lin, C. W., Wang, T. K., and Chang, C. P., 2000, Geodynamic processes of Taiwan arc-continent collision and comparison with analogs in Timor, Papua New Guinea, Urals and Corsica, *in* Brown, D., Spadea, P., and Anma, R., editors, Processes of arc-continent collision: Tectonophysics, v. 325, p. 1–21.

Imlay, R. W., 1986, Jurassic ammonites and biostratigraphy of eastern Oregon and western Idaho, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington; geologic implications of Paleozoic and Mesozoic paleontology and biostratigraphy, Blue Mountains Province, Oregon and Idaho: U. S. Geological Survey Professional Paper 1435, p. 53–57.

Ingersoll, R. V., and Schweickert, R. A., 1986, A plate-tectonic model for Late Jurassic ophiolite genesis, Nevadan orogeny and forearc initiation, northern California: Tectonics, v. 5, p. 901–912.

Jordan, T. E., 1981, Thrust loads and foreland basin evolution, Cretaceous, western United States: American Association of Petroleum Geologists Bulletin, v. 65, p. 2506–2520.

—— 1985, Tectonic setting and petrography of Jurassic foreland basin sandstones, Idaho-Wyoming-Utah, *in* Kerns, G. J., and Kerns, R. L., editors, Orogenic patterns and stratigraphy of north-central Utah and southeastern Idaho: Utah Geological Association Publication 14, p. 201–213.

Juras, D. S., ms, 1973, Pre-Miocene geology of the northwest part of the Olds Ferry Quadrangle, Washington County, Idaho: Moscow, Idaho, University of Idaho, M. S. thesis, 82 p.

Kays, M. A., Stimac, J. P., and Goebel, P. M., 2006, Permian-Jurassic growth and amalgamation of the Wallowa composite terrane, northeastern Oregon, *in* Snoke, A. W., and Barnes, C. G., editors, Geological studies in the Klamath Mountains province, California and Oregon: Geological Society of America Special Paper 410, p. 465–494.

Keskin, M., 2003, Magma generation by slab steepening and breakoff beneath a subduction-accretion complex: An alternative model for collision-related volcanism in Eastern Anatolia, Turkey: Geophysical Research Letters, v. 30, n. 24, doi:10.1029/2003GL018019.

Kleinspehn, K. L., 1985, Cretaceous sedimentation and tectonics, Tyaughton-Methow Basin, southwestern British Columbia: Canadian Journal of Earth Sciences, v. 22, p. 154–174.

Klootwijk, C., Giddings, J., Pigram, C., Loxton, C., Davies, H., Rogerson, R., and Falvey, D., 2003a, Papua New Guinea Highlands: palaeomagnetic constraints on terrane tectonics: Tectonophysics, v. 362, p. 239–272.

—— 2003b, North Sepik Region of Papua New Guinea: palaeomagnetic constraints on arc accretion and deformation: Tectonophysics, v. 362, p. 273– 301.

Krézsek, C., and Bally, A. W., 2006, The Transylvanian Basin (Romania) and its relation to the Carpathian fold and thrust belt: Insights in gravitational salt tectonics: Marine and Petroleum Geology, v. 23, May 2006, p. 405–442.

Lallemand, S., Liu, C. S., Angelier, J., and Tsai, Y. B., 2001, Active subduction and collision in Southeast Asia: Tectonophysics, v. 333, p. 1–7.

LaMaskin, T. A., 2005, Mixed carbonate-volcaniclastic facies of the Olds Ferry terrane, eastern Oregon and western Idaho: Geological Society of America Abstracts with Programs, v. 37, n. 7, p. 16.

—— 2008, Late Triassic (Carnian-Norian) Mixed Carbonate-Volcaniclastic Facies of the Olds Ferry Terrane, Eastern Oregon and Western Idaho: Geological Society of America Special Paper: The Terrane Puzzle: New Perspectives on Paleontology and Stratigraphy from the North American Cordillera.

Levin, V., Shapiro, N., Park, J., and Ritzwoller, M., 2002, Seismic evidence for catastrophic slab loss beneath Kamchatka: Nature, v. 418, p. 763–766.

Lund, K., 2004, Geology of the Payette National Forest and vicinity, west-central Idaho: U.S. Geological Survey Professional Paper 1666-A, -B, 89 p.

