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Stratigraphy of the Triassic Martin Bridge Formation, Wallowa terrane: Stratigraphy and depositional setting

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ABSTRACT

The Upper Triassic (Carnian–Norian) Martin Bridge Formation of northeastern Oregon, southeastern Washington, and western Idaho is characterized by rapidly shifting depositional processes within a tropical volcanic island arc setting. Martin Bridge sequences in the Hells Canyon and northern Wallowa Mountains document shallow-water peritidal evaporitic sediments that are succeeded by deeper and predominantly subtidal deposits. This indicates drowning of the carbonate platform and a transition to deeper-water turbiditic sedimentation before a late Triassic transition into the overlying mid-Norian to Jurassic Hurwal Formation. At the type locality in the southern Wallowa Mountains, dysaerobic shales, carbonate debris sheets, and turbiditic sediments indicate distal slope and basinal environments while other facies at other sites in the Wallowa Mountains and Hells Canyon area s indicate reef and shallow-water platform settings.

In this paper we formally recognize the name Martin Bridge Formation and reinstate the type locality in the southern Wallowa Mountains as the principal unit stratotype. An additional reference section is given at Hurricane Creek in the northern Wallowa Mountains. The Martin Bridge is formally divided into four members: the Eagle Creek and Summit Point Members are introduced and formally proposed herein and the BC Creek and Scotch Creek Members also are elevated to formal status.

A partial reconstruction of the Wallowa terrane during deposition of the Martin Bridge Formation suggests a north-south (or northeast-southwest) trending platform margin facing a forearc basin situated to the east (or southeast). The lithofacies and paleontological characteristics of the Martin Bridge can be put into the framework of a deposition and a tectonic model to help better explain many of the stratigraphic and

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paleontologic problems previously encountered. We believe that the Wallowa terrane provides one of the best and most complete examples yet known for shallow-water carbonate depositional patterns in an oceanic island arc setting.

Keywords: Triassic, Wallowa, Oregon, stratigraphy, paleontology.

INTRODUCTION

The Martin Bridge Formation is the only conspicuous Triassic limestone unit exposed in northeastern Oregon and adjacent Idaho. It is part of a thicker late Paleozoic to early Mesozoic volcanic and sedimentary succession called the Wallowa terrane (Silberling and Jones, 1984). The Wallowa terrane is one volcanic island arc and related sedimentary rock assemblage separated from another island arc, the Olds Ferry terrane (Brooks and Vallier, 1978), by the intervening Baker terrane, which represents a subduction mélange complex (Mullen, 1985). Together these tectonostratigraphic terranes constitute part of the Blue Mountains Region of northeast Oregon, southeast Washington, and western Idaho (Fig. 1). In late Mesozoic time, these terranes amalgamated and by Cretaceous time were accreted to the North American craton. They share few stratigraphic relationships with coeval Permian and Triassic rocks on the craton (Dickinson and Thayer, 1978; Vallier and Brooks, 1986) but have been compared with Wrangellia and other island arc terranes in the North American Cordillera (Jones et al., 1977; Mortimer, 1986). This tectonic model and the related rock types are quite different from those developed for cratonal sequences and are more comparable to modern-day western Pacific island arcs and associated oceanic crust (Brooks and Vallier, 1978; Follo, 1992).

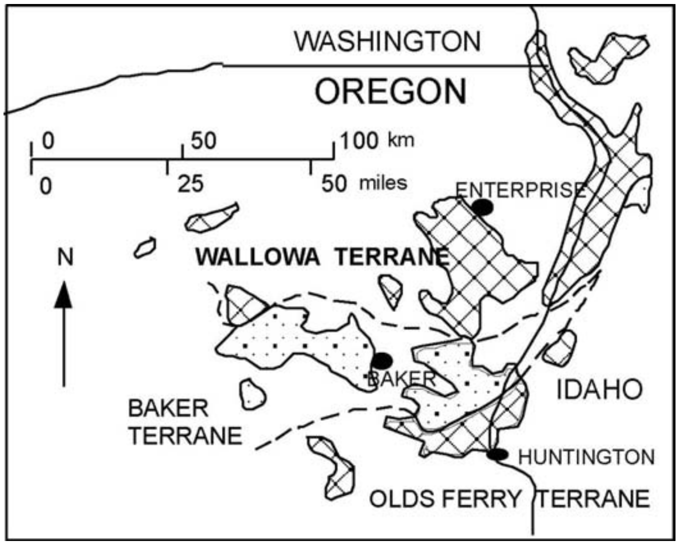

Figure 1. Generalized map showing three principal terranes in the Blue Mountains Region. Cross-hatch—island arc; stipple—subduction mélange.

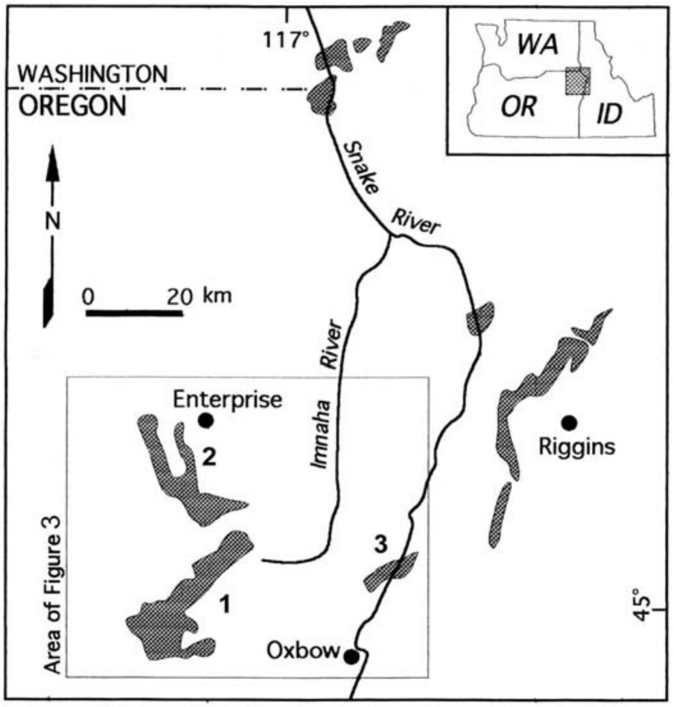

Figure 2. Index map showing the outcrop pattern of the Martin Bridge Formation and the various regions discussed in the text (modified from Brooks and Vallier, 1978). 1—southern Wallowa Mountains; 2—northern Wallowa Mountains; 3—Hells Canyon and Seven Devils Mountains.

The Wallowa terrane is now known to represent an Early Permian to Late Triassic volcanic island arc mantled by a cover of Mesozoic sediment. Initiation of a tropical carbonate platform, represented by the Martin Bridge Formation, began in Late Triassic (late Carnian) time. By the early Norian, a steep-sided, shallow-water platform with protected lagoons and a shelf margin of carbonate sand shoals and coral-sponge-algal patch reefs developed. The platform-to-basin transition is marked downslope by an abrupt facies change to coarse-grained gravity-flow breccia, conglomerate and other slope deposits, which laterally grade into deep-water starved-basin facies (Follo, 1992). This transition from platform to slope and basinal facies is one of the best documented examples of a platform-basin transition in any Cordilleran terrane.

Emplacement of the Wallowa batholith and subsidiary satellites during Late Jurassic and Early Cretaceous time (Armstrong et al., 1977) altered the country rocks and obscured many stratigraphic relationships. Early Mesozoic tectonic events deformed pre-batholith rocks (Nolf, 1966; Follo, 1986; Mirkin, 1986) and Tertiary uplifts resulted in erosion of much of the early Mesozoic rocks. Finally, the Neogene eruption of Columbia River basalt covered and deeply buried much of the Wallowa terrane and restricted exposures to three main regions: (1) the southern Wallowa Mountains, near Halfway, Oregon, (2) the northern Wallowa Mountains, near Enterprise, Oregon, and (3) portions of Hells Canyon and Seven Devils Mountains on the Oregon-Idaho border where the Snake River cuts through the overlying Columbia River basalt (Fig. 2). Other areas where the Wallowa terrane is exposed include metamorphosed rocks west of Riggins and exposures at Pittsburg Landing and adjacent areas, near the Washington, Oregon, Idaho borders (Fig. 2).

The Martin Bridge Formation is a well-known and distinctive unit in the succession of the Wallowa terrane and it remains one of the best studied and dated early Mesozoic shallow-water sequences in North America. Ranging from the Carnian through Norian stages of the Upper Triassic, intervals within the Martin Bridge display a relatively complete succession containing ammonoids, conodonts, and flat clams belonging to the genus *Halobia*. The carbonate rocks have been compared with other Carnian–Norian carbonate sequences such as those found in Wrangellia (Jones et. al., 1977).

This paper focuses on the Martin Bridge and synthesizes biostratigraphic and sedimentologic data to improve correlations and better interpret its history and paleogeography. The principal areas to be discussed are presented in Figure 3. Our purpose is to reconcile some of the stratigraphic problems, formalize some of the units, and offer a concept of a Martin Bridge stratotype that is both intellectually acceptable in the context of depositional processes and operational in the sense of a practical stratigraphy.

TECTONOSTRATIGRAPHIC SETTING

The Martin Bridge Formation is part of the ~8-km-thick Lower Permian to Upper Jurassic sequence of volcanic and sedimentary rocks of the island arc referred to as the Wallowa terrane. It is best exposed in northeastern Oregon, western Idaho, and southeastern Washington (Fig. 2). Although the outcrops of the Martin Bridge are small in extent and scattered, it is important to remember that the Wallowa terrane was not a single volcanic edifice but a series of volcanic island groups within an island arc. Furthermore it is not an isolated terrane but is complexly associated with four other tectonostratigraphic terranes of the Blue Mountains Province (Fig. 1). These terranes amalgamated during the Jurassic, prior to Cretaceous accretion to the North American craton (Brooks and Vallier, 1978; Silberling and Jones, 1984).

The Martin Bridge Formation contains diverse carbonate and argillaceous rock types that represent patch reefs, platform shoals, restricted peritidal basins, lagoons, slope deposits, and basinal rocks. All of these were deposited within an island arc setting following the abrupt cessation of volcanism (Stanley, 1986; Stanley and Senowbari-Daryan, 1986; Whalen, 1988; Follo, 1994). The diverse shallow-water invertebrate fauna of calcareous algae, sponges, spongiomorphs, corals, and bivalves (Newton, 1986; Stanley, 1986; Stanley and Senowbari-Daryan, 1986; Newton et al., 1987; Senowbari-Daryan and Stanley, 1988; Stanley and Whalen, 1989), together with the thick carbonate rocks of the Wallowa terrane, provides evidence of a tropical setting. Evidence of carbonate deposition and tropical marine fauna is corroborated by paleomagnetic results indicating Triassic paleolatitudes of 18°–24° (±4°) north or south of the equator (Hillhouse et al., 1982; May and Butler, 1986). Although Newton (1983) and Malmquist (1991) favored a paleoposition in the Southern Hemisphere, Stanley and Vallier (1992) supported a location in the Northern Hemisphere on the basis of Permian paleolatitudes derived from paleomagnetic investigations of Harbert et al. (1988).

The Late Triassic paleolongitudinal positions of the tropical Wallowa terrane relative to North America are even more equivocal. Studies of early Norian silicified faunas from Hells Canyon yield conflicting results. Shallow-water bivalves, for example, indicate that the Wallowa terrane was in the eastern Pacific and close enough to the craton to allow exchange with cratonal faunas (Newton, 1987, 1988; Malmquist, 1991), but sponges, scleractinian corals, and spongiomorphs revealed some endemic elements with no links to the craton and strong Tethyan connections, suggesting that a substantial body of ocean lay between the Wallowa terrane and the North American craton (Senowbari-Daryan and Stanley, 1988; Stanley and Whalen, 1989; Stanley and Yancey, 1990; Stanley and Vallier, 1992). Follo (1992, p. 1572) believed that an eastern Pacific site for Wallowa would make it

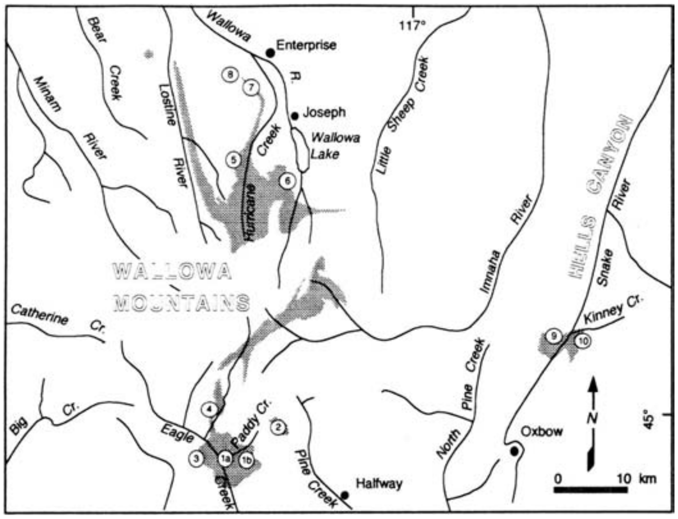

Figure 3. Locality map showing outcrop pattern (stippled) of Martin Bridge Formation and metamorphosed equivalents (modified from Follo, 1986). Localities discussed in text: 1a and 1b—principal stratotype at Eagle and Paddy Creeks; 2—Summit Point Member stratotype; 3—Torchlight Gulch; 4—East Eagle Creek near Bradley Mine; 5—reference section at Hurricane Creek; 6—BC Creek stratotype at Chief Joseph Mountain; 7—Scotch Creek Member stratotype; 8—Black Marble Quarry; 9—Spring Creek; 10—Kinney Creek .

geometrically difficult to account for the large amounts of northward displacement and extensive oblique convergence indicated for the Wallowa terrane between Triassic time and accretion to North America at the end of the Early Cretaceous. On the other hand, May and Butler (1986) suggest there has been little or no northward displacement of Wallowa in relation to the craton since the Late Triassic, but during this time, North America had been moving northward from Pangea.

