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Mesozoic collision and accretion of oceanic terranes in the Blue Mountains province of northeastern Oregon: New insights from the stratigraphic record

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ABSTRACT

The Blue Mountains Province (BMP) of northeastern Oregon contains Paleozoic-Mesozoic sedimentary and volcanic rocks that formed in a complex convergent-margin setting and later were accreted to the western margin of North America. In this paper we describe a new tectonic model for the BMP that includes: (1) Late Triassic to Early Jurassic Molucca Sea-style collision between the Wallowa and Olds Ferry magmatic arcs, and (2) Early to Late Jurassic collision of previously amalgamated terranes with the North American continent (Papua New Guinea-style terrane-continent collision). This is a significant departure from previous models that interpreted the BMP as the site of non-collisional east-dipping subduction of oceanic crust beneath a west-facing magmatic arc from Late Triassic through Late Jurassic time. Our reinterpretation is based on a synthesis of prior studies that reveals critical provenance links and time-space patterns of deposition and basin migration that were not previously recognized. Comparison of stratigraphic relationships in the BMP with the complex mosaic of active convergent margins in present-day Southeast Asia provides useful insights into plate interactions that may have driven regional crustal deformation and basin evolution in western North America during Triassic and Jurassic time.

INTRODUCTION

Accreted terranes of the Blue Mountains Province (BMP) in northeastern Oregon preserve a record of Mesozoic magmatism, basin formation, sedimentation, and crustal deformation. The BMP is located between similar-age terranes in British Columbia to the north and the Klamath Mountains and northwestern Nevada to the south, and thus contains useful information about Mesozoic crustal evolution of the western North America Cordillera. Our work in the Blue Mountains is focused on stratigraphic and provenance analysis of Triassic and Jurassic sedimentary rocks, and development of new models for the tectonic evolution of Oregon and adjacent areas of the western U.S. Cordillera. According to most existing models for eastern Oregon, a thick succession of Triassic-Jurassic marine sedimentary rocks – commonly known as the Izee terrane – 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 (e.g., Dickinson and Thayer, 1978; Dickinson, 1979, 2004; Brooks and Vallier, 1978; Vallier, 1995). Based on a synthesis of prior studies, we suggest that the Blue Mountains region was instead the site of protracted arc-arc and terrane-continent collision from Late Triassic to Late Jurassic time. This interpretation employs the reconstruction of Wyld and Wright (2001), which restores northeast Oregon to the latitude of northwest Nevada prior to Cretaceous time. In this paper we illustrate and summarize key aspects and regional implications of our new tectonic model, which is presented in more detail by Dorsey and LaMaskin (2007).

Geologic and Stratigraphic Overview

Rocks of the Blue Mountains Province (BMP) are traditionally divided into four terranes (Fig. 1): (1) Middle to Late Triassic volcanic rocks of the Olds Ferry terrane, which is correlated to the Quesnel terrane in British Columbia and

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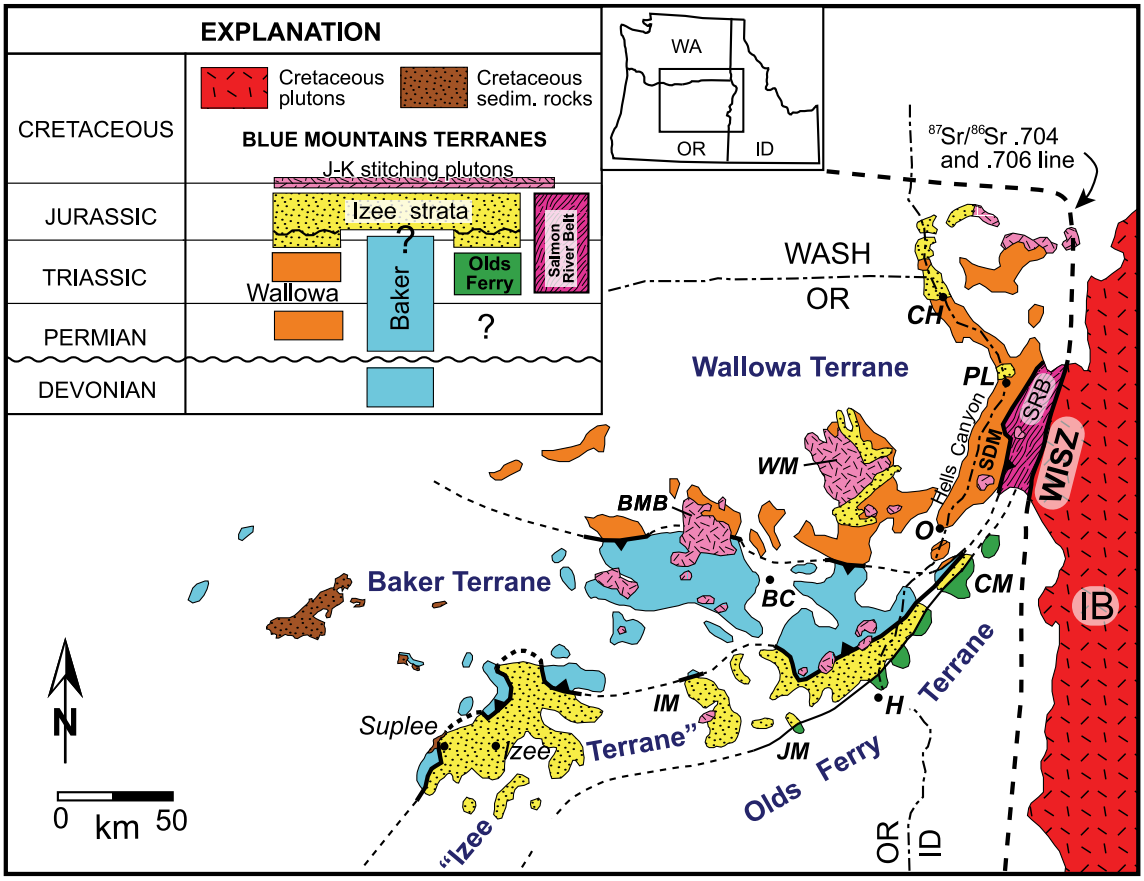