Lund, K., and Snee, L. W., 1988, Metamorphism, structural development, and age of the continent-island arc juncture in west-central Idaho, *in* Ernst, W. G., editor, Metamorphism and crustal evolution of the western United States, Rubey Volume III: Englewood Cliffs, New Jersey, Prentice Hall, p. 297–331.

Lundberg, N., and Dorsey, R. J., 1988, Synorogenic sedimentation and subsidence in a Plio-Pleistocene collisional basin, eastern Taiwan, *in* Kleinspehn, K. L., and Paola, C., editors, New perspectives in basin analysis: New York, New York, Springer-Verlag, p. 265.

Macpherson, C. G., Forde, E. J., Hall, R., and Thirlwall, M. F., 2003, Geochemical evolution of magmatism in an arc-arc collision; the Halmahera and Sangihe Arcs, eastern Indonesia, *in* Larter, R. D., and Leat, P. T., editors, Intra-oceanic subduction systems: Tectonic and magmatic processes: London, Geological Society Special Publication, v. 219, p. 207–220.

Manduca, C. A., Silver, L. T., and Taylor, H. P., 1992, ^{87}Sr/^{86}Sr and ^{18}O/^{16}O isotopic systematics and geochemistry of granitoid plutons across a steeply-dipping boundary between contrasting lithospheric blocks in western Idaho: Contributions to Mineralogy and Petrology, v. 109, p. 355–372.

Manduca, C. A., Kuntz, M. A., and Silver, L. T., 1993, Emplacement and deformation history of the western margin of the Idaho Batholith near McCall, Idaho; influence of a major terrane boundary: Geological Society of America Bulletin, v. 105, p. 749–765.

Mann, G. M., 1989, Seismicity and late Cenozoic faulting in the Brownlee Dam area, Oregon-Idaho; a preliminary report: Reston, Virginia, U. S. Geological Survey, Open-File Report, OF-429, 46 p.

Martin-Chivelet, J., 1995, Sequence stratigraphy of mixed carbonate-siliciclastic platforms developed in a tectonically active setting, Upper Cretaceous, Betic continental margin (Spain): Journal of Sedimentary Research, v. B65, p. 235–254.

Mazzotti, S., and Hyndman, R. D., 2002, Yakutat collision and strain transfer across the northern Canadian Cordillera: Geology, v. 30, p. 495–498.

McClelland, W. C., Tikoff, B., and Manduca, C. A., 2000, Two-phase evolution of accretionary margins: examples from the North American Cordillera: Tectonophysics, v. 326, p. 37–55.

McRoberts, C. A., 1993, Systematics and biostratigraphy of halobiid bivalves from the Martin Bridge Formation (Upper Triassic), Northeast Oregon: Journal of Paleontology, v. 67, p. 198.

Monger, J. W. H., Price, R. A., and Tempelman-Kluit, D. J., 1982, Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera: Geology, v. 10, p. 70–75.

Monger, J. W. H., Wheeler, J. O., Tipper, H. W., Gabrielse, H., Harms, T., Struik, L. C., Campbell, R. B., Dodds, C. J., Gehrels, G. E., and O'Brian, J., 1992, Upper Devonian to Middle Jurassic assemblages; Cordilleran terranes, *in* Gabrielse, H., and Yorath, C. J., editors, The Cordilleran Orogen: Ottawa, Canada, Geological Survey of Canada, Geology of Canada Series, v. 4 (Geological Society of America, The Geology of North America, v. G-2), ch. 8, part b, p. 281–327.

Morris, E. M., and Wardlaw, B. R., 1986, Conodont ages for limestones of eastern Oregon and their implication for pre-Tertiary melange terranes, *in* Vallier, T. L., and Brooks, H. C., editors: U. S. Geological Survey Professional Paper 1435, p. 59–63.

Morrison, R. K., ms, 1963, Pre-Tertiary geology of the Snake River Canyon between Cache Creek and Dug Bar, Oregon-Idaho boundary: Eugene, Oregon, University of Oregon, Ph. D. thesis, 290 p.

Mortimer, N., 1986, Late Triassic, arc-related, potassic igneous rocks in the North American Cordillera: Geology, v. 14, p. 1035–1038.