Compared with other terranes in Canada and Alaska, the Wallowa terrane is a relatively small tectonic fragment and it has been suggested that it might correlate with larger terranes further North. To what larger parent might the orphaned Wallowa terrane belong? The Wallowa terrane was originally interpreted as a southern extension of Wrangellia on the basis of paleolatitude and similarity of the general stratigraphic successions (Jones et al., 1977). Subsequently, a range of volcanic rock types and paleontological evidence based on silicified Late Triassic corals has been used to recognize a distinction between the Wallowa terrane and Wrangellia (Sarewitz, 1983; Mortimer, 1986; Stanley, 1986; Whalen, 1988). Studies of some silicified gastropods from the Wallowa terrane, on the other hand (Blodgett et al., 2001; Frýda et al., 2003; Nützel et al., 2003), show some endemic taxa and paleogeographic linkage with Alaskan Wrangellia as well as parautochthonous rocks in Peru but indicate less similarity with most other terranes of North America.

By Middle Jurassic (Bajocian) time, coral and bivalve faunas from the Wallowa terrane show stronger links to the Western Interior Embayment of the craton (Stanley and Beauvais, 1990). In conjunction with paleobotanical findings (Ash, 1991a, 1991b), these data suggest that by the Middle Jurassic the Wallowa terrane was closer to North America and in its northward journey, moving out of the Tropics into temperate paleolatitudes (Stanley and Beauvais, 1990; White et al., 1992).

CORRELATIONAL AND NOMENCLATURAL PROBLEMS

Since the first description of the Martin Bridge Formation, conceptual and nomenclatural misunderstandings have plagued stratigraphers. Without designating a stratigraphic name, Smith (1912) described a partial stratigraphic sequence of Upper Triassic limestone, limy shales, and associated invertebrate fossils near the confluence of Paddy and Eagle Creeks at Martin's Bridge in the southern Wallowa Mountains. Smith (1912) discussed these fossils in the context of reef development and recognized the presence of corals, the flat bivalve *Halobia*, and ammonoids similar to taxa from central Europe. Later Smith (1927) described a more detailed stratigraphic section containing Carnian to Norian fossils. The term "Martin Bridge" first appeared in an International Geological Congress guidebook by Chaney (1932) and was used not only for limestone but also for a variety of rock types including shale, basalt, andesite, and tuff. At nearly the same time, Gilluly et al. (1933, p. 12, citing work in preparation by C.P. Ross), without defining a type section, designated the Martin Bridge in the Wallowa Mountains as "1000 to 3000 feet of limestone, limy shale, and interbedded volcanic rocks of Upper Triassic age."

Subsequently, Ross (1938, p. 32) used the name Martin Bridge Formation for rocks in the southern Wallowa Mountains. He described characteristic rock types and well-preserved and abundant fossils, and designated a type section at Smith's (1912, 1927) locality near Martin Bridge (a bridge once existing near the confluence of Eagle and Paddy Creeks). Because Smith (1912) did not designate a name, Ross (1938) must be regarded as the original author for the Martin Bridge Formation.

With little reference to the section in the southern Wallowa Mountains, Smith and Allen (1941, p. 10) defined the Martin Bridge on the basis of stratigraphic sections at Hurricane Creek and the Upper Imnaha River drainage in the northern Wallowa Mountains as 200–2000 ft of "grey to black, crystalline limestone, which toward the top is both intercalated with and grades into the argillaceous Hurwal Formation." Their definition and scope of the Martin Bridge clearly establishes it as a prominent rock type composed of limestone and marble that overlies the informally named "Lower Sedimentary Series." The latter is a structurally and petrographically complex volcanic and sedimentary unit regarded as part of the Clover Creek Formation by Nolf (1966) and subsequent workers. According to Smith and Allen (1941), the Martin Bridge is identified as the first prominent limestone unit above the "Lower Sedimentary Series." As Nolf (1966, p. 56) pointed out, a strict application of this definition of the Martin Bridge would be impossible to apply in the southern Wallowa Mountains, where several prominent limestone beds occur in both the Martin Bridge and the overlying Hurwal Formations.

Other inconsistencies have occurred in the nomenclature and concept of this formation. Hamilton (1963) introduced the name "Martin Bridge Limestone" for metamorphosed limestone exposed in the Riggins Region of western Idaho. Following Hamilton's lead, Vallier (1977) also used the name "Martin Bridge Limestone" to describe thick limestone and dolomite exposed in Hells Canyon at a stratigraphic section measured just south of Kinney Creek near Hells Canyon Dam. It seems clear that Hamilton (1963) attributed the term "Limestone" to the Martin Bridge only in an informal sense and his usage followed Smith and Allen's (1941) concept of Martin Bridge solely as a carbonate unit. This, as well as other cited examples, is inconsistent with the rule of priority (Article 7c, North American Stratigraphic Code) because the original stratotype in the southern Wallowa Mountains (Ross, 1938) was disregarded.

References to the unit "Martin Bridge Limestone" in the northern and southern Wallowa Mountains and Hells Canyon (e.g., Newton, 1986; Stanley, 1986; Vallier and Brooks, 1986; Whalen, 1988; Follo, 1992) perpetuated the problem. Despite a reexamination of the originally designated stratotype of the Martin Bridge Formation on Eagle Creek (McRoberts, 1993), misuse under the name "Martin Bridge Limestone" continued (Follo, 1994; White, 1994; White and Vallier, 1994). The proliferation of informal, and often conflicting, stratigraphic names poses further problems. Many of the subunits designated within the Martin Bridge (Nolf, 1966; Follo, 1992, 1994) either are informal or, in the case of Nolf (1966), are proposed in a thesis and therefore not sanctioned by the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005, Article 4). These inconsistencies result from improper use of stratigraphic terminology, but they also reflect the complex nature of depositional patterns and processes in an island arc setting where rapid vertical and lateral facies changes occurred.

STRATIGRAPHY AND REDEFINITION OF THE MARTIN BRIDGE FORMATION

The Martin Bridge Formation conformably overlies Upper Triassic (Carnian) volcanic and volcaniclastic strata (Fig. 3) informally designated the "Lower Sedimentary Series" (Smith and Allen, 1941), the Clover Creek Formation in the northern Wallowa Mountains (Nolf, 1966), or the Doyle Creek Formation (Seven Devils Group) of Hells Canyon (Vallier, 1977). Where observed in both the northern and southern Wallowa Mountains (Follo, 1994), the contact is gradational. The Martin Bridge is conformably overlain by and/or may grade laterally into the Hurwal Formation (Smith and Allen, 1941; Vallier, 1977; Follo, 1992). Formational boundaries between the Hurwal, Martin Bridge, and underlying volcanic and volcaniclastic rocks are not exposed at the Martin Bridge stratotype. They are known from other localities in the southern and northern Wallowa Mountains and Hells Canyon, however. The Martin Bridge is discussed below at its better occurrences in three principal regions: (1) southern Wallowa Mountains, (2) northern Wallowa Mountains, and (3) Hells Canyon (Fig. 3).

Erection of a Composite Stratotype

A composite stratotype (North American Commission on Stratigraphic Nomenclature, 1983, p. 853) is necessary for the Martin Bridge Formation because the present reference section does not adequately represent the diversity of Martin Bridge rock types present throughout the Wallowa terrane. Follo (1994, p. 7) discussed the stratigraphic nomenclature and presented some informal lithofacies subdivisions of the Martin Bridge, but he emphasized that formal designation was outside the scope of his work. In redefining the Martin Bridge Formation, we propose retention of both the original name—Martin Bridge Formation—and the original type section as one of the principal reference sections. Furthermore, we formally propose four members defined by reference stratotypes within the northern and southern Wallowa Mountains (Fig. 3). Generalized columnar sections are presented in Figure 4, which is keyed to the map on Figure 3.

Southern Wallowa Mountains

Excellent exposures of the Martin Bridge Formation can be found in the southern Wallowa Mountains (Table 1) but many outcrops, like the one at Summit Point (Fig. 3, site 2), are more or less isolated and preserved as windows in the Columbia River Basalt. Significant structural deformation in the southern Wallowa Mountains makes exact stratigraphic relationships uncertain. Locally, the Martin Bridge is deformed by numerous thrust faults of unknown displacement, and by innumerable high-angle normal faults, and in certain areas is tightly to isoclinally folded (Vallier, 1977; Mirkin, 1986; McRoberts, 1990; Follo, 1994). Structurally repeated or omitted strata are common, as illustrated by the carbonate "ridge bed," which is found to be repeated several times in the primary stratotype at Eagle Creek (McRoberts, 1990, 1993). Structural deformation in the southern Wallowa Mountains appears to be related to accretion of the island arc to the continent and to emplacement of the Wallowa Batholith (Late Jurassic–Early Cretaceous) and during the initial phases of Basin and Range extension (Mirkin, 1986).

We designate the principal reference section of the greater composite stratotype of the Martin Bridge Formation, in the southern Wallowa Mountains at Eagle Creek near Ross's original site. This reference section also serves as the stratotype for the proposed Eagle Creek Member. A second reference section is designated at Summit Point in the southern Wallowa Mountains.

Eagle Creek Member

The Eagle Creek Member is here designated to include alternating calcareous shale, calcareous mudstone, and well-bedded limestone as well as bioclastic and lithoclastic rudstones exposed in the Wallowa-Whitman National Forest, along the Eagle Creek drainage (Fig. 3). The lowermost 100 m of the Eagle Creek Member is exposed along Paddy Creek (Fig. 3; Table 1) and the remainder of the member, comprising ~125 m of the original type section (Figs. 4 and 5A; Table 1) of the Martin Bridge Formation, is exposed along Eagle Creek (Smith, 1927; Ross, 1938; McRoberts, 1990, 1993). It showed that post-Triassic structural deformation, including at least three low-angle thrust faults of unknown displacement and nearly 20 high-angle faults of limited (<5 m) displacement, disrupted the sequence at the stratotype. In spite of the structural complexities, occurrences of abundant biostratigraphic fossils allowed the stratigraphic reconstruction of the principal stratotype by rearrangement of five structural blocks into an upper Carnian to lower Norian sequence (McRoberts and Stanley, 1991; McRoberts, 1993).

Sedimentologic studies of the unit stratotype by Follo (1992, 1994) and stratigraphic investigations by McRoberts (1990, 1993) indicated that the Eagle Creek Member is primarily composed of finely laminated, slightly calcareous, organic-rich shale, dark mudstone, and impure limestone (Eagle Creek facies A of Follo, 1994). Common invertebrates are ammonoids and halobiids as well as rarer shallow-water bivalves (McRoberts, 1992, 1993; Tamura and McRoberts, 1993). The shales of the Eagle Creek Member are interpreted as representing normal background sedimentation on a carbonate slope environment (McRoberts, 1990; Follo, 1994), rather than shallow-water backreef lagoonal muds as suggested by Prostka (1962). This deeper-water interpretation is substantiated by the fining-upwards in

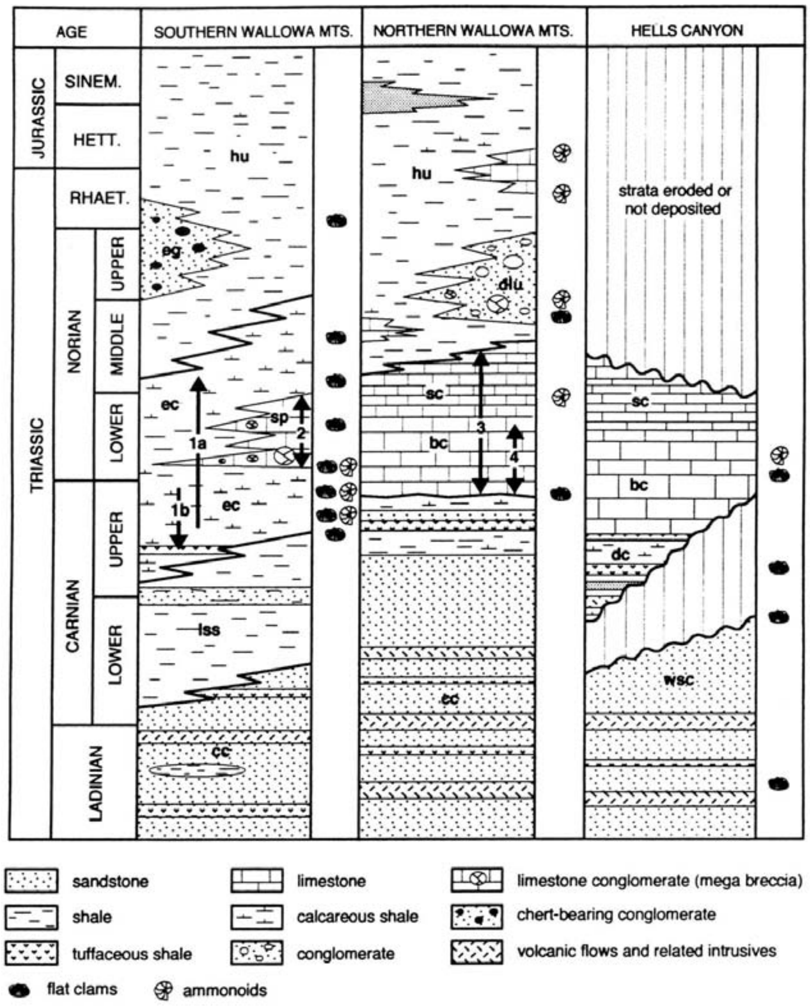

Figure 4. General lithostratigraphic and chronostratigraphic correlations of the Martin Bridge and other units within the Wallowa terrane. Abbreviations: hu—Hurwal Formation; eg—Excelsior Gulch conglomerate (Follo, 1992); sp—Summit Point Reef (Stanley and Senowbari-Daryan, 1986); ec—Eagle Creek locality and type section (McRoberts, 1993); lss—"Lower Sedimentary Series; cc—Clover Creek greenstone; dlu—Deadman Lake unit; sc—Scotch Creek facies; bc—BC Creek facies (Nolf, 1966); dc—Doyle Creek Formation (Nolf, 1966; Vallier, 1977); wsc—Wild Sheep Creek Formation (Vallier, 1977). Stratigraphic sections: 1a and 1b—the principal stratotype; 2—Summit Point; 3—Hurricane Creek; 4—BC Creek.