Figure 1. Simplified geologic of the Blue Mountains Province showing pre-Cenozoic geology, modified from Dorsey and LaMaskin (2007). White areas represent Cenozoic rocks and deposits. BC, Baker City; BMB, Bald Mountain batholith; H, Huntington; IB, Idaho Batholith; IM, Ironside Mountain; JM, Juniper Mountain; O, Oxbow; PL, Pittsburg Landing; CM, Cuddy Mountains; CH, Coon Hollow; SDM, Seven Devils Mountains; SRB, Salmon River belt; WM, Wallowa Mountains and Wallowa batholith; WISZ, Western Idaho Shear Zone.

the Cordilleran fringing-arc system in western Nevada and eastern California (Oldow et al., 1989; Wyld and Wright, 2001; Gray and Oldow, 2005); (2) the Baker terrane, a wide belt of sheared Permian to Early 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 (Bishop, 1995a; 1995b; Ferns and Brooks, 1995; Vallier, 1995); (3) Permian to early Jurassic volcanic and sedimentary rocks of the Wallowa terrane, which record evolution of an intraoceanic island arc system and change to clastic input from the Baker terrane (Vallier, 1977, 1995; Follo, 1986, 1992, 1994); and (4) the Izee terrane, a thick succession of Triassic and Jurassic sedimentary rocks that locally rest in depositional contact on older rocks of the other 3 terranes (Dickinson and Thayer, 1978; Brooks and Vallier, 1978; Dickinson, 1979). When corrected for post-Jurassic clockwise rotation, terranes of the BMP restore to an approximately N-S orientation (Wilson and Cox, 1980; Hillhouse et al., 1982; Oldow et al., 1984, 1989; Housen, 2007).

Figure 2 is a simplified time-stratigraphic diagram, constructed from data in Dorsey and LaMaskin (2007), for Triassic and Jurassic deposits of the BMP. We divide volcanic and sedimentary rocks into two unconformity-bounded megasequences (Fig. 2): (1) MS-1, Late Triassic to Early Jurassic strata, which change up-section from (1a) volcanic and volcaniclastic rocks to (1b) marine argillite and turbidites with chert-bearing conglomerate and olistostromes derived from the Baker terrane; and (2) MS-2, Early to Late Jurassic marine deposits that overlie older rocks along a major angular unconformity and record ~20-40 m.y. of deep subsidence in a large marine basin. Megasequences are regional-scale 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 et al., 1999; Burton-Ferguson et al., 2005; Krézsek and Bally, 2006). Regional stratigraphic subdivisions of this type provide a useful tool for interpreting genetically related stratal packages and their bounding unconformities.

A distinguishing characteristic of Megasequence 1 is the presence of chert clast-bearing sandstone and conglomerate in Late Triassic marine deposits of the southern Wallowa Mountains and Izee area (Figs. 1, 3). In the southern Wallowa