Naylor, M., and Sinclair, H. D., 2007, Punctuated thrust deformation in the context of doubly vergent thrust wedges: Implications for the localization of uplift and exhumation: Geology, v. 35, p. 559–562.

Newton, C. R., 1986, Late Triassic bivalves of the Martin Bridge Limestone, Hells Canyon, Oregon; taphonomy, paleoecology, paleozoogeography, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington; geologic implications of Paleozoic and Mesozoic paleontology and biostratigraphy, Blue Mountains Province, Oregon and Idaho: U.S. Geological Survey Professional Paper 1435, p. 7–22.

Nolf, B., 1966, Geology and stratigraphy of part of the northern Wallowa Mountains, Oregon: Princeton, New Jersey, Princeton University, 138 p.

Nützel, A., and Erwin, D. H., 2004, Late Triassic (Late Norian) gastropods from the Wallowa terrane (Idaho, USA): Palaeontologische Zeitschrift, v. 78(2), p. 361–416.

Oldow, J. S., 1984, Evolution of a late Mesozoic back-arc fold and thrust belt, northwestern Great Basin, U.S.A.: Tectonophysics, v. 102, p. 245–274.

Oldow, J. S., Avé Lallemant, H. G., and Schmidt, W. J., 1984, Kinematics of plate convergence deduced from Mesozoic structures in the Western Cordillera: Tectonics, v. 3, p. 201–227.

Oldow, J. S., Bally, A. W., Lallemant, H. G. A., and Leeman, W. P., 1989, Phanerozoic evolution of the North American Cordillera: United States and Canada, *in* Bally, A. W., and Palmer, A. R., editors, The geology of North America: an overview: Geological Society of America, The Geology of North America, Volume A, p. 139–232.

Payne, J. D., and Northrup, C. J., 2003, Geologic Map of the Monroe Butte 7.5 Minute Quadrangle, Idaho-Oregon: Idaho Geological Survey, Technical Report 03-01, Scale 1:24,000.

Pessagno, E. A., and Blome, C. D., 1986, Faunal affinities and tectonogenesis of Mesozoic rocks in the Blue Mountains province of eastern Oregon and western Idaho, *in* Vallier, T. L., and Brooks, H. C., editors, Geologic implications of Paleozoic and Mesozoic paleontology and biostratigraphy, Blue Mountains province, Oregon and Idaho: U.S. Geological Survey Professional Paper 1435, p. 65–78.

Phinney, E. J., Mann, P., Coffin, M. F., and Shipley, T., 1999, Sequence stratigraphy and structure of the southwestern Ontong Java Plateau adjacent to the North Solomon trench and Solomon Islands: Journal of Geophysical Research, v. 104, p. 20,449–20,466.

Pigram, C. J., and Davies, H. L., 1987, Terranes and the accretion history of the New Guinea Orogen: BMR Journal of Australian Geology and Geophysics, v. 10, p. 193–211.

Pigram, C. J., and Symonds, P. A., 1991, A review of the timing of the major tectonic events in the New Guinea Orogen: Journal Southeast Asian Earth Science 6, p. 307–318.

Plafker, G., Moore, J. C., and Winkler, G. R., 1994, Geology of the Southern Alaska margin, *in* Plafker, G., and Berg, H. C., editors, The geology of Alaska: Geological Society of America, Geology of North America, Volume G-1, p. 389–449.

Pubellier, M., Bader, A. G., Rangin, C., Deffontaines, B., and Quebral, R., 1999, Upper plate deformation induced by subduction of a volcanic arc; the Snellius Plateau (Molucca Sea, Indonesia and Mindanao, Philippines): Tectonophysics, v. 304, p. 345–368.

Quinn, M. J., Wright, J. E., and Wyld, S. J., 1997, Happy Creek igneous complex and tectonic evolution of the early Mesozoic arc in the Jackson Mountains, northwest Nevada: Geological Society of America Bulletin, v. 109, p. 461–482.

Roca, X., and Nadon, G. C., 2007, Tectonic Control on the Sequence Stratigraphy of Nonmarine Retroarc Foreland Basin Fills: Insights from the Upper Jurassic of Central Utah, U.S.A.: Journal of Sedimentary Research, v. 77, p. 239–255.