TABLE 1. GEOGRAPHIC AND STRATIGRAPHIC DETAILS FOR LOCALITIES

No.	Locality name	Member	Geographic reference	Type*
1a	Eagle Creek	Eagle Creek	Confluence of Eagle and Paddy Creeks	S
1b	Paddy Creek	Eagle Creek	Along Forest Road 360, east side of Paddy Creek	S
2	Summit Point	Summit Point	Southwest from the top of Summit Point	S
3	Torchlight Gulch	Summit Point	Along Forest Road 075, south side of Torchlight Gulch	R
4	East Eagle Creek	Scotch Creek	Near the Bradley Mine	R
5	Hurricane Creek	Scotch Creek	West side of Hurricane Creek	R
6	BC Creek	BC Creek	North Fork of Creek	S
7	Scotch Creek	Scotch Creek	Between 6000′ and 6400′ on the south fork of Scotch Creek	S
8	Black Marble Quarry	unknown	Along Murray Creek at 6800′	F
9	Spring Creek	Scotch Creek	West side of the Snake River	F
10	Kinney Creek	Scotch Creek	North side of Kinney Creek	R

*S—stratotype section; R—reference section; F—fossil locality.

millimeter- to centimeter-thick, carbonate-rich and carbonate-poor couplets (Fig. 5B). These most likely represent the distal fringes of carbonate turbidites. Well-bedded limestone also alternates with calcareous shale in the Eagle Creek Member (Eagle Creek facies B of Follo, 1994). Limestone beds are characterized by coarse-grained, normally graded grainstone and packstone including bioclasts of corals, spongiomorphs, and other shallow-water fossils. The normally graded carbonates of the Eagle Creek Member are consistent with allochthonous deposition as gravity or turbiditic flows from shallow-water carbonates to the north.

Sporadic occurrences of beds, up to 2 m thick, of lumachelle limestone (bioclastic rudstone) form a minor constituent of the Eagle Creek Member (McRoberts, 1993). These monospecific *Halobia* lumachelle beds are bounded both above and below by organic-rich mudstones and black (dysoxic) shales. Such thick shell beds may represent extremely condensed intervals or protracted population blooms of halobiid bivalves in response to a relaxation of oxygen deficient conditions. Regardless of their genesis, these beds may serve as event horizons locally correlatable in the southern Wallowa Mountains.

A distinctive 10-m-thick lithoclastic and bioclastic conglomerate unit, exposed on prominent ridges above Eagle Creek (McRoberts, 1990; Follo, 1994), forms a conspicuous lithofacies of the Eagle Creek Member. A majority of the bioclasts within this conglomerate bed are corals and spongiomorphs, which may have led Smith (1912, 1927) to misinterpret this unit as a coral reef. The rounded nature of the conglomerate clasts within this bed implies a history of erosion and reworking on a shallow shelf prior to transportation into the basin as debris flows. Although Follo (1992, 1994) interpreted this conglomerate unit (his Eagle Creek facies C) to represent numerous gravity-flow debris sheets, field mapping, biostratigraphic relationships, and overall similarity of these debris beds at the Martin Bridge type locality show that they probably represent a single bed that has been repeated by several high-angle thrust faults (McRoberts, 1990).

Unfortunately the upper and lower contacts of the Eagle Creek Member are not exposed at the unit stratotype. At many places in the southern Wallowa Mountains the lower contact of the Eagle Creek Member of the Martin Bridge and the Lower Sedimentary Series is unconformable (Ross, 1938), but it may be conformable or slightly diachronous along Paddy Creek (Prostka, 1962; Mirkin, 1986; Follo, 1994) where minor thrust faults occur between competent limestone and incompetent shale (Follo, 1994). Unlike Prostka (1962), who defined the lower contact of the Martin Bridge as the first massive limestone overlying the calcareous argillite of the Lower Sedimentary Series, we regard the boundary as intercalated and gradational and define the transition between the two units as the first calcareous interval, either calcareous mudstone or pure limestone, above the non-calcareous or slightly calcareous green and gray fissile argillite of the Lower Sedimentary Series.

The upper contact of the Eagle Creek Member with the Hurwal Formation has not been identified at the stratotype in the southern Wallowa Mountains. Ross (1938) mentioned the presence of rocks overlying the Martin Bridge but never identified them with any particular unit. Prostka (1962) assigned poorly exposed rocks of the southern Wallowa Mountains to the Hurwal but relationships to the Martin Bridge were ambiguous. The uncertain nature of the contact in the southern Wallowa Mountains is highly problematical because there is little lithologic similarity between the dark argillites referred to the Hurwal and the uppermost calcareous argillites occurring at the Martin Bridge stratotype.

Smith (1912, 1927), who first studied the faunal sequence of the Martin Bridge type locality, recognized *Halobia oregonensis*, *H. salinarum*, *H. dilatata*, and *H. halorica* as well as some Tethyan coral species. In the absence of ammonoids from the Martin Bridge Formation, Smith placed the Carnian-Norian boundary within 121 m of barren shale and limestone between the last occurrence of *H. oregonensis* and an overlying "Coral Zone" of lower Norian age. Subsequently, Stanley (1979, 1986) noted a lower Norian coral assemblage. Orr (1986) described the ichthyosaur *Shastasaurus*, and Gruber (*in* Kristan-Tollmann and Tollmann, 1983) reported Carnian halobiids (*H. rugosa* and *H. radiata radiata*) from structurally complex outcrops near the type section.

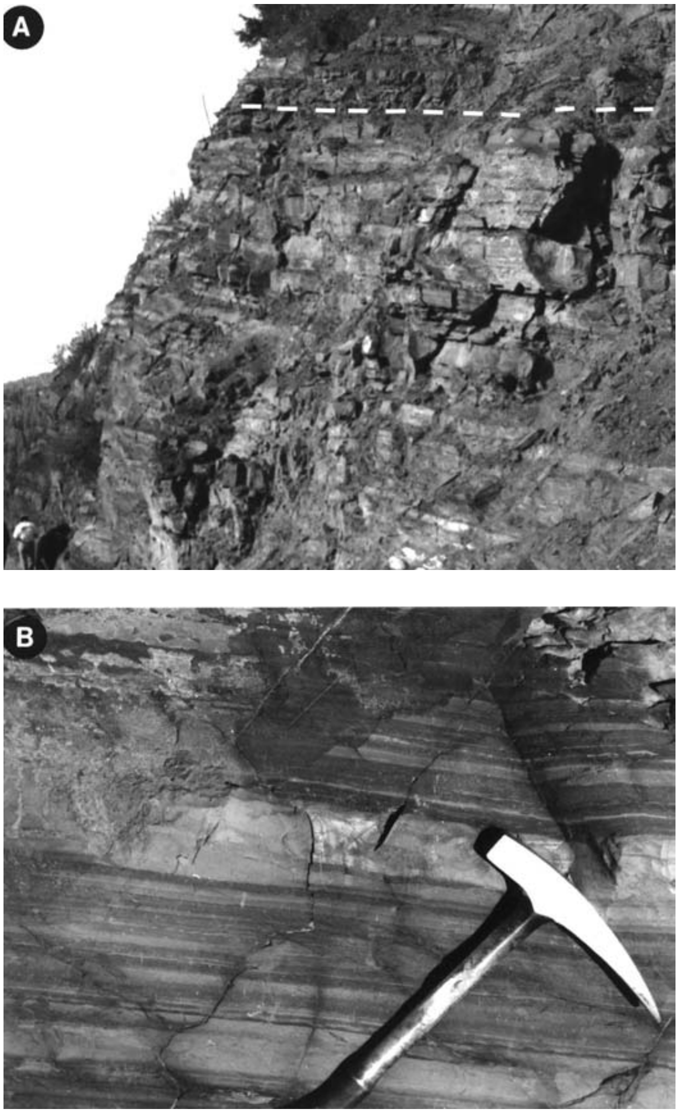

Figure 5. Field photos of principal stratotype of Martin Bridge Formation. (A) Outcrop at the confluence of Eagle and Paddy Creeks; note dashed line represents approximate Carnian-Norian stage boundary based on halobiid bivalves. (B) Carbonate-rich laminated distal turbidite showing soft-sediment structures.

Work by McRoberts and Stanley (1991) and McRoberts (1993) reveals a rather complete sequence across the Carnian-Norian boundary with diverse assemblages of halobiid bivalves and ammonoids. In ascending order, the mudstones and bedded carbonates of the lower part of the Martin Bridge contain the bivalve *Halobia superba superba* and the ammonoids *Discotropites* sp., *Arietoceltites* sp., and possibly *Anatropites* sp. Together

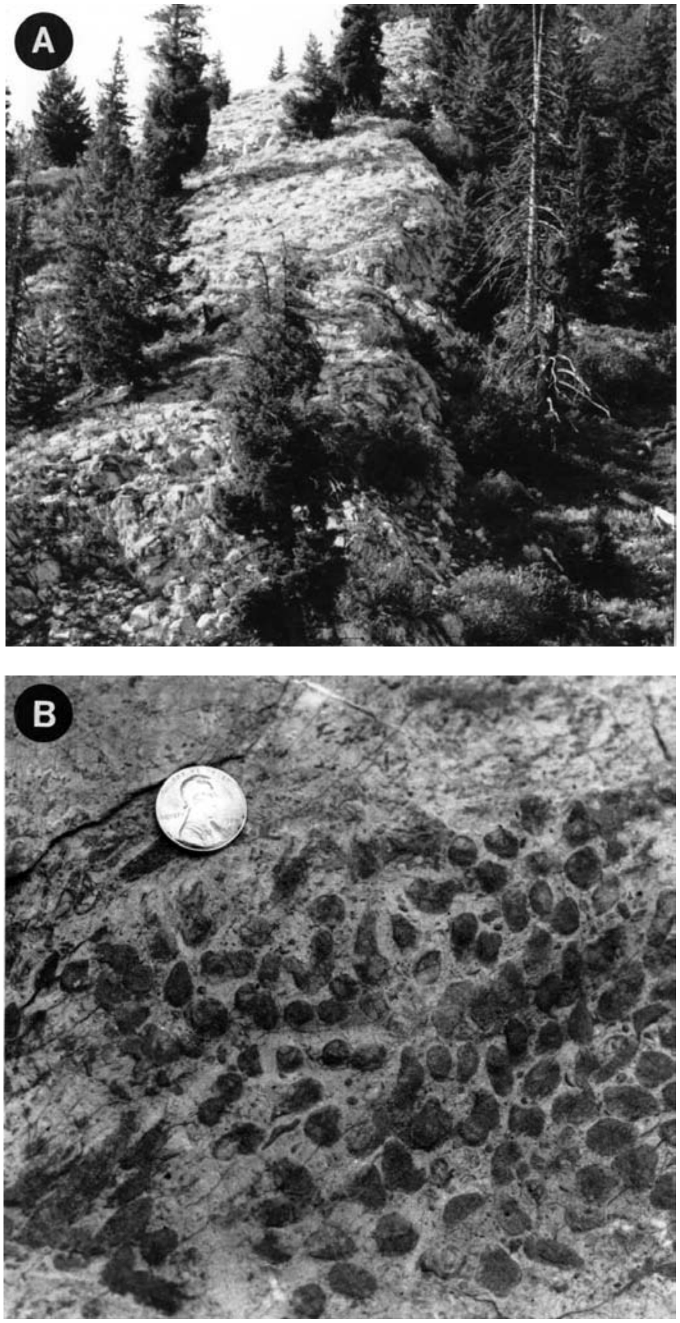

Figure 6. Summit Point locality in the southern Wallowa Mountains. (A) Base of section showing exposure of massive limestone of the Summit Point Member, which can be traced up the slope of Summit Point. (B) Coral framestone, *Retiophyllia*. Surface view of a colony in situ within the massive limestone of the Summit Point Member.

these fossils are indicative of a late Carnian age (Dilleri–Macrolobatus Zones). About 2.7 m above the highest occurrence of *H. superba superba*, *H. beyrichi* is found in several horizons, indicating a lower (Kerri Zone) Norian age and thus indicating the proximity of the Carnian-Norian boundary. Abundant shell beds containing the middle Norian bivalve *H. halorica* occur in the structural block above *H. beyrichi* to the top of the stratotype section. More recent work on conodonts under way with M.J. Orchard and Shunxin Zhang supports and further refines these age assignments indicating late Carnian to early Norian ages.

Summit Point Member

A second reference section of the Martin Bridge Formation is located 8 km northeast of the Eagle Creek type locality on the hillside of Summit Point in the Wallowa-Whitman National Forest (Figs. 3 and 4; Table 1). The section, described in more detail below, is designated the Summit Point Member and it has been published by Stanley and Senowbari-Daryan (1986). The Summit Point Member is exposed as a small outlier at a second site at Torchlight Gulch, (Fig. 3, site 3; Table 1). However, this site is much smaller and presents no contacts with any adjacent units. Extensive limestone exposed on the hillside along the southwest slopes of Summit Point (Fig. 6A) display in depositional contact both the Summit Point Member and the overlying Scotch Creek Member (Fig. 7). The best exposures occur from Twin Bridge Creek up the slope. The section begins in massive limestone of the Summit Point Member at the base of a thrust fault. The Summit Point Member is overlain by bedded bioclastic carbonate rocks of the Scotch Creek Member (Fig. 7) that continue northeast up toward the Summit Point lookout tower. The top of the section presents an unconformity with the Columbia River Basalt. The Hurwal Formation is not present at this site because of pre–Columbia River Basalt erosion, which was extensive and varied over the extent of the Wallowa terrane. At this Summit Point site, the Summit Point Member is 33–35 m thick. The overlying Scotch Creek Member (Fig. 7) is difficult to measure because of repeated sections due to thrust faults, but it could reach as much as 150–200 m in thickness.

At this locality, the Summit Point Member is quite distinct from the exposures on the section along Eagle Creek because it consists entirely of massive to thick bedded, light-colored to medium-gray limestone. The limestone dips ~45° to the southwest. The stratigraphy is complicated by small thrust faults that offset and duplicate this section of carbonate rocks, causing repetition of the Summit Point Member at both higher and lower elevation along the slope. A large thrust fault, more or less parallel to bedding, is clearly present at the base of the section along a northwest-trending forest road near Twin Bridges Creek. A stratigraphic section of the Summit Point and Scotch Creek Members in Figure 7 is described in more detail below. Framework-building and binding fossils characterize the Summit Point Member (unit 1). These include the phaceloid-dendroid coral *Retiophyllia* (Fig. 6B), a solitary to pseudocolonial coral *Distichophyllia*, the thalamid sponge *Salzburgia*, spongiomorphs, tabulozoans, and masses of the red alga *Solenopora*. The light-gray limestone contains local breccia and mostly massive limestone. Cavities within the limestone may be lined with biogenic cyanobacterial (porostromate algae) crusts.