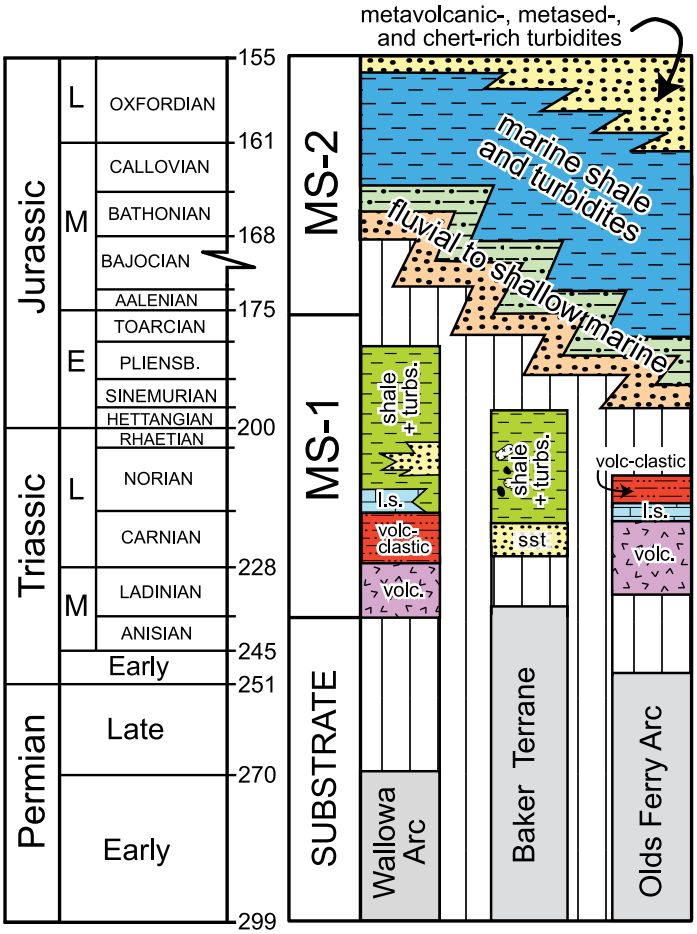

Figure 2. Simplified chronostratigraphy of Triassic and Jurassic rocks in the Blue Mountains, based on compilation of previous studies (references in Dorsey and LaMaskin, 2007). MS-1, megasequence 1; MS-2, megasequence 2.

Mountains, MS-1 changes up section from Ladinian to Carnian volcanic and volcaniclastic rocks (Wild Sheep Creek and Doyle Creek formations), through the Norian Martin Bridge Limestone, to Norian – Early Jurassic marine shale and fine-grained turbidites (Hurwal Formation) with interbedded conglomerate that contains rounded clasts of chert, marble, and plutonic and metamorphic rocks derived from the Baker terrane (Figs. 3, 4; Follo, 1986, 1992, 1994). In the Izee area, MS-1 includes Late Triassic marine argillite, turbidites, chert-clast sandstone and conglomerate, and submarine breccias and olistostromes of the Vester and Fields Creek formations, which accumulated in tectonically active sub-basins during thrusting, uplift and erosion in the nearby Baker terrane (Dickinson and Thayer, 1978; Dickinson, 1979).

Jurassic deposits of megasequence 2 make up a regionally extensive overlap assemblage that displays a time-transgressive up-section change from fluvial and shallow-marine deposits, through deep marine mudstone and flysch, to upward-coarsening sandy turbidites that contain volcanic, metavolcanic, metasedimentary and cherty petrofacies (Fig. 5; Dickinson and Thayer, 1978; Dickinson et al., 1979;