Sajona, F. G., Maury, R. C., Pubellier, M., Leterrier, J., Bellon, H., and Cotten, J., 2000, Magmatic source enrichment by slab-derived melts in a young post-collision setting, central Mindanao (Philippines): Lithos, v. 54, p. 173–206.

Saleeby, J. B., 1983, Accretionary Tectonics of the North American Cordillera: Annual Review of Earth and Planetary Sciences, v. 11, p. 45–73.

Saleeby, J. B., and Busby-Spera, C., 1992, Early Mesozoic tectonic evolution of the Western U.S. Cordillera, *in* Burchfiel, B. C., Lipman, P. W., and Zoback, M. L., editors, The Cordilleran Orogen: conterminous U.S.: The Geology of North America: Geological Society of America, United States, Volume G-3, Decade of North American Geology, p. 107–168.

San Filippo, R., ms, 2006, The stratigraphic and structural evolution of Triassic rocks north of Huntington, eastern Oregon: Eugene, Oregon, University of Oregon, B. S. Honors thesis, 34 p.

Schweickert, R. A., Bogen, N. L., Girty, G. H., Hanson, R. E., and Merguerian, C., 1984, Timing and structural expression of the nevadan orogeny, Sierra Nevada, California: Geological Society of America Bulletin, v. 95, p. 967–979.

Selverstone, J., Wernicke, B. P., and Aliberti, E. A., 1992, Intracontinental subduction and hinged unroofing along the Salmon River suture zone, west central Idaho: Tectonics, v. 11, p. 124–144.

Sengor, A. M. C., and Dewey, J. F., 1990, Terranology: Vice or Virtue?: Philosophical Transactions of the Royal Society of London, Series A, Mathematical and Physical Sciences, v. 331, p. 457-477.

Silberling, N. J., Jones, D. L., Blake, M. C., Jr., and Howell, D. G., 1984, Lithotectonic terrane map of the western conterminous United States: U. S. Geological Survey, Open File Report 84–0523, p. C1–C43.

Silver, E. A., and Smith, R. B., 1983, Comparison of terrane accretion in modern Southeast Asia and the Mesozoic North American Cordillera: Geology, v. 11, p. 198–202.

Smith, D. L., Miller, E. L., Wyld, S. J., and Wright, J. E., 1993, Progression and timing of Mesozoic crustal shortening in the northern Great Basin, Western U.S.A., *in* Dunne, G. C., and McDougall, K. A., editors, Mesozoic paleogeography of the Western United States II, Field Trip Guidebook: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 71, p. 389–405.

Smith, P. L., 1980, Correlation of the members of the Jurassic Snowshoe Formation in the Izee Basin of East-central Oregon: Canadian Journal of Earth Sciences, v. 17, p. 1603–1608.

Snee, L. W., Lund, K., Sutter, J. F., Balcer, D. E., and Evans, K. V., 1995, An ^{40}Ar/^{39}Ar chronicle of the tectonic development of the Salmon River suture zone, western Idaho, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington; petrology and tectonic evolution of pre-Tertiary rocks of the Blue Mountains region: U.S. Geological Survey Professional Paper 1438, p. 359–414.

Stanley, G. D., Jr., 1986, Late Triassic coelenterate faunas of western Idaho and northeastern Oregon: Implications for biostratigraphy and paleogeography, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington; geologic implications of Paleozoic and Mesozoic paleontology and biostratigraphy, Blue Mountains Province, Oregon and Idaho: U. S. Geological Survey Professional Paper 1435, p. 23–40.

Suppe, J., 1984, Kinematics of arc-continent collision, flipping of subduction, and backarc spreading near Taiwan: Geological Society of China Memoir 6, p. 21–33.

——— 1987, The active Taiwan mountain belt, *in* Schaer, J. P., and Rodgers, J., editors, The anatomy of mountain ranges: Princeton, New Jersey, Princeton University Press, p. 277–293.

Taylor, D. G., 1982, Jurassic shallow marine invertebrate depth zones, with exemplification from the Snowshoe Formation, Oregon: Oregon Geology, v. 44, p. 51–56.

Taylor, D. G., and Guex, J., 2002, The Triassic/Jurassic System boundary in the John Day Inlier, east-Central Oregon: Oregon Geology, v. 64, p. 3–28.

Thayer, T. P., and Brown, C. E., 1966, Geologic Quadrangle Map, Aldrich Mountain Quadrangle, Oregon: United States Geological Survey, GQ-438, Scale 1:62,500.