The base of the Summit Point stratotype, where the Summit Point Member is well exposed, begins along the forest road on

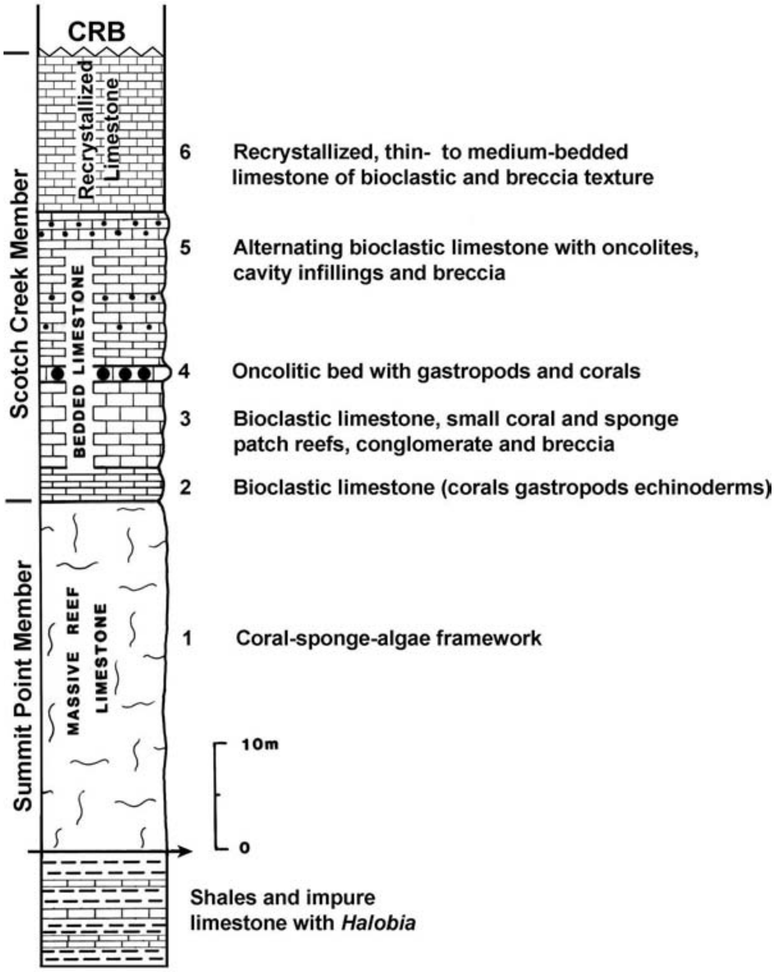

Figure 7. Columnar section of the limestone at Summit Point showing the various members of the Martin Bridge at this site. The section begins above a thrust fault at the base of the section and is overlain by the Columbia River Basalt. The exact thickness of unit 6 is not known and is most likely much thicker than indicated. CRB—Columbia River Basalt.

the southwest side of Summit Point at a topographic map elevation of 5550 ft and continues up the slope toward the fire lookout tower to a topographic map elevation of 6580 ft. At the lower level of the forest road, the massive limestone begins above a low-angle thrust fault. Below the thrust fault lies tectonically sheared calcareous shale characterized by *Halobia* and some bedded limestone containing bivalves and gastropods. The Summit Point Member (unit 1, Fig. 7) consists of 33–35 m of massive, unbedded light-gray limestone chiefly dominated by in situ solitary and colonial scleractinian corals, chambered sponges, and red algae. Where well exposed, the limestone presents the fabric of in situ reef framework. It begins on the forest road and continues eastward up the slope of the hill to Summit Point (Fig. 6A). This massive limestone is succeeded by medium-bedded units of coarse-grained bioclastic limestone (units 2–5) of the Scotch Creek Member. These are characterized by solitary and colonial corals, gastropods, crinoid ossicles and echinoid plates, and bivalves. Some beds are rich in oncolites. Unit 4 (Fig. 7) is a marker bed composed of large oncolites, 2–5 cm in diameter, the nuclei of which are coral fragments, crinoid ossicles, and low-spired gastropods. Bedded carbonate lithologies within the upper part of the member are characterized by breccia, dissolution cavities, and small fissures infilled with fine-grained, yellow-colored, often laminated sediment. Small in situ patch reefs 1–2 m high and 5–6 m long occur within this interval. Channels between the patches are indicated by skeletal debris, breccia, and conglomerate. The top of the section (unit 6) merges into fine- to medium-grained, dark-gray, recrystallized bioclastic limestone that weathers almost white in color. These rocks attain dips of up to 60° west. Because of the pervasive recrystallization that increases upward in the section, the only discernable fossils are vague indications of bioclasts, gastropods, and bivalves.

The carbonate sequence at Summit Point contrasts with that at Eagle Creek in displaying massive and mostly unbedded, pure carbonate rock with a predominance of framestone and bindstone. It contains an abundance of reef-related fossils characteristic also of the Dachstein Reef Limestone of the Northern Calcareous Alps in central Europe (Stanley and Senowbari-Daryan, 1986) . Conglomerate and breccia textures also are present in the overlying Scotch Creek Member, most of which contains bioclastic beds and some low-angle cross-beds. A rich and diverse fauna of corals, sponges, tabulozoans, bivalves, gastropods, crinoid ossicles, spongiomorphs, red algae, benthic foraminifers, and cidaroid echinoids characterizes the Scotch Creek Member at Summit Point. Many of these are preserved as bioclasts (Fig. 8). Among these are large thick-shelled megalodontid bivalves (Fig. 9). This is the first report of these reef-adapted bivalves in the Wallowa terrane, but they are very common to Upper Triassic reef complexes of the Tethys (Flügel, 2002) and also are known from carbonate rocks from Upper Triassic (Norian) reef complexes in the Stikine terrane (Reid, 1988).

The Summit Point Member is interpreted to be part of a reef complex very similar in biota, size, and composition to those from the thicker Dachstein Reef Limestone of the Northern Calcareous Alps of Austria and southern Germany (Zankl, 1969; Stanley and Senowbari-Daryan, 1986). Norian Dachstein reefs in the Alps were interpreted as having formed on a broad ramp rather than being shelf-edge buildups, which characterize some later reef complexes of the Rhaetian (Stanton and Flügel, 1989). Age-diagnostic megafossils are absent from the Summit Point Member but the megalodont bivalves, corals, sponges, red algae, and foraminifers are well known from most Norian–Rhaetian reef complexes in the Northern Calcareous Alps. Coral, sponge, and spongiomorph taxa occurring in conglomerate beds of the Eagle Creek Member appear to be similar, if not identical, to taxa present in the Summit Point Member.

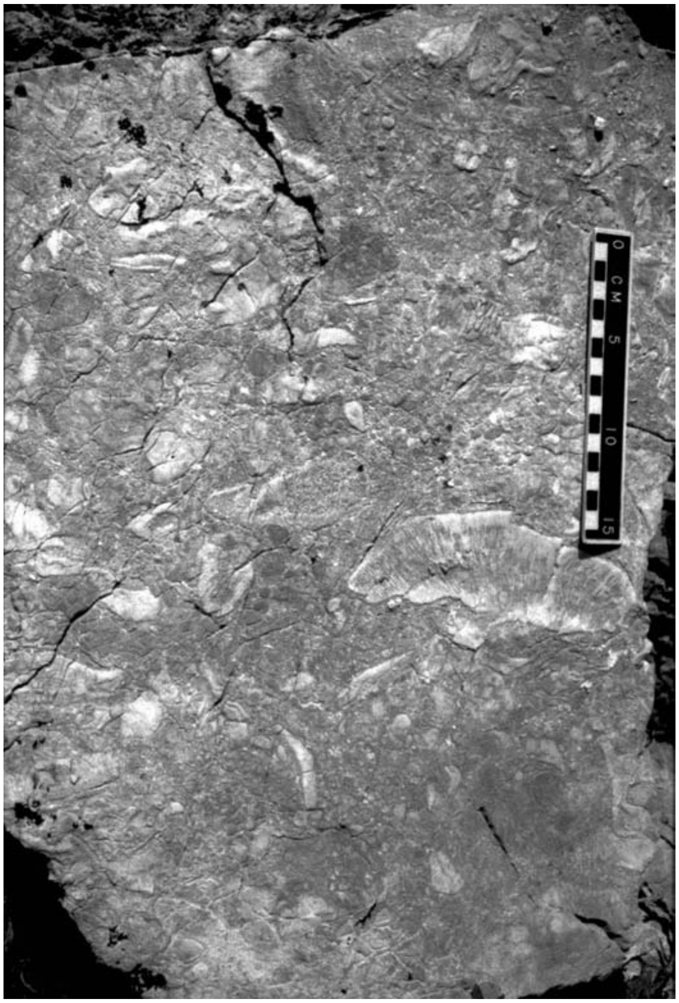

Figure 8. Field photo of unsorted bioclasts consisting mostly of colonial corals (large flat clasts), bivalve shells, sponges, crinoid ossicles and echinoid spines, and other shallow-water biota in the Scotch Creek Member, Summit Point, southern Wallowa Mountains. Scale in centimeters.

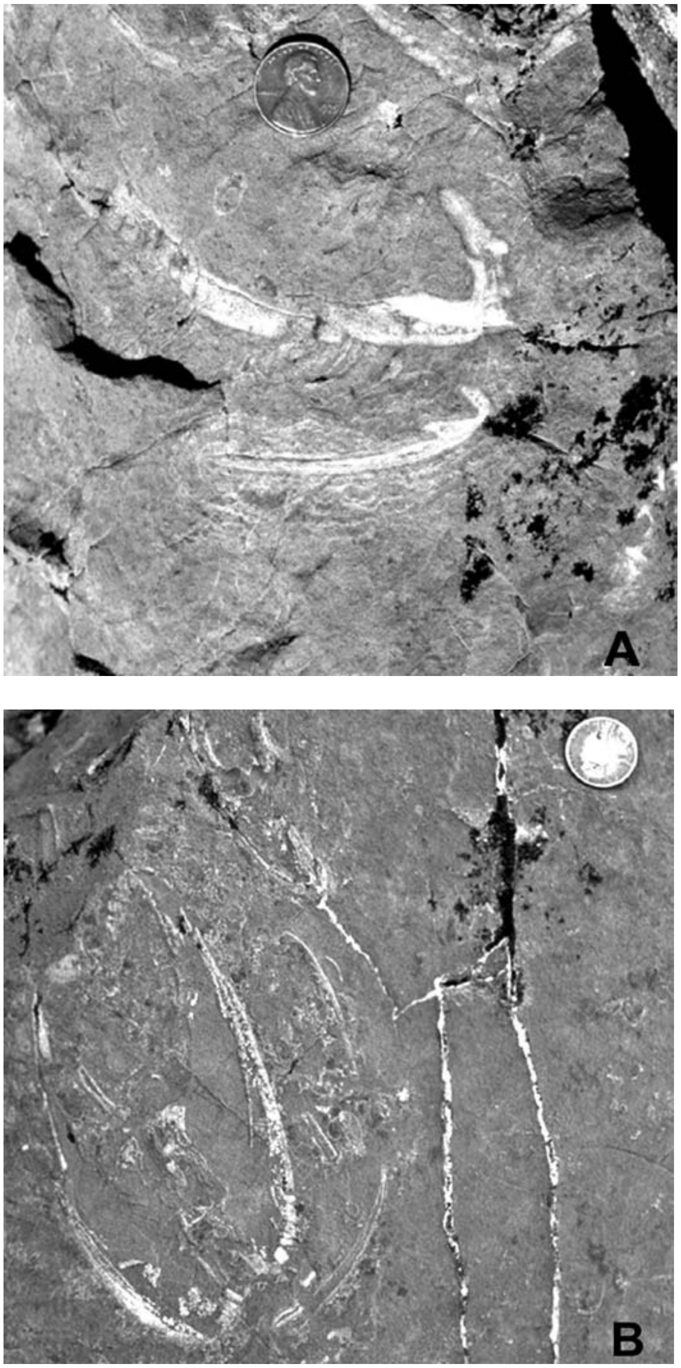

Figure 9. Two different examples of megalodontid bivalve facies (A and B) in massive unbedded limestone. These thick-shelled, gregarious bivalves are photographed in outcrop in the Summit Point Member, Summit Point, southern Wallowa Mountains. One cent coin for scale.

Conodonts retrieved from this sequence at Summit Point currently are under study with Shunxin Zhang and M. J. Orchard, and preliminary findings indicate late Carnian to early middle Norian ages.

Locally, the contact between the Summit Point Member and underlying shale and limestone is a thrust fault. The strata below the thrust fault are reminiscent of the Eagle Creek Member but because of the structural complications, depositional relationships are unclear. A geologic map produced by Follo (1986) suggests a possibility that the Summit Point Member and overlying Scotch Creek Members might be an integral block thrust over the Eagle Creek Member, but structural evidence in support of this idea would require more extensive fieldwork. The faunal composition of the Summit Point Member is similar to fossils found in conglomerate clasts of Eagle Creek Member at the stratotype, and they are unlike the fauna at the Black Marble Quarry in the northern Wallowa Mountains (see below).