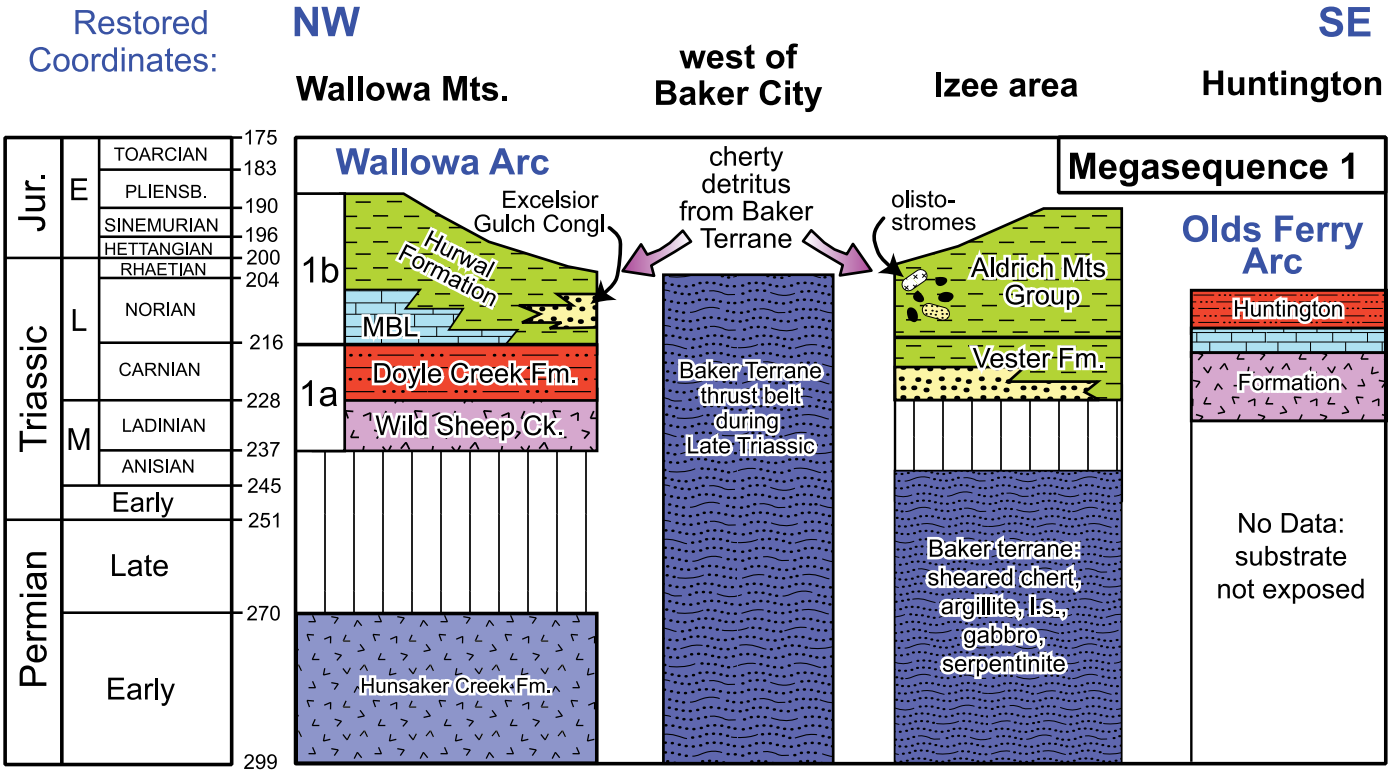

Figure 3. Chronostratigraphic diagram for volcanic and sedimentary rocks of megasequence 1, based on compilation of previous studies (references in Dorsey and LaMaskin, 2007). Patterns represent same lithologies as in Figure 1, or as indicated here.

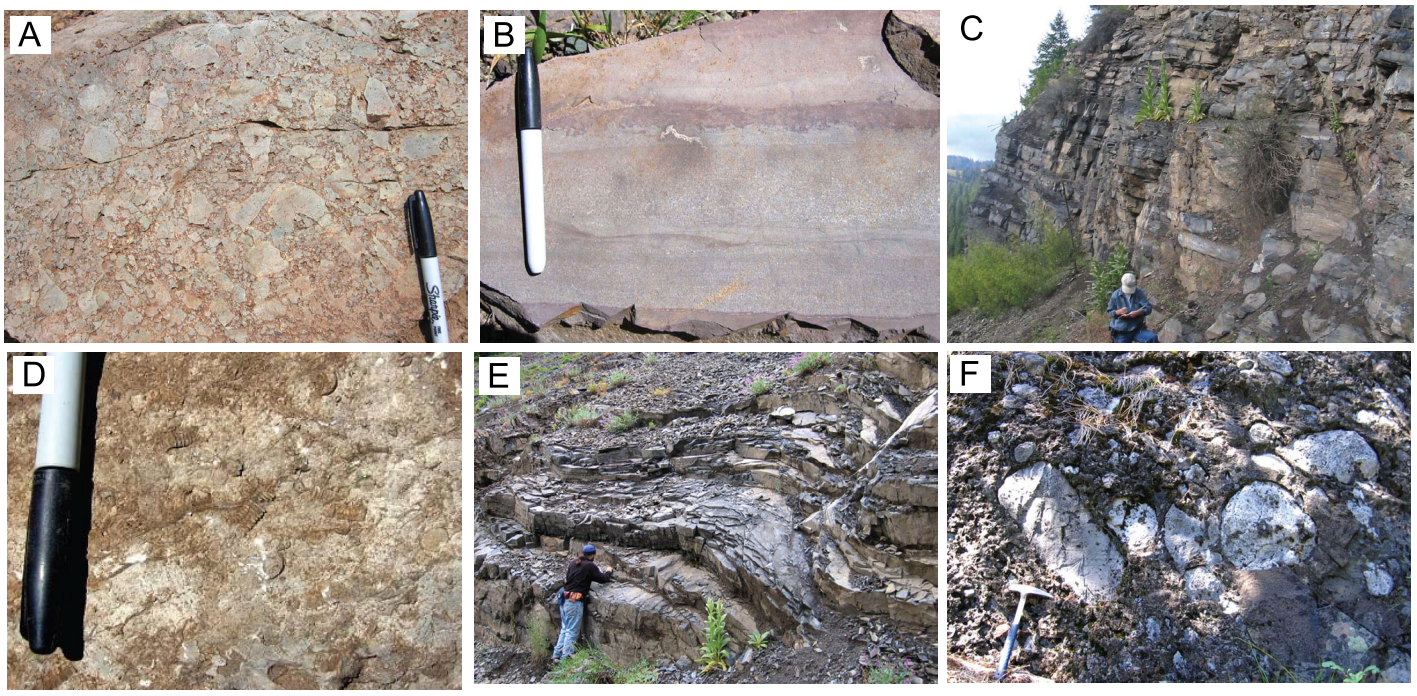

Figure 4. Photographs of megasequence 1 rocks in the southern Wallowa Mts. A. Volcanic breccia of the Wild Sheep Creek Formation (local name is Gold Creek Greenstone). B. Graded fine-grained turbidites of the Doyle Creek Formation. C. Well-bedded carbonate turbidites in the basinal facies of the Martin Bridge Limestone. D. Close-up of crinoid debris and other shallow marine faunas in platform facies of the Martin Bridge Limestone. E. Shale, argillite and thin-bedded turbidites of the Hurwal Formation. F. Submarine conglomerate in Excelsior Gulch Conglomerate of the Hurwal Formation. Ages of units shown in Figure 3.