Tikoff, B., Kelso, P., Manduca, C., Markley, M. J., and Gillaspy, J., 2001, Lithospheric and crustal reactivation of an ancient plate boundary: The assembly and disassembly of the Salmon River Suture zone, Idaho, USA, *in* Holdsworth, R. E., Strachan, R. A., and Magloughlin, J. F., editors, Fault reactivation: London, Geological Society Special Publication, v. 186, p. 213–231.

Vail, P. R., Mitchum, Jr., R. M., and Thompson, S., 1977, Seismic stratigraphy and global changes of sea level part III: Relative changes of sea level from coastal onlap, *in* Payton, C. E., editor, Seismic stratigraphy: applications to hydrocharbon exploration: AAPG Memoir 26, p. 63–81.

Vallier, T. L., 1974, A preliminary report on the geology of part of the Snake River canyon, Oregon and Idaho: Oregon Department of Geology and Mineral Industries, Geological Map Series GMS-6, Scale 1:125,000.

——— 1977, The Permian and Triassic Seven Devils Group, western Idaho and northeast Oregon: U.S. Geological Survey Bulletin 1437, 58 p.

——— 1995, Petrology of pre-Tertiary igneous rocks in the Blue Mountains region of Oregon, Idaho, and Washington; implications for the geologic evolution of a complex island arc, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington: petrology and tectonic evolution of pre-Tertiary rocks of the Blue Mountains region: U.S. Geological Survey Professional Paper 1438, p. 125–209.

——— 1998, Islands and Rapids: A geologic story of Hells Canyon: Lewiston, Idaho, Confluence Press, Lewis-Clark State College, 151 p.

Vallier, T. L., Brooks, H. C., and Thayer, T. P., 1977, Paleozoic rocks of eastern Oregon and western Idaho, *in* Stewart, J. H., Stevens, C. H., and Fritsche, A. E., editors, Paleozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section: Pacific Coast paleogeography symposium 1, p. 455–466.

Wagner, N. S., and Brooks, H. C., 1962, Marine Jurassic outliers in the Juniper Mountain area of northern Malheur County, Oregon (abstract): The Ore Bin, v. 24, p. 25.

Wagner, N. S., Brooks, H. C., and Imlay, R. W., 1963, Marine Jurassic exposures in Juniper Mountain area of eastern Oregon: Bulletin of the American Association of Petroleum Geologists, v. 47, p. 687–691.

Walker, N. W., ms, 1986, U/Pb geochronologic and petrologic studies in the Blue Mountains Terrane, northeastern Oregon and westernmost-central Idaho; implications for pre-Tertiary tectonic evolution: Santa Barbara, California, University of California, Santa Barbara, Ph. D. thesis, 224 p.

——— 1995, Tectonic implications of U-Pb zircon ages of the Canyon Mountain Complex, Sparta Complex, and related metaplutonic rocks of the Baker Terrane, northeastern Oregon, *in* Vallier, T. L., and Brooks, H. C., editors, Geology of the Blue Mountains region of Oregon, Idaho, and Washington; petrology and tectonic evolution of pre-Tertiary rocks of the Blue Mountains region: U.S. Geological Survey Professional Paper 1438, p. 247–269.

Wernicke, B. P., and Klepacki, D. W., 1988, Escape hypothesis for the Stikine Block: Geology, v. 16, p. 461–464.

Whalen, M. T., 1988, Depositional history of an Upper Triassic drowned carbonate platform sequence; Wallowa Terrane, Oregon and Idaho: Geological Society of America Bulletin, v. 100, p. 1097–1110.

White, D. L., and Vallier, T. L., 1994, Geologic evolution of the Pittsbug Landing area, Snake River Canyon, Oregon and Idaho, *in* Vallier, T. L., and Brooks, H. C., editors, Stratigraphy, Physiography, and Mineral Resources of the Blue Mountains Region: U. S. Geological Survey, Reston, Virginia, U.S. Geological Survey Professional Paper 1439, p. 55–74.

White, J. D. L., 1994, Intra-arc basin deposits within the Wallowa Terrane, Pittsburg Landing area, Oregon and Idaho, *in* Vallier, T. L., and Brooks, H. C., editors, Stratigraphy, Physiography, and Mineral Resources of the Blue Mountains Region: U. S. Geological Survey, Reston, Virginia, U.S. Geological Survey Professional Paper 1439, p. 75–90.