Northern Wallowa Mountains

The northern Wallowa Mountains, located near the town of Enterprise, Oregon, display impressive and rugged exposures of early Mesozoic sedimentary and volcanigenic rocks subjected to the forceful intrusion of granitic rocks related to the Wallowa Batholith (Fig. 10A). The impressive exposures in the northern Wallowa Mountains are situated some 50 km northeast of the Martin Bridge stratotype on Eagle Creek (Fig. 3; Table 1). This part of the Wallowa Mountains displays some of the thickest exposures of the Martin Bridge Formation. A thickness of ~350 m was estimated for the Martin Bridge at the west end of Hurricane Creek as measured from the base where it contacts the underlying Triassic volcaniclastic and volcanic rock below to the contact with the overlying Hurwal Formation. However, folding and ductal flow, resulting from the intense local metamorphism and batholith implacement that characterizes this region, has produced locally apparent thicknesses of over 1000 m (Follo, 1994). Follo (1994) estimated a more realistic thickness for the Martin Bridge of 350–450 m from exposures west and southwest of Enterprise. The strata cannot be physically traced between these two regions because of the intrusion of the Wallowa batholith and extrusion of the extensive Columbia River Basalt, which cover much of the exposures of early Mesozoic rocks. The stratigraphy and fossils of this region were discussed by Smith and Allen (1941), Stanley (1979), and Follo (1994), but the most detailed treatment was given in a doctoral thesis by Nolf (1966) who informally described three members of the Martin Bridge—the Hurricane Creek, BC Creek, and Scotch Creek. We here elevate two of Nolf's units, the BC Creek and Scotch Creek Members, to formal status as members within the Martin Bridge Formation. We here designate the section measured by Nolf along Hurricane Creek (Fig. 11) as a reference section for the composite stratotype of the Martin Bridge Formation.

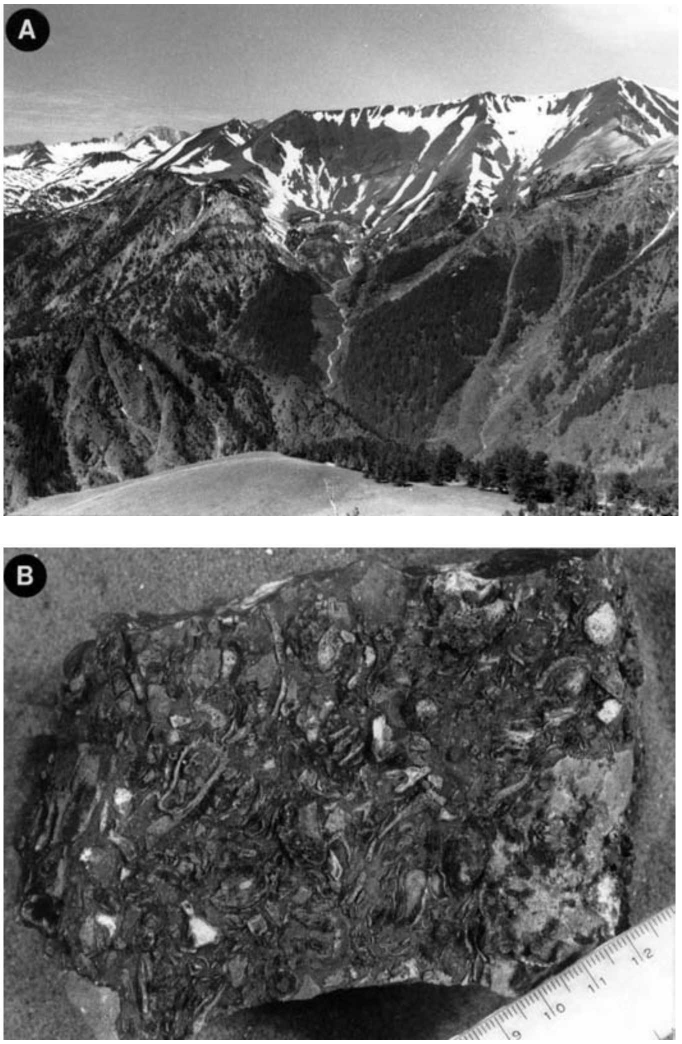

Figure 10. (A) Exposure of the Martin Bridge and associated rocks in the northern Wallowa Mountains. Photo is of the succession near Joseph, Oregon, looking from Mount Howard toward BC Basin and BC Creek (center) and Chief Joseph Mountain (highest point to the right of view). Near the base of the section and halfway up the slope, dark-colored Triassic volcanic and volcaniclastic rocks are succeeded upward by lighter-colored limestone of the Martin Bridge Formation, BC Creek Member (stratotype). Above the tree line on the right, light-colored rock belongs to the Scotch Creek Member. The top ridge (darker) is Hurwal Divide. To the left of BC Basin, light-colored granitic rocks of the Wallowa Batholith are intruded by horizontal feeder dikes. (B) Typical lithology of Scotch Creek Member from south side of Hurricane Creek. Hand specimen contains poorly sorted bivalves, gastropods, and echinoderm fragments. Scale in millimeters.

BC Creek Member

This member was informally named and described by Nolf (1966) for 150 m of fine-grained, well-bedded limestone directly overlying volcanic rocks of the Clover Creek Greenstone of the Seven Devils Group. At the stratotype along BC Creek in BC Basin, it is sublithographic and pale yellow-brown, light gray or light brownish gray, or distinctly pink colored, owing to iron

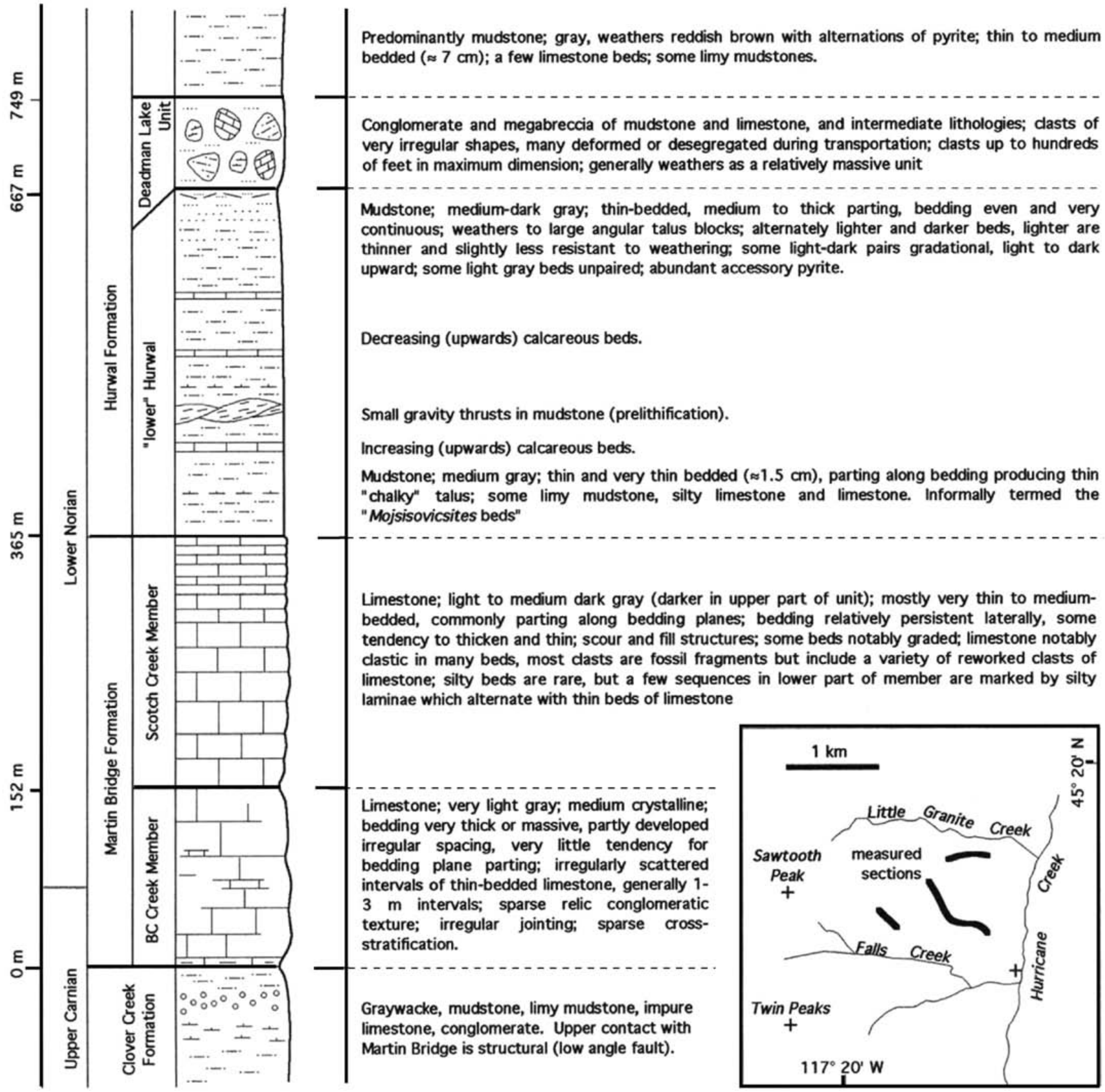

Figure 11. Detailed section of Martin Bridge Limestone and adjacent units in the Northern Wallowa Mountains as measured by Bruce Nolf along the west side of Hurricane Creek. Index locator map inset at bottom right. Modified from Nolf (1966); here his Hurricane Creek Member is included as a metamorphosed part of the BC Creek Member, the lowest unit of the Martin Bridge Formation.

oxide. Some beds of the BC Creek are finely cross-bedded. Rare fossils consist of echinoid spines and plates and bivalve shells. This unit was redescribed by Follo (1994) as his BC Creek unit. We designate the composite section Nolf (1966) measured and described at the head of the north fork BC Creek between the 8800 and 9450 foot topographic elevation lines (Fig. 3; Table 1) as the stratotype for the BC Creek Member of the Martin Bridge Formation. This member is exposed on Chief Joseph Mountain also.

The BC Creek Member consists of thin-bedded (5.0–25.0 cm) laminated and cross-bedded limestone. Laminae are silty or dolomitic with irregular bedding planes and stylolites. Rip-up clasts and nodular limestone are also common in beds 50 cm to 2 m thick. Replacement chert and “chicken-wire” textures are common. Follo (1994) also noted salt casts, karstic solution collapse structures, and evidence of nodular anhydrite. This member is represented also at the base of the thick limestone section exposed in Hells Canyon near Spring Creek (Whalen, 1988).

The Hurricane Creek Member is interpreted to be laterally equivalent to the BC Creek Member (Nolf, 1966). According to Nolf, no fossils and few sedimentary features are known from the marble-like limestone of the Hurricane Creek Member. Nolf's reef interpretation for the Hurricane Creek Member was based solely on the massive nature of this member, its thickening, and its apparent lateral transition into the bedded BC Creek Member. Field examination of stratigraphic relationships between the Hurricane Creek Member and the BC Creek Member at Nolf's original sections prompted our reinterpretation. Both Nolf's (1966) original view of a reef and Follo's subsequent (1992, 1994) interpretation of the Hurricane Creek as a high-energy barrier are, in our opinion, erroneous. Field relationships suggest to us that the marble lithology of Nolf's Hurricane Creek Member resulted primarily from contact metamorphism from the intrusion of the Wallowa batholith. Thus the apparent thickening and lateral transition of the massive Hurricane Creek into the bedded BC Creek Member is mostly a function of decreasing metamorphism away from the batholith. We therefore do not advocate use of the Hurricane Creek Member as a formal stratigraphic member.

On the basis of this apparent stratigraphic relationship, sparse fossil content, and evaporitic textures including nodular anhydrites, Nolf interpreted the BC Creek Member as a backreef, evaporitic lagoon facies. These data accord well with the presence of dolomitic textures, cryptalgal laminites, and solution collapse breccias as noted by Follo (1994). Limestone and dolomite exposed at the base of the Martin Bridge section in Hells Canyon contain similar features (Whalen, 1988) and also belong to this member (see below).

Scotch Creek Member

The Scotch Creek Member was first established by Nolf (1966) for bedded calcarenites exposed at an elevation between 6000 and 6400 ft on the south fork of Scotch Creek. It was described also on the west side of Hurricane Creek. The 150–250-m-thick Scotch Creek Member overlies the BC Creek Member. We retain the original section of Nolf (1966) along Scotch Creek as the stratotype. The unit is well exposed also along the west side of Hurricane Creek where, in its upper part, it is gradational with overlying shales and argillites of the Hurwal Formation. We designate the exposures along the west side of Hurricane Creek as a reference section of the Scotch Creek Member. This member also is present in the southern Wallowa Mountains at Summit Point and in Hells Canyon (Fig. 3; Table 1) where it is exposed at Kinney Creek (Vallier, 1977).

The Scotch Creek Member at its stratotype is mostly coarse-grained, poorly sorted bioclastic limestone but also includes abundant silt-size and finer siliciclastic material (Follo, 1994). Texturally the limestone of this member is mostly grainstone to packstone but coarser-grained carbonate conglomerate and breccia also are present. Beds range from 1.0 cm to 1.0 m or more in thickness. The bioclastic beds are poorly sorted, rich in fossil debris (Stanley, 1982, Fig. 10A) and are normally to inversely graded with channel scouring and slump features commonly present. Some of these beds resemble calcareous tempestites similar to those reported in the Martin Bridge Formation in Hells Canyon (Newton, 1986; Whalen, 1988) but others appear to be slope-related gravity-flow deposits. Shallow-water fossils reported by Nolf (1966) include abundant but fragmentary and abraded bivalves *Septocardia* and *Parallelodon*, gastropods *Naticopsis*, *Cirras*, and *Eucyclis*, as well as fragments and debris of corals, spongiomorphs, tabulozoans, echinoid spines, and ammonoids (Fig. 10B). The fauna and bioclastic textures in Scotch Creek carbonate rocks in the northern Wallowa Mountains appear similar to counterparts previously discussed from the Summit Point site.

The Scotch Creek Member is interpreted to represent downslope carbonate deposition in slightly deeper water. This member records the initial phases in drowning of the shallow carbonate platform. Slope instability is indicated by the frequent occurrence of debris and gravity-flows associated with turbidite sedimentation. As in the southern Wallowa Mountains, the transition from carbonate platform to basin is marked by a progressive decrease in limestone and increase in mudstone and shale. Nolf (1966) and Follo (1994) correctly interpreted the Scotch Creek to represent drowning of the carbonate platform. Voluminous carbonate debris, including large clasts of corals and other reef organisms, were transported downslope along a carbonate ramp. Whether the slope was characterized by a reef rim is unclear. However, the only evidence for an in situ reef occurs in the southern Wallowa Mountains at Summit Point and at Torchlight Gulch. The voluminous coral and sponge debris characterizing the Scotch Creek in the northern Wallowa Mountains most likely was derived from patch reefs similar in lithologies to those discussed from Summit Point. However, with the notable exception of the Black Marble Quarry (discussed below), no such reef facies have been discovered in the northern Wallowa Mountains.