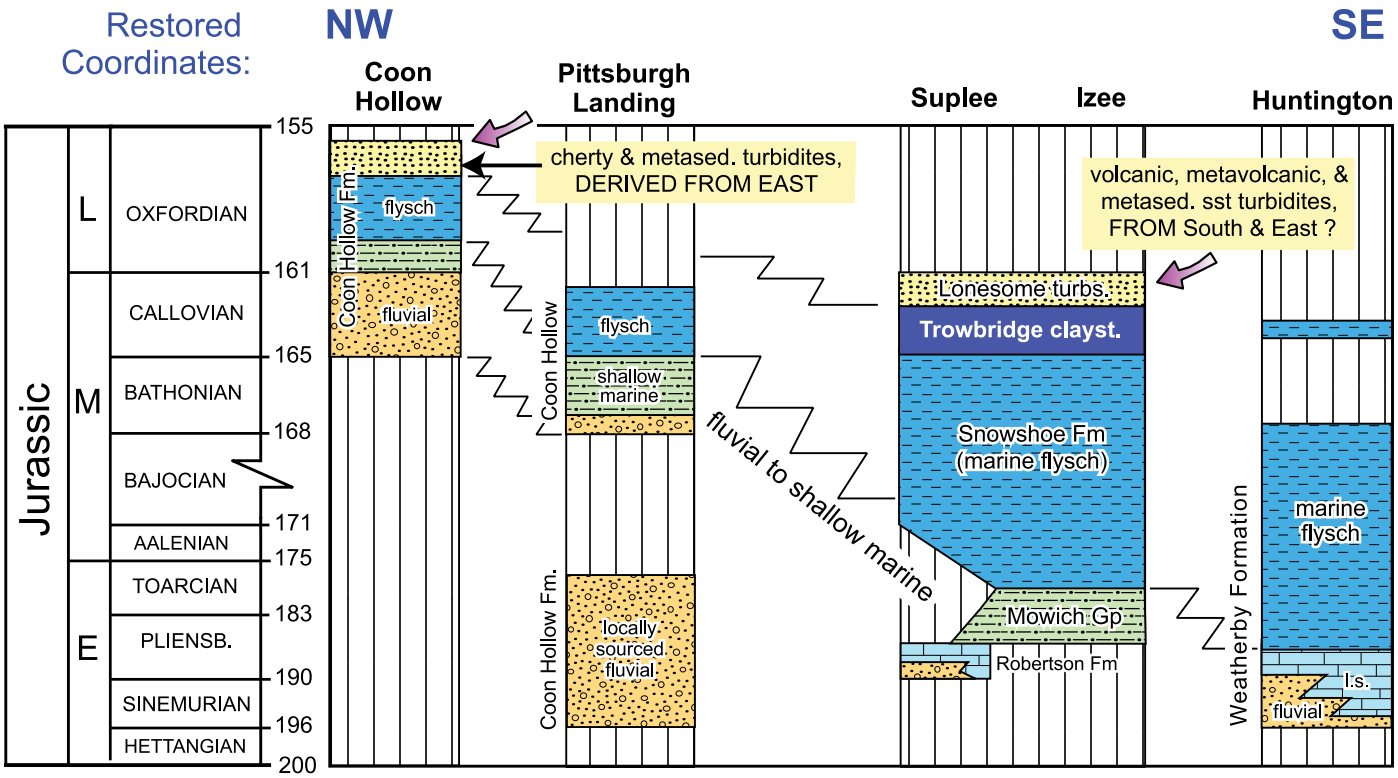

Figure 5. Chronostratigraphic diagram for megasequence 2 deposits, based on compilation of previous studies (references in Dorsey and LaMaskin, 2007). Patterns represent same lithologies as in Figure 1, or as indicated here.