White, J. D. L., White, D. L., Vallier, T. L., Stanley, G. D., Jr., and Ash, S. R., 1992, Middle Jurassic strata link Wallowa, Olds Ferry, and Izee terranes in the accreted Blue Mountains island arc, northeastern Oregon: Geology, v. 20, p. 729–732.

Willett, S., Beaumont, C., and Fullsack, P., 1993, Mechanical model for the tectonics of doubly vergent compressional orogens: Geology, v. 21, p. 371–374.

Wilson, D., and Cox, A., 1980, Paleomagnetic evidence for tectonic rotation of Jurassic plutons in Blue Mountains, eastern Oregon: Journal of Geophysical Research, v. 85, p. 3681–3689.

Wortel, M. J. R., and Spakman, W., 2000, Subduction and slab detachment in the Mediterranean-Carpathian region: Science, v. 290, p. 1910–1917.

Wright, J. E., and Fahan, M. R., 1988, An expanded view of Jurassic orogenesis in the western United States Cordillera; Middle Jurassic (pre-Nevadan) regional metamorphism and thrust faulting within an active arc environment, Klamath Mountains, California: Geological Society of America Bulletin, v. 100, p. 859–876.

Wright, J. E., and Wyld, S. J., 2007, Alternative tectonic model for Late Jurassic through Early Cretaceous evolution of the Great Valley Group, California, *in* Cloos, M., Carlson, W. D., Gilbert, M. C., Liou, J. G., and Sorensen, S. S., editors, Convergent Margin Terranes and Associated Regions: A Tribute to W.G. Ernst: Geological Society of America Special Paper 419, p. 81–95.

Wright, P. J., ms, 2005, Evidence for shear at the contact between the Huntington and Weatherby formations, eastern Oregon: Eugene, Oregon, University of Oregon, B. S. Honors thesis, 45 p.

Wyld, S. J., 2000, Triassic evolution of the arc and back-arc of northwest Nevada, and evidence for extensional tectonism, *in* Soreghan, M. J., and Gehrels, G. E., editors, Paleozoic and Triassic paleogeography and tectonics of western Nevada and northern California: Geological Society of America Special Paper 347, p. 185–207.

——— 2002, Structural evolution of a Mesozoic backarc fold-and-thrust belt in the U.S. Cordillera: new evidence from northern Nevada: Geological Society of America Bulletin, v. 114, p. 1452–1468.

Wyld, S. J., and Wright, J. E., 2001, New evidence for Cretaceous strike-slip faulting in the United States Cordillera and implications for terrane-displacement, deformation patterns, and plutonism: American Journal of Science, v. 301, p. 150–181.

Wyld, S. J., Quinn, M. J., and Wright, J. E., 1996, Anomalous(?) Early Jurassic deformation in the western United States Cordillera: Geology, v. 24, p. 1037–1040.

Wyld, S. J., Rogers, J. W., and Copeland, P., 2003, Metamorphic evolution of the Luning-Fencemaker fold-thrust belt, Nevada: illite crystallinity, metamorphic petrology, and ^{40}Ar/^{39}Ar geochronology: Journal of Geology, v. 111, p. 17–38.

Wyld, S. J., Umhoefer, P. J., and Wright, J. E., 2006, Reconstructing northern Cordilleran terranes along known Cretaceous and Cenozoic strike-slip faults: Implications for the Baja British Columbia hypothesis and other models, *in* Haggart, J. W., Enkin, R. J., and Monger, J. W. H., editors, Paleogeography of the North American Cordillera: Evidence For and Against Large-Scale Displacements: Geological Association of Canada, Special Paper 46, p. 277–298.

Yancey, T. E., and Stanley, G. D., Jr., 1999, Giant alatoform bivalves in the Upper Triassic of western North America: Palaeontology, v. 42, Part 1, p. 1-23.

Zhang, S., Orchard, M. J., and Stanley, G. D., Jr., 2000, Late Triassic conodonts from Martin Bridge Formation, Oregon and Hosselkus Limestone, California: Geological Society of America Abstracts with Programs, v. 32, n. 6, p. 77.