The age of the Scotch Creek is based on the occurrence in this member of ammonoids identified by N.J. Silberling. These include *Juvavites* sp. and *Mojsisovicites kerri* (Nolf, 1966) and they indicate the lower Norian Kerri Zone. The Scotch Creek Member exposed on the west side of Hurricane Creek yielded the ammonoids *Arcestes* sp. indet. and *Tropiceltites columbianus*, again establishing an early Norian age (Nolf, 1966). The carbonate textures and fossils all correspond closely to some of the limestone exposed at Hells Canyon (see below).

Martin Bridge at Hells Canyon

The Martin Bridge has been exposed by dissection deep into the Columbia River Basalt in the gorge of Hells Canyon (Fig. 3). It is well exposed and has been mapped on both sides of Hells Canyon by Vallier (1977). The exposure is structurally complex, with tight to isoclinal folds on the west side of the canyon that open into a broad synform to the east (Fig. 12) where stratigraphic relationships are best deciphered. The depositional history of the Martin Bridge at this locality has been interpreted by Whalen (1988). Approximately 330 m of bedded limestone is present in the Hells Canyon section.

In Hells Canyon, Martin Bridge sediments were deposited atop the volcaniclastic Doyle Creek Formation of the Seven Devils Group (Fig. 12). The Doyle Creek is equivalent to the Clover Creek unit in other parts of the Wallowa terrane. The basal contact of the Martin Bridge is not well exposed in Hells Canyon but intercalation of thin beds of volcaniclastic siltstone in the lower 25 m (Fig. 13) indicates a gradational contact with the underlying Doyle Creek Formation (Whalen, 1988). Similar intercalated relationships were observed near the Martin Bridge unit stratotype in the southern Wallowa Mountains (McRoberts, 1993; Follo, 1994). The onset of pure marine carbonate deposition indicates cessation of volcanic activity and a relatively abrupt shutdown of terrigenous sediment supply (Whalen, 1988).

Figure 12. Field photo on the west side of Hells Canyon showing the dark volcanic rocks of the Clover Creek Greenstone of the Seven Devils Group below and the bedded limestone of the Martin Bridge Formation above.

Figure 13. Field photo from the west side of Hells Canyon showing the contact of the Martin Bridge Formation with the Clover Creek Greenstone (dashed line). The bedded carbonate rocks begin with the BC Creek Member. Unlike Figure 12 which shows some structural dislocation, the contact between the two units appears conformable.

Detailed facies analysis of the Martin Bridge Limestone (Whalen, 1988) reveals a suite of shallow-water platform carbonates deposited as an overall-deepening upward sequence. The basal Martin Bridge facies (60 m thick) includes laminated and fenestral dolostones with gypsum casts and algal laminated intervals interbedded with mudstones and peloid wackestones. Supratidal to shallow intertidal conditions are indicated by algal laminated dolomudstones, gypsum casts, and fenestral textures. Interbedded mudstones and peloid wackestones were deposited in relatively quiet water peritidal settings. We assign and correlate this lower portion of the Martin Bridge in Hells Canyon to the BC Creek Member.

Peritidal facies are overlain by bioclast, intraclast, peloid wackestone and packstone, bioclast or ooid grainstone, and spongiomorph bafflestone (~150 m thick). The normal marine fauna and coarse-grained packstone and grainstone indicate deposition in shallow to deep subtidal, moderate- to high-energy environments. The uppermost portion of the Martin Bridge (120 m thick) in Hells Canyon is a series of 5–20-m-thick fining-upward subtidal cycles, which probably indicate minor relative sea-level variations from above to below fair-weather wave base (Whalen, 1988). This upper member is well exposed on the west side of Hells Canyon at Spring Creek and contains beds of bioclastic limestone remarkably similar in thickness and faunal composition to those from the Scotch Creek stratotype in the northern Wallowa Mountains. Because silification is better at Spring Creek, tempestite beds here have yielded a wealth of fossils consisting of bivalves, corals, spongiomorphs, and sponges (Newton et al., 1987; Senowbari-Daryan and Stanley, 1988; Stanley and Whalen, 1989). More recently, gastropods have been described (Blodgett et al., 2001; Frýda et al., 2003; Nützel et al., 2003).

The upper portion of the limestone at Hells Canyon is similar to the Scotch Creek Member but does not contain any appreciable siliciclastic material or any indication of slope deposition. It thus represents platform interior facies correlative with the Scotch Creek Member in the Wallowa Mountains and we designate the exposure along Kinney Creek (Fig. 3; Table 1), following Vallier (1967), as a reference section. This section well illustrates the level-bottom facies model for this member. The upper contact of the Martin Bridge in Hells Canyon is either a modern erosional surface or an older unconformity overlain by Tertiary Columbia River Basalt (Vallier, 1977; Whalen, 1988).

Biostratigraphically useful fossils from the Hells Canyon Region are rather scarce and restricted to only a few occurrences of ammonoids and undescribed halobiid bivalves. Recently conodonts have been retrieved from beds adjacent to the silicified Spring Creek site. They represent the late Carnian–early Norian Primitius and Communisti Zones (Nützel et al., 2003), thus reinforcing the ages derived from megafossils. Stanley (1986) and Newton et al. (1987) described silicified bivalve molluscs and coral-spongiomorph assemblages at Spring Creek. This is a site first described by Vallier (1967) and designated U.S. Geological Survey (USGS) locality M2672. It is assigned to the early Norian Kerri Zone on the basis of ammonoids, including the diagnostic *Tropiceltites* cf. *T. columbianus* (identified by N. J. Silberling and cited *in* Vallier, 1977, p. 49). An early Norian age is consistent with the occurrence of the late Carnian to early Norian bivalve *Halobia austriaca* found in float nearly 20 m below M2672 by McRoberts (unpublished data). The bivalves reported by Newton et al. (1987) are temporally wide-ranging, and include both Carnian and Norian taxa widely correlative with those of the Tethys. The corals, however, do not include Carnian species but rather relate to those occurring in Norian–Rhaetian rocks of the Alps. The sponge *Amblysiphonella* cf. *A. steinmanni*, reported from Hells Canyon, is known from the Rhaetian Zlambach Formation as are most of the coral taxa.

Other "Martin Bridge" Occurrences

Several isolated outcrops of limestone have been attributed to the Martin Bridge Formation but neither dating nor correlations are well established. Three problematical localities are discussed below.

Black Marble Quarry

Another possible occurrence of the Martin Bridge Formation is in a quarry in the eastern slopes of the northern Wallowa Mountains, northwest of Enterprise, Oregon (Fig. 3, loc. 8). This locality is referred to as the Black Marble Quarry (Smith and Allen, 1941), formerly mined by the Black Marble Lime Company. Cut into the hillside of a wooded area between Sheep Ridge and Ruby Peak, it presents a fresh exposure of dark limestone (Fig. 14A).

As described by Nolf (1966) and later Stanley (1979), the limestone is thick bedded and dark gray to black in color. It appears to be carbonaceous although subsequent analysis of total organic content yielded carbon percentages ranging from 0.86 to 1.18 and not unlike values for average light-colored limestone of the Martin Bridge in Hells Canyon (0.52%–1.52%). The limestone of the Black Marble Quarry is rich in reefal fossils such as molluscs, corals, and spongiomorphs as well as large alatoform bivalves (Fig. 14B). The quarry is located near the upper mapped extent of the Martin Bridge (Fig. 15) but unfortunately it is covered by the Tertiary Columbia River Basalt so that relationships with adjacent units are not visible. However, the quarry is situated slightly higher than the mapped exposure of the Martin Bridge, which could perhaps place it in the overlying Hurwal. The isolation makes the quarry stratigraphically anomalous and difficult to correlate with adjacent units. Interestingly, the fauna does not resemble any reported from reef limestone in the southern Wallowa Mountains.

Stanley (1979) illustrated some of the reefal fossils from the Black Marble Quarry and reported foraminifers, chambered sponges, colonial and solitary corals, spongiomorphs, crinoid ossicles, and echinoids. Large branching spongiomorphs (probable hydrozoan colonies) are distinctive and abundant (Fig. 16). Thin sections revealed predominantly fine-grained micritic to peloid textures (mudstone, packstone) as well as abundant in situ coral and spongiomorph framestone. The fauna indicates a shallow-water, low-energy back-reef environment characterized by small thickets of branching corals, spongiomorphs, and chambered sponges. Smith and Allen (1941) assigned the Black Marble Quarry to the Martin Bridge Formation and reported ammonoids *Juvavites* sp. and *Sagenites herbicho* Mojsisovics (identified by S. W. Muller) from and near the quarry. Many years of subsequent work failed to locate such ammonites and it appears that the reported specimens were collected as float in areas surrounding the quarry rather from the quarry itself. Although conodonts or diagnostic ammonoids have not been recovered, the fauna of the quarry clearly suggests a Norian age.

Nolf (1966) presented two hypotheses to explain the isolated Black Marble Quarry: (1) as a unit of the Martin Bridge moved structurally by normal fault to a higher stratigraphic position, or (2) as an exotic slide block, displaced into the Hurwal basin much later in the Norian. Stanley (1979) pointed out that the faunal composition and lithology were atypical of the Martin Bridge but resembled some dark limestone already known from parts of the overlying Hurwal, notably as clasts within the Deadman Lake unit (Fig. 11), an observation also made by Nolf (1966) who favored the idea that the quarry might be a large olistholith or slide block.

Unpublished data on involutinid foraminifers recovered from limestone in the quarry revealed a diverse assemblage including *Aulotortus communis* Kristan and *A. tumidus* Kristan-Tollmann. These taxa are characteristic of middle to late Norian in their occurrences in Alpine reef sequences. Giant alatoform bivalves, up to 1 m across (Fig. 14B) (Yancey and Stanley, 1999), occur in the quarry. These authors designated the bivalves as Family Wallowaconchidae, and they also have been reported from sites and terranes very distant from the Wallowa Mountains (Fig. 17). Identical or closely related species of wallowaconchids also occur in Norian limestone in Sonora, Mexico and in the Norian rocks of the Chulitna terrane and Stikinia (Yancey and Stanley, 1999) and similar bivalves also have been reported from Norian rocks of the Tethys (Yancey et al., 2005).

Lewiston, Idaho

Upper Triassic carbonate rocks have long been known from a limestone quarry on the Lapwai Indian Reservation located on the east side of Mission Creek near Lewiston, Idaho (Cooper, 1942; Haas, 1953). Silicified fossils were collected as limestone blocks by Norman D. Newell. Squires (1956) described a Norian silicified coral fauna and Hoover (1991) described brachiopods. However, no authors have assigned the limestone to the Martin Bridge. The Lapwai quarry lies in a remote position some 50 km northeast of known exposures of the Martin Bridge. The abandoned quarry is exposed on a hillside completely surrounded by Tertiary Columbia River Basalt. Thus its stratigraphic relationship with any overlying and underlying units cannot be established.

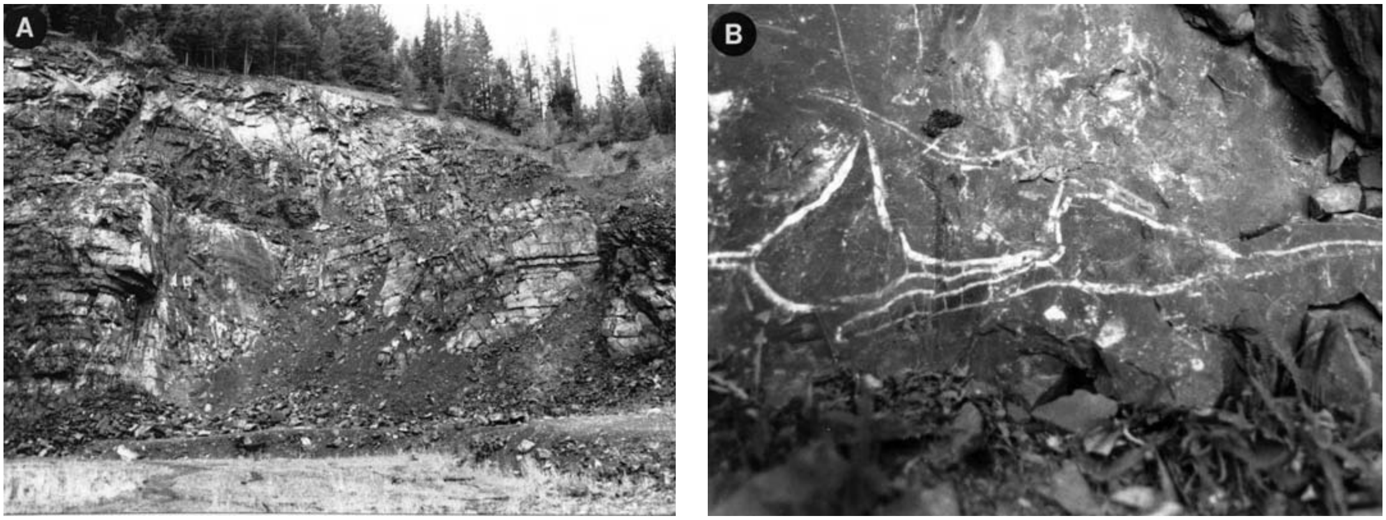

Figure 14. The Black Marble Quarry. (A) Photo of a portion of the Black Marble Quarry in the northern Wallowa Mountains. Note the dark-colored limestone is bedded and more or less horizontal. (B) Large alatoform bivalves of the family Wallowaconchidae in life position as exposed in the quarry wall. These bivalves (Yancey and Stanley, 1999) have wing-like septate extensions from the main shell. Two individuals are shown with the wing-like extensions overlapping. The commissure between the valves was vertical.