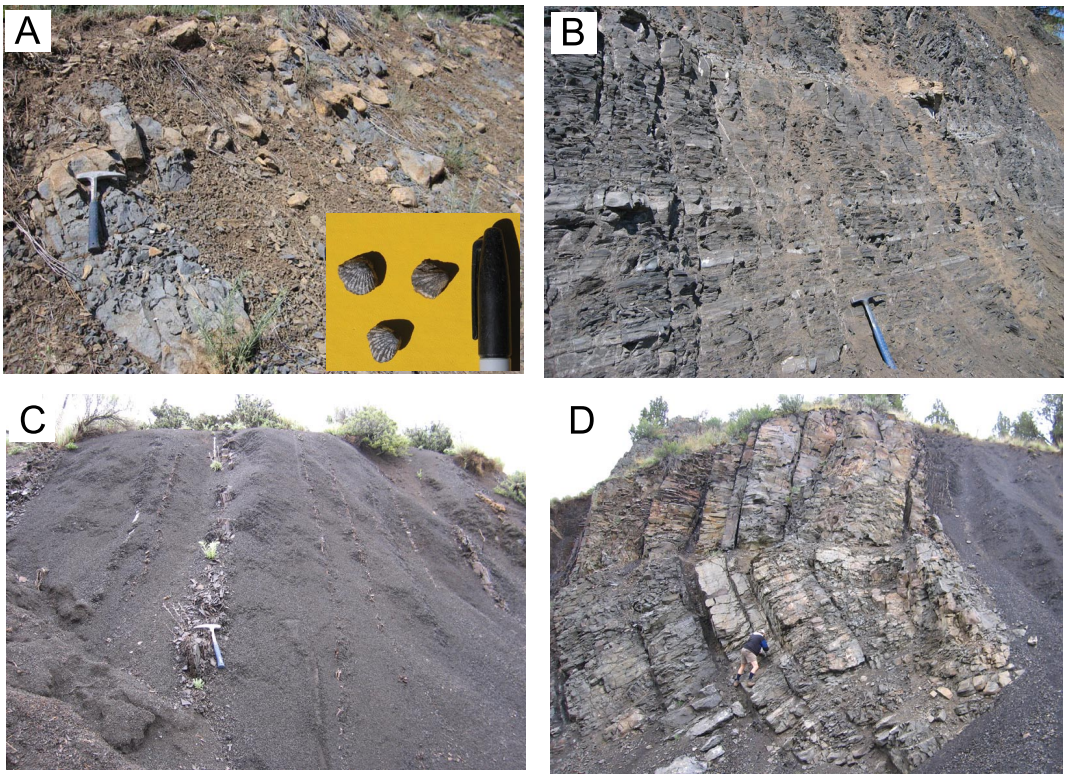

Figure 6. Photographs of megasequence 2 deposits in the Izee-Suplee area. A. Shallow marine sandstone of Suplee Formation (lower unit of Mowich Group), inset shows close-up of articulated brachiopods. B. Thin-bedded turbidites of the Snowshoe Formation. C. Sediment-starved marine clay-shale of the Trowbridge Formation. D. Thick-bedded sandy turbidites in the Lonesome Formation. Ages of units shown in Figure 5.

Goldstrand, 1987, 1994). This succession is well displayed in the Izee area (Fig. 6), where MS-2 is about 5 km thick and shows an up-section change to NW-directed paleocurrents in the upper sandy turbidites (Lonesome Formation) (Dickinson and Thayer, 1978). In the Coon Hollow area along the Snake River, upper turbiditic sandstone and pebble conglomerate of MS-2 contain abundant chert and metasedimentary clasts, with paleocurrents that indicate input from an orogenic highland to the southeast (Goldstrand, 1987, 1994). The large thickness of MS-2 deposits provides evidence for deep subsidence of previously eroded and deformed older terranes beneath a regionally extensive marine basin.

NEW TECTONIC MODEL FOR THE BLUE MOUNTAINS PROVINCE

Based on a compilation of existing data, we propose a new tectonic model for the BMP that includes: (1) Middle Triassic subduction and related magmatism in the Wallowa and Olds Ferry arcs; (2) Late Triassic collision (amalgamation) between facing accretionary wedges of the two arcs, and growth of flexural basins on opposite flanks of a doubly-vergent Baker terrane thrust belt; (3) Early to Late Jurassic growth of a large marine basin due to thrust loading in the Cordilleran thrust belt to the east, during protracted collision between the amalgamated BMP terranes and western North America; and (4) Latest Jurassic thrusting, tectonic burial, and metamorphism of the Jurassic basinal rocks during final accretion of the BMP terranes to North America (Dorsey and LaMaskin, 2007). This model employs the reconstruction of Wyld and Wright (2001), in which the BMP was located outboard of NW Nevada during Triassic and Jurassic time, and later was translated northward into its present position by offset on Cretaceous dextral strike-slip faults. Below we describe and illustrate the two main collisional stages (2 and 3, above) with comparison to modern analogs.

Late Triassic arc-arc collision (MS-1). Stratigraphic data summarized above provide a record of Middle Triassic subduction-related volcanism in the Wallowa and Olds Ferry arcs (MS-1a), followed by Late Triassic to Early Jurassic growth of a large thrust belt in the Baker terrane and deposition of turbidites and chert clast-bearing conglomerate in marine basins on opposite flanks of the thrust belt (MS-1b) (Fig. 3). Syn-tectonic deposits accumulated on crust of the Wallowa arc on the north side of the thrust belt (west side in restored coordinates) and the Olds Ferry arc on the south side (east side in restored coordinates). These relationships provide evidence for collision of the facing accretionary wedges of the Wallowa and Olds Ferry arcs, similar to modern arc-arc collision in the Molucca Sea (Fig. 7; Silver and Smith, 1983; Hamilton, 1988; Hall, 2000; Lallemand et al., 2001). It is important to note that arc-arc collision necessarily begins in the facing accretionary wedges, and the resulting crustal deformation is predicted to include significant crustal thickening and horizontal shortening of the forearc regions. We suggest that the Late Triassic Baker terrane thrust belt was thicker and larger than the doubly-vergent thrust belt seen in the present-day Molucca Sea, and that the large crustal thickness resulted in significant uplift, erosion, and delivery of coarse clastic sediments into the flanking marine basins (Fig. 7; Dorsey and LaMaskin, 2007).