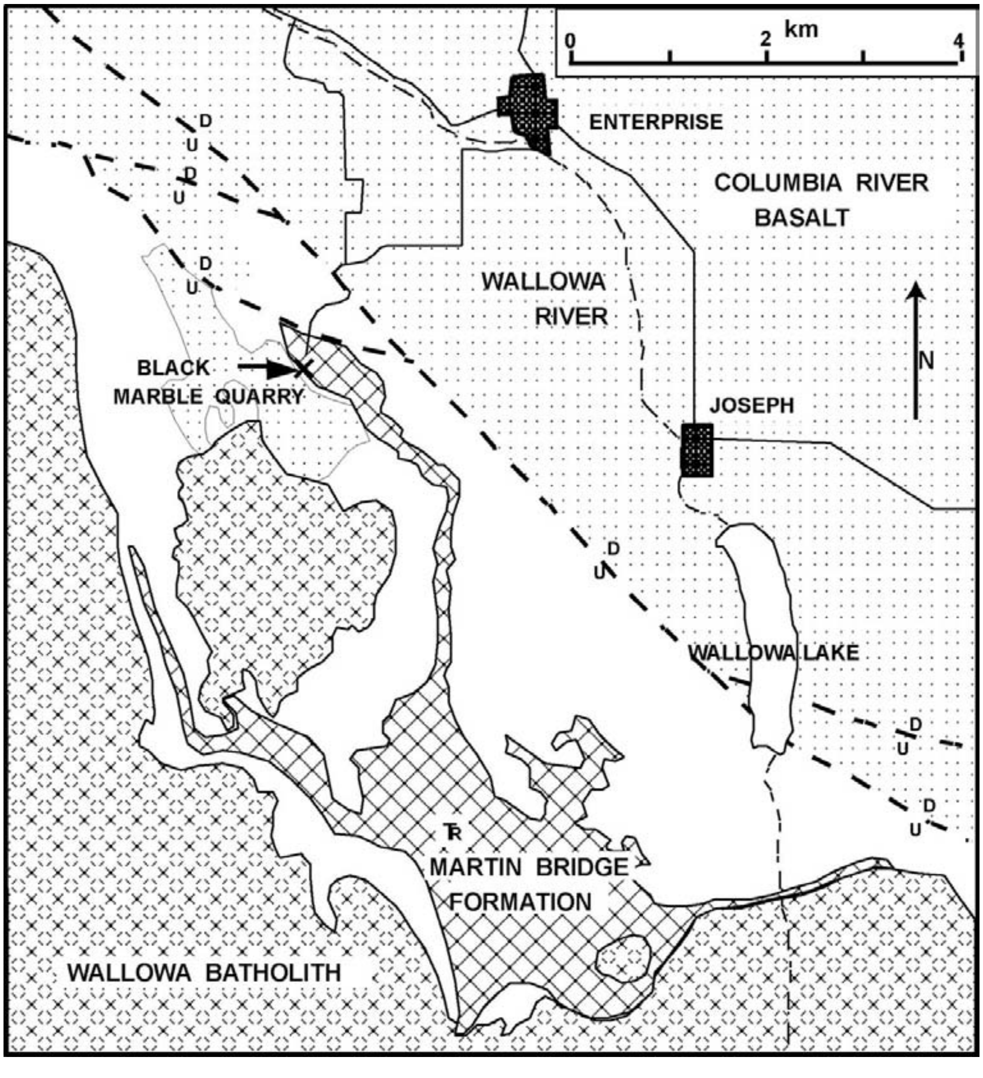

Figure 15. Generalized geologic map of the Martin Bridge Formation exposed in the northern Wallowa Mountains. The Black Marble Quarry is indicated. Upthrown (U) and downthrown (D) blocks are shown. Modified from Nolf (1966).

The quarry consists of thick- to medium-bedded recrystallized limestone. Investigations by Stanley (1979, 1986) and Whalen (1985) showed at least 150 m of thick-bedded recrystallized limestone, which yielded a diverse silicified fauna of sponges, corals, "tabulozoan" brachiopods, bivalves and gastropods, and three new echinoid taxa. Although correlation with the Martin Bridge at Hells Canyon and in the northern Wallowa Mountains would seem logical, the silicified corals show greater resemblance to a silicified fauna in medium- to thick-bedded limestone from the Sutton Formation dated as Rhaetian (Crickmayi Zone) on Vancouver Island (Caruthers and Stanley, 2008), This is part of the greater Wrangellia succession. A rich gastropod fauna from the Lapwai quarry, reported by Haas (1953, p. 310), has been described by Nützel and Erwin (2004) who reported over 60 species and similarity with some Wallowa gastropods. Nützel and Erwin (2004) illustrated from the Lapwai quarry the ammonoid *Gnomohalorites cordilleranus*, indicative of early late Norian (Sevatian) time, thus confirming the late Norian age suggested by Stanley (1979). Such dates, however, would suggest more appropriate correlations with the Hurwal Formation rather than the Martin Bridge (Fig. 4).

Carbonate facies at the Lapwai quarry include mudstones, bioturbated peloid and bioclast wackestone, peloid-intraclast packstone, bioclast grainstone, peloid grainstone, and coral-spongiomorph bafflestone (Whalen, 1985). Coral-spongiomorph bafflestone units occur as lenses or thickets 1–5 m in diameter and 1–2 m thick. Mudstone and wackestone facies represent deposition under relatively deep subtidal conditions below fair-weather wave base, whereas packstones and grainstones were probably deposited above fair-weather wave base (Whalen, 1985). Broken and rotated coral colonies (Squires, 1956) are evidence of strong wave or current activity. Although pervasive reef structure is not indicated, the fossil associations and microfacies do suggest that a patch reef-type environment with numerous thickets of corals and spongiomorphs must have existed.

Halobia has not been reported from the Lapwai quarry and many invertebrate species do not appear similar to those of the Martin Bridge Formation (Stanley, 1986). At present we can assign this limestone to neither the Martin Bridge nor the Hurwal. Perhaps the best approach is to refer to the limestone of the Lapwai quarry as "the Mission Creek Limestone" (Nützel and Erwin, 2004). Furthermore, we cannot exclude the possibility that the Lapwai quarry might represent a fragment of another terrane, separate from the Wallowa terrane .

Other Occurrences?

Two other localities of potential Martin Bridge rock types occur in the Seven Devils Mountains. They include the metamorphosed marble, phyllite, schist, and related rocks of the Riggins area (Hamilton, 1963) and a locality near the mouth of the Grande Ronde River (Vallier, 1977, p. 48). The Riggins locality, near the town of Lucile, Idaho (10–11 mi north of Riggins), is near the suture zone of the Wallowa terrane (Fig. 2). Unfortunately it is too intensely sheared and metamorphosed to be compared profitably with other sections discussed above. The Grande Ronde locality has not been studied in any detail, but

Figure 16. Light-colored branching spongiomorphs (recrystallized) and some smaller coral fragments stand out from the darker matrix in a fallen block in the Black Marble Quarry. Scale in centimeters.

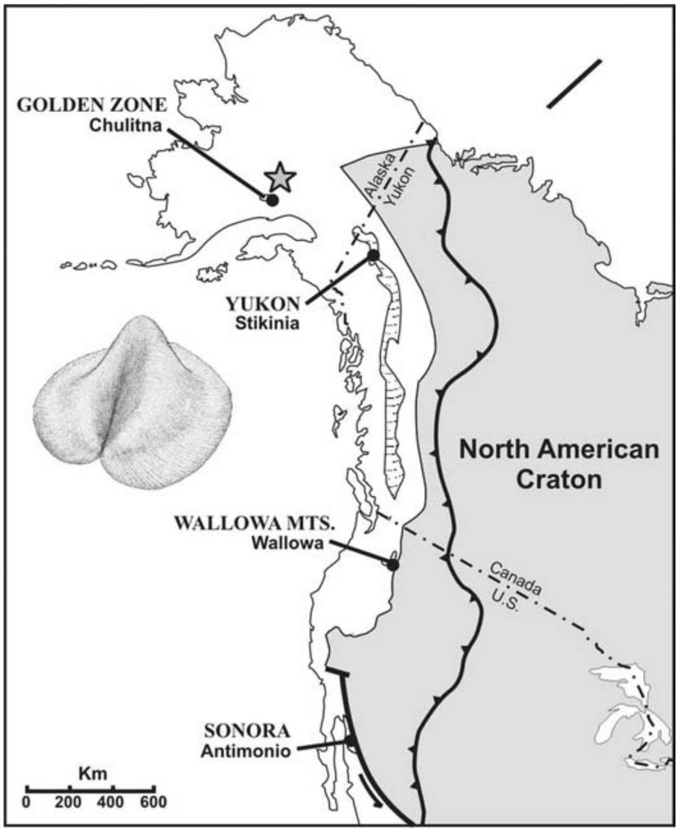

Figure 17. Generalized terrane map showing sites in four terranes of western North America that have yielded Norian wallowaconchid bivalves. Shaded area is the North American craton, and line of teeth marks indicates position of fold and thrust belt.

according to Follo (1994) it is intensively metamorphosed and structurally complicated and thus not useful for stratigraphic study. Another site at the mouth of Cottonwood Creek (Goldstrand, 1994, p. 1439) near the Triassic-Jurassic unconformity may contain the lower part of the Martin Bridge.

Martin Bridge–Type Limestone Occurrences in the Hurwal Formation

The post–Martin Bridge history of the Wallowa terrane is revealed in conglomerate and breccia, which occur in the overlying deeper-water Hurwal Formation. Nolf (1966) cited huge chaotic breccia deposits of the Deadman Lake unit (Fig. 11) that contain limestone blocks, some of which reach up to 300 m across. The Black Marble quarry may lie within one of these clasts. Reef corals, spongiomorphs, and other fossils of Norian age contained within some limestone clasts of this unit are similar to those of the Martin Bridge. Follo (1992) believed the deposit was an olistostromal megabreccia derived by downslope slump and/or debris flow from a source area located somewhere north of the outcrop area. The limestone clasts within the Deadman Lake unit most likely came from an extensive, but as yet unknown, carbonate complex in existence during post–early Norian time after the Martin Bridge of the northern Wallowa Mountains had already been drowned (Nolf, 1966). We believe, however, that like the Deadman Lake unit, reef blocks within this Hurwal unit could also have been derived from another Upper Triassic carbonate platform complex within the Wallowa terrane, lying to the north or the northwest. The limestone at Mission Creek, Idaho, could be part of that carbonate platform. A land source is indicated in the rounded nature of the clasts within the Excelsior Gulch, which implies “fluvial transport or wave reworking in a coastal environment prior to redeposition in deeper water” (Follo, 1992, p. 1568).

The Excelsior Gulch Conglomerate (Fig. 4) is another distinctive unit in the Hurwal Formation of the southern Wallowa Mountains containing limestone clasts (Follo, 1992). Dated as middle Norian or younger, it contains a much more abundant and diverse reef fauna with lithofacies and fossils nearly identical to those of the Summit Point Member, but it also yields chert clasts like those from the Baker terrane and unknown from the Wallowa terrane. The Excelsior Gulch conglomerate also produced rare clasts containing abundant dasycladacean algae, which are unknown from the Martin Bridge (Flügel et al., 1989). Follo (1992) recognized the clasts and noted the differences between the Excelsior Gulch and the Deadman Lake unit. He suggested the nearby Baker terrane as the source of those clasts. However, it seems equally plausible, owing to the similarity of the reefal fossils in the Excelsior Gulch clasts to those from the Summit Point Member, that the abundant reef limestone clasts could also have been derived from uplifted middle to late Norian carbonate reef limestone within the Wallowa terrane.

DEPOSITIONAL HISTORY OF THE WALLOWA TERRANE

The Martin Bridge Formation records the relatively abrupt onset of carbonate sedimentation following cessation of volcanic activity and a decrease in output of volcaniclastic sediment. Vallier (1995) interpreted this as marking a change in plate vector with the consequent firing up of volcanism in the Olds Ferry terrane (Huntington Island Arc). This terrane, adjacent to the Wallowa terrane, is characterized by volcanic and mixed carbonate and volcaniclastic rocks and linked by provenance to the Wallowa terrane (see LaMaskin, this volume). If so, the Wallowa terrane may have become forearc to the Olds Ferry terrane. Eventually the Wallowa terrane amalgamated with other terranes in the Blue Mountains and by Cretaceous time had collided with the North American craton. Relative to other Triassic sequences in the North American Cordillera, limestone deposits of the Martin Bridge are not as thick as those found in other terranes, notably in the Alaskan portion of Wrangellia, but they nevertheless record a whole suite of typical shallow- to deeper-water carbonate facies. These include reef development, downslope debris, and deeper-water, black-shale environments. With the aid of diagnostic fossils, various members and lithologies within the Martin Bridge Formation may be correlated and their depositional history reconstructed. The often abrupt lateral facies changes from one rock type to another are actually predicted in models of carbonate sequences deposited on subsiding volcanic oceanic islands (Soja, 1996), and patterns differ greatly from those from cratonal settings.

Paleogeography and Tectonic History

Paleomagnetic findings confirm a tropical oceanic setting for the Wallowa terrane at ~18° north or south of the paleoequator in Middle and Late Triassic time (Hillhouse et al., 1982). Early Permian data dictate a Northern Hemisphere position (24° ± 12°) and possible subsequent southward transport relative to North America (Harbert et al., 1988). The present geographic relationships and paleopole data on the Wallowa terrane relative to the North American craton confirm that the Wallowa terrane has not experienced any major relative latitudinal shifts since the Triassic like those of many other Cordilleran terranes, although both craton and Wallowa terrane moved northward.