Jurassic terrane-continent collision (MS-2). The change to megasequence 2 requires a major change in geom-

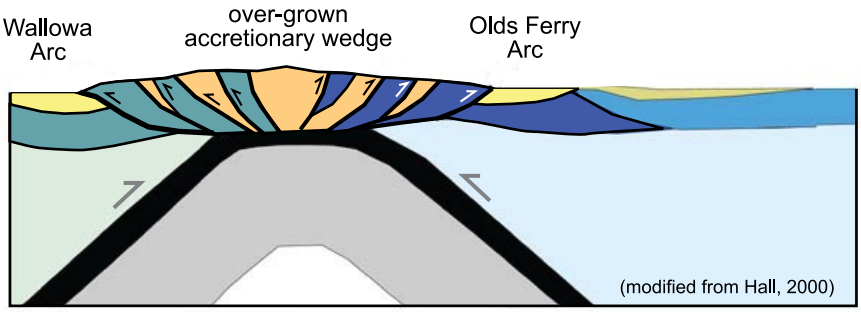

Figure 7. Interpretive diagram showing interpretation of doubly-vergent thrust belt produced by Late Triassic to Early Jurassic arc-arc collision in the Blue Mountains, based on analogy to the modern Molucca Sea (modified from Hall, 2000).

etry, tectonic setting, and subsidence mechanism in the Blue Mountains. Any tectonic model for the Jurassic must explain: (1) overlap of MS-2 deposits onto previously amalgamated and deformed rocks of the Wallowa, Baker, and Olds Ferry terranes; (2) at least 5 km of crustal subsidence in the Jurassic marine basin; and (3) systematic westward migration (in restored coordinates) of sedimentary facies that record transgression and deepening followed by progradation of easterly derived low-grade metamorphic detritus (Fig. 5). Restoring the BMP to the latitude of NW Nevada (Wyld and Wright, 2001), these relationships can be explained by growth of a large marine basin in front of an advancing thrust load during protracted collision of the amalgamated terranes with the western margin of North America. We therefore infer that Jurassic strata accumulated in a large collisional basin that migrated to the west in response to crustal loading and convergence in the western part of a doubly-vergent thrust belt located to the east (Fig. 8; Dorsey and LaMaskin, 2007). This is consistent with evidence for a large orogenic mountain belt in Nevada (Cordilleran thrust belt) that drove eastward migration of the Utah-Idaho Trough foreland basin during Jurassic time (Oldow, 1984; Jordan, 1985; Bjerrum and Dorsey, 1995; Allen et al., 2000; Wyld, 2002; Wyld et al., 2003).

We suggest that Jurassic terrane-continent collision in western North America produced a major phase of crustal shortening in the Cordilleran thrust belt that preceded and was unrelated to the Cretaceous phase, which took place at an Andean-type convergent margin. The Jurassic episode was similar in many respects to terrane-continent collision that is presently taking place in Papua New Guinea (Fig 9a; Cooper and Taylor, 1987; Pigram and Davies, 1987; Pigram and Symonds, 1991; Abbott et al., 1994; Abbott, 1995; Cloos et al., 2005). Using this analogy we can correlate three main tectonic elements: (1) the modern Papuan foredeep, which is formed by flexural subsidence on continental crust of northern Australia, provides a modern analog for the Jurassic Utah-Idaho Trough foreland basin; (2) the modern PNG highlands thrust belt is analogous to the Jurassic Cordilleran thrust belt; and (3) the marine basin north of Papua New Guinea today is similar to the marine collisional basin that formed in eastern Oregon during Jurassic time (Fig. 9b). The Jurassic setting of western North America was somewhat different because it involved collision of oceanic terranes with a continent-fringing magmatic arc and backarc basin, rather than a passive continental margin as seen in present-day PNG. However, the driving processes of collisional tectonics, doubly-vergent mountain building, crustal loading, and resultant formation of flanking flexural foredeep basins, are the same.

CONCLUSIONS

A synthesis of existing stratigraphic data from Triassic and Jurassic rocks in NE Oregon provides evidence for a history of protracted, multi-stage collisional tectonics that has not been recognized in previous studies. The two main stages of this history are: (1) Late Triassic to Early Jurassic collision of

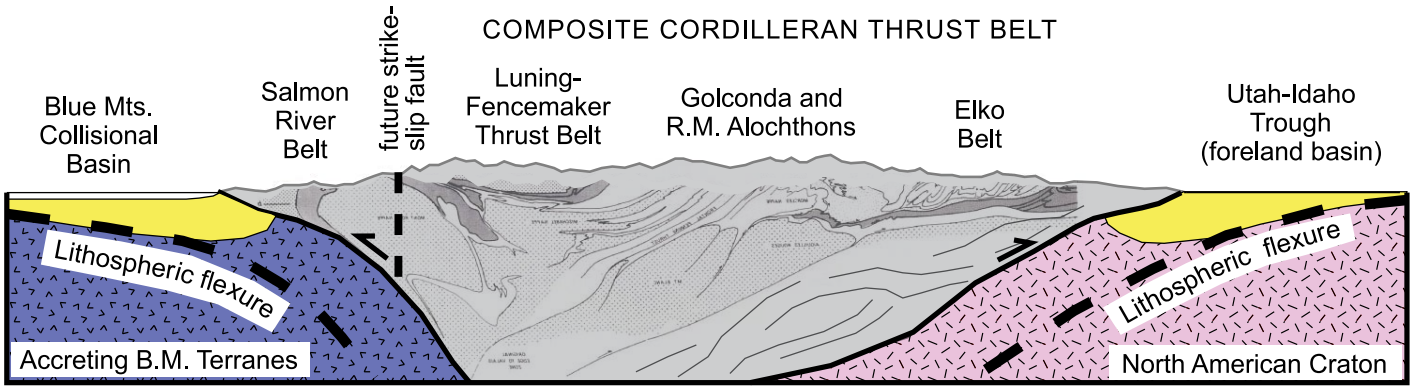

Figure 8. Proposed model for Jurassic terrane-continent collision in the northwestern U.S. Cordillera, based on analogy to the Cenozoic Alpine system (Coward and Dietrich, 1989). Using the pre-Cretaceous reconstruction of Wyld and Wright (2001), we restore NE Oregon to the latitude of NW Nevada during Jurassic time.

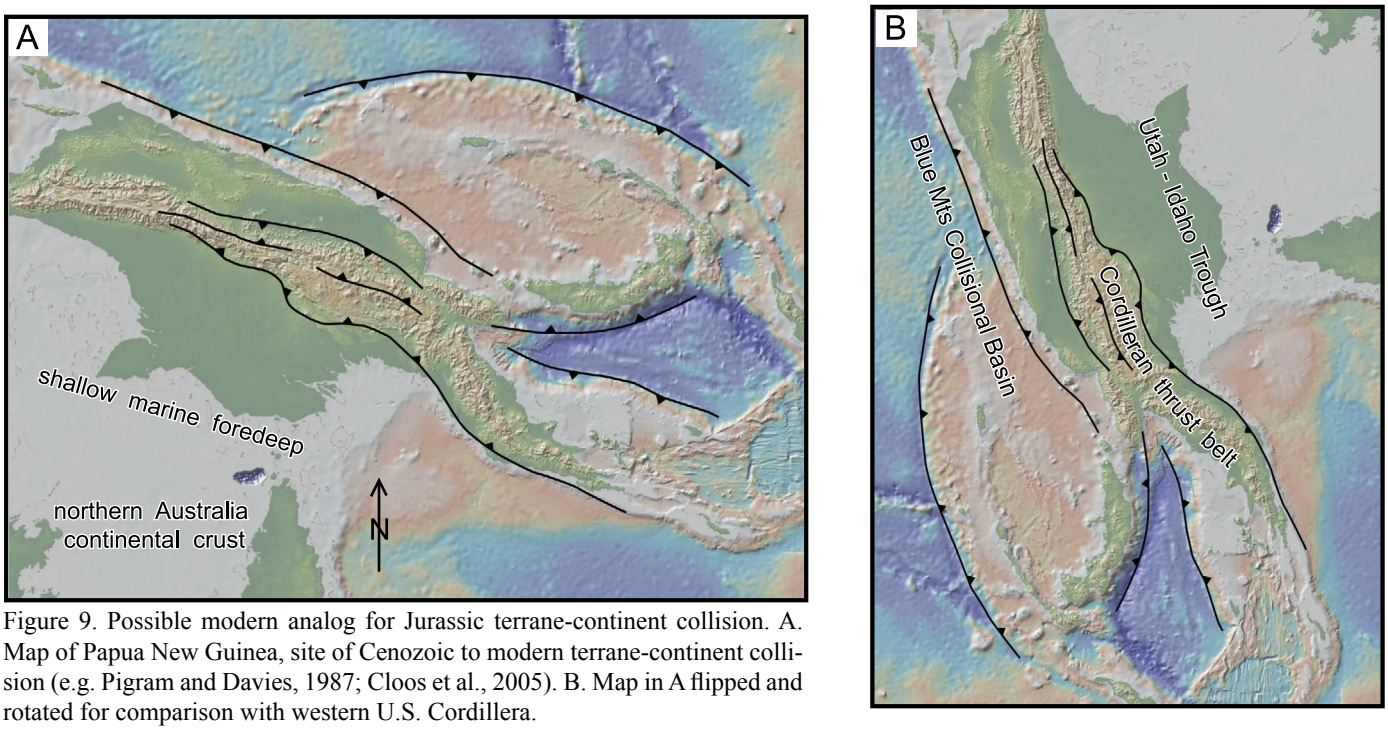

Figure 9. Possible modern analog for Jurassic terrane-continent collision. A. Map of Papua New Guinea, site of Cenozoic to modern terrane-continent collision (e.g. Pigram and Davies, 1987; Cloos et al., 2005). B. Map in A flipped and rotated for comparison with western U.S. Cordillera.

the facing accretionary wedges of the Wallowa and Olds Ferry magmatic arcs, growth of a large doubly-vergent thrust belt in the Baker terrane, and related evolution of marine basins on both the west and east flanks (in restored coordinates) of the thrust belt (Fig. 7); and (2) Jurassic collision of the amalgamated terranes with the western margin of North America, and growth of a large foredeep basin in the Blue Mountains that migrated to the west in response to crustal thickening, loading, and advance of the Cordilleran thrust belt in Nevada (Fig. 8). We have identified modern analogs for both collisional stages, in the Molucca Sea (arc-arc collision) and Papua New Guinea (terrane-continent collision). We therefore suggest that collisional tectonics may have played a significant role in lithospheric processes that drove mountain building and basin evolution in the northwestern U.S. during Late Triassic and Jurassic time. The Jurassic collisional margin may have changed along strike to the south, to an Andean-type subduction margin in the southwestern U.S. This idea needs to be tested in future work.

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