Exposures of shallow- and deeper-water Martin Bridge facies and members in the northern and southern Wallowa Mountains respectively (Follo, 1992), indicate a northeast-southwest platform to basin transition. However, rotation has affected the Wallowa terrane since deposition of the early Mesozoic rocks. The Wallowa terrane is assumed to have experienced ~65° of clockwise rotation following Mesozoic accretion (Wilson and Cox, 1980). Restoration of this tectonic rotation would produce a roughly west to east platform-to-basin transition between early and middle Norian time as depicted in cartoon form (Fig. 18). Follo (1992) interpreted slope and basinal Martin Bridge facies

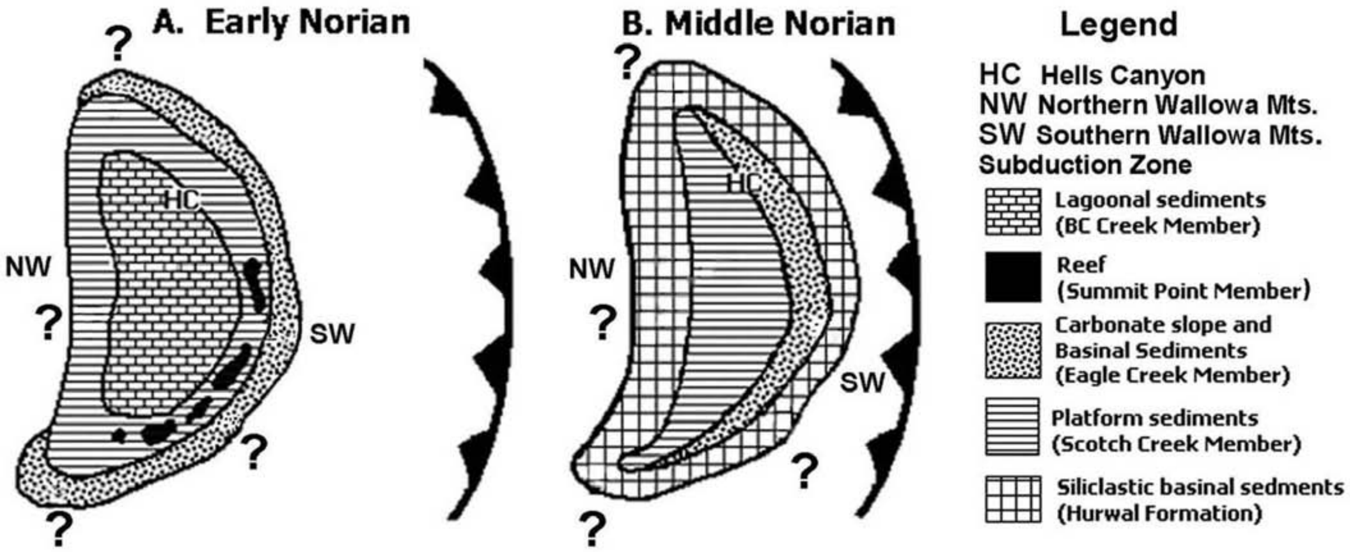

Figure 18. Geotectonic-lithofacies “cartoon” for the Wallowa terrane during (A) early Norian and (B) late Norian time (after White et al., 1992). Subduction zone and polarity of subduction indicated by teeth marks. Letters indicate areas discussed in text. Note map area has been restored to its Triassic position (unrotated 65° counter clockwise) following Hillhouse et al., (1982), and for simplification, the Wallowa terrane is treated as one island. Question marks indicate uncertainties. By Middle Norian time the terrane is closer to the subduction zone and the reef and lagoon sediments have vanished, being replaced with deeper-water facies as platform drowning occurs.

as having been deposited along the western margin of a forearc basin with accretionary wedge deposits of the Baker Terrane overlying a west-dipping subduction zone.

Depositional History of the Martin Bridge

The stratigraphic problems discussed earlier illustrate the nature of facies changes within a volcanic island arc setting and the resulting stratigraphic problems in classification and physical lithostratigraphic correlation. Combined localities of the Martin Bridge reveal a late Carnian to middle Norian carbonate sequence that begins with peritidal sedimentation and progressively deepens upward. Although frequently considered an “island” there is actually little, if any, evidence for subaerial exposure or land surfaces after the initial evaporitic deposition characterizing the base of the Martin Bridge. There is no evidence of soil profiles, caliche, root casts, or terrestrial deposits, and most of the Norian sequence indicates the presence of a single (or a series of) shallowly submerged platform(s) where carbonate sedimentation kept pace. By late Norian time, subsidence finally outpaced sedimentation. This resulted in the drowning of the platform (Whalen, 1988) as indicated by the transition to deeper-water platform and slope deposits (Scotch Creek Member) that both overlie and interfinger laterally with platform and reef deposits of the BC Creek and Summit Point Members (Fig. 4).

This drowning sequence and an overall relative rise in sea level are clearly seen in the Martin Bridge at Hells Canyon. Following cessation of volcanism and volcaniclastic deposits, carbonate deposition was initially under supratidal, then peritidal, and finally shallow subtidal conditions. The peritidal interval (60 m) is about one-third thinner than the sequence of similar facies in the northern Wallowa Mountains (Whalen, 1988; Follo, 1992), indicating a more distal depositional and deeper paleogeographic setting. Peritidal deposits in Hells Canyon were quickly replaced by deeper subtidal facies (bioclast, intraclast, peloid wackestones and packstones, spongiomorph bafflestones) as relative sea level rose. Bioclast and ooid grainstones were deposited in open-shelf shoal environments and they are interbedded with subtidal facies. In the Summit Point site the reef facies of the Summit Point Member is overlain by the Scotch Creek Member (Figs. 4 and 7), which represents a deeper-water slope facies. This change would represent a response to the subsiding nature of the platform margin.

The sequence in the northern Wallowa Mountains records the deposition of open shelf subtidal deposits and carbonate sand shoals thought to be laterally equivalent to algal laminated and replaced evaporite-bearing peritidal limestones (Follo, 1986, 1994). The Martin Bridge rocks in the northern Wallowa Mountains thus represent a lateral facies change that can only be seen as a vertically stacked sequence in Hells Canyon. Peritidal and open shelf facies are overlain by silty bioclastic carbonate grainstones with graded beds, scour and fill structures, and slump folds, which are interbedded with calcareous argillites that Follo (1986, 1994) interpreted as slope deposits implying a deepening-upward sequence. The Martin Bridge is overlain by even deeper water facies of the Hurwal Formation, but in the northern Wallowa Mountains lateral lithofacies relationships between the Martin Bridge and the Hurwal are not exposed (Follo, 1992).

Both in the southern Wallowa Mountains (Smith and Allen, 1941; Nolf, 1966) and near Riggins, Idaho (Lund et al., 1983), the Martin Bridge is overlain and intercalated with rocks that indicate a deeper-water origin. The volcaniclastic and calcareous argillites, graywackes, and conglomerates of the Hurwal Formation (Smith and Allen, 1941; Nolf, 1966) and metamorphosed equivalents in the Lucile Slate (Lund et al., 1983) indicate a platform-to-basin transition as well as drowning of the Martin Bridge carbonate platform (Whalen, 1988). Tropical platform carbonates have the potential to outpace most relative rises in sea level (Schlager, 1981) and several factors may have contributed to platform drowning, including (1) rapid rates of relative sea-level rise, (2) increased volcaniclastic input, (3) northward tectonic transport out of the tropics, and (4) lack of a significant reefal rim. Whalen (1988) mentioned the possibilities for points 1 and 4 playing a role. These characteristics are shown in Figure 19.

Late Triassic eustatic sea level is poorly understood, but most localities imply a Norian lowstand (Vail et al., 1977; Haq et al., 1987; Hallam, 1992). The general deepening-upward trend of the Martin Bridge–Hurwal sequence is thus interpreted to represent thermal subsidence of the island arc (Whalen, 1988). High rates of short-term sea-level rise can cause platform drowning (Schlager, 1981) and may have contributed to the lack of a reefal rim around the Martin Bridge platform (Whalen, 1988). High rates of sea-level rise, however, may not have been necessary to drown the Martin Bridge platform, because of to the synergistic effects of arc subsidence, volcaniclastic input, northward transport, and lack of a persistent reef rim. Clastic sediment input and change in environmental conditions and nutrient influx are all accepted causes of carbonate platform drowning. Facies of the Hurwal Formation provide clear evidence of increased clastic input. If a Northern Hemisphere paleolatitude for the Wallowa

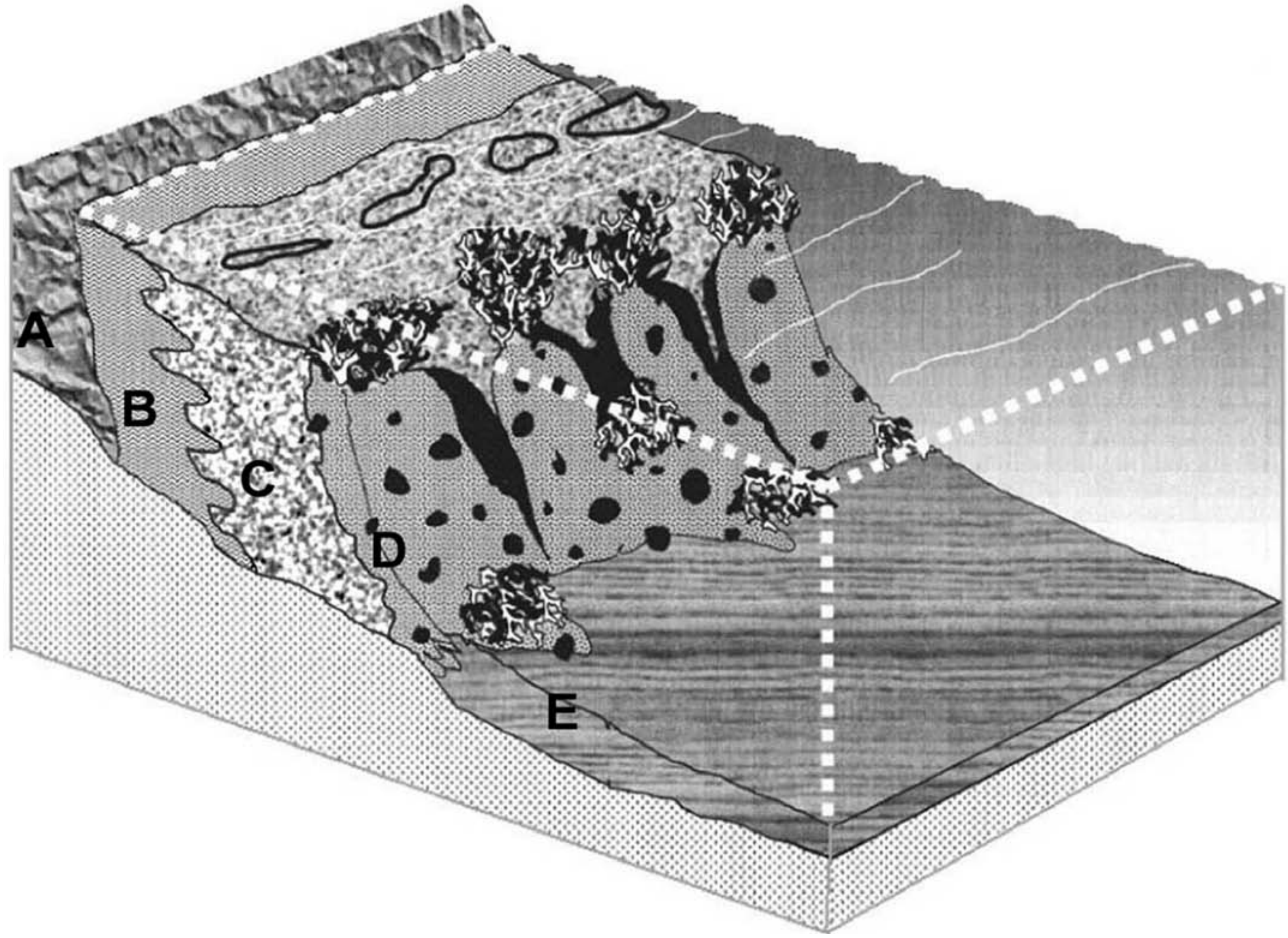

Figure 19. Schematic model of deposition for various members of the Martin Bridge Formation. (A), Shoreline (subaerial); (B), evaporitic and peritidal sediments of the BC Creek Member; (C) shallow water, more normal salinity, lagoonal sediments, and patch reefs of the Scotch Creek and Summit Point Members; (D) downslope debris beds, including olistostromal slide blocks of the slope that occur within the sequence at Eagle Creek as well as at other sites in the Wallowa Mountains; (E), deeper-water basin including the dysaerobic black mud environment of the Eagle Creek Member.

terrane is accepted (Harbert et al., 1988), then progressive northward transport during Late Triassic time may have caused environmental stress, and cooling may have contributed to the demise of the platform and drowning, similar to the "Darwin point" concept postulated for the Hawaiian-Emperor seamount chain (Grigg, 1982).

CONCLUSIONS

We suggest that the Wallowa terrane provides one of the best and most complete examples in the Triassic of North America for shallow-water carbonate depositional patterns in an oceanic island arc setting. The stratigraphic problems in both the nomenclature and classification of the Martin Bridge can be attributed to the complex variety of subenvironments and expected depositional patterns within an island arc setting. Detailed stratigraphic, sedimentologic, and paleontologic studies have helped resolve correlation problems and allow reconstruction of depositional patterns within the island arc setting. A better understanding of the depositional settings allows us to establish a composite stratotype with a number of reference sections and four members to better account for variations in rock types within the stratigraphic framework of the island arc. A depositional model for the Martin Bridge takes into account the development in such a setting, where one would expect rather sudden facies changes from deeper disaerobic mud to downslope accumulations to shallow platform (patch reef and lagoon) facies. The various members of the Martin Bridge can best be understood in the context of such a model (Fig. 20).

We propose retention of the name Martin Bridge Formation defined by a composite section. This composite section includes the original type section of the Martin Bridge Formation in the southern Wallowa Mountains as well as other sections (Fig. 4). We include a supplemental reference section from Hurricane Creek in the northern Wallowa Mountains near Enterprise and we formally designate four members of the Martin Bridge Formation from stratotypes in both the northern and southern Wallowa Mountains. These are the Eagle Creek and Summit Point Members in the southern Wallowa Mountains, and the BC Creek and the Scotch Creek Members from northern Wallowa Mountains and Hells Canyon. Units of the Martin Bridge Formation record rapidly shifting facies and depositional patterns within the framework of a tropical volcanic island arc. The proposed stratigraphic nomenclature and stratotypes reflect and better account for the complex depositional patterns in an island arc setting. They record the initial establishment of shallow-water, peritidal, evaporitic conditions after an abrupt cessation of volcanic activity. Facies of the Martin Bridge Formation indicate that the platform initially kept pace with subsidence but was eventually drowned, as indicated by the deepening-upward succession. Shoal and reef margin facies grade laterally and vertically into deeper-water platform and slope deposits, which in turn were transitional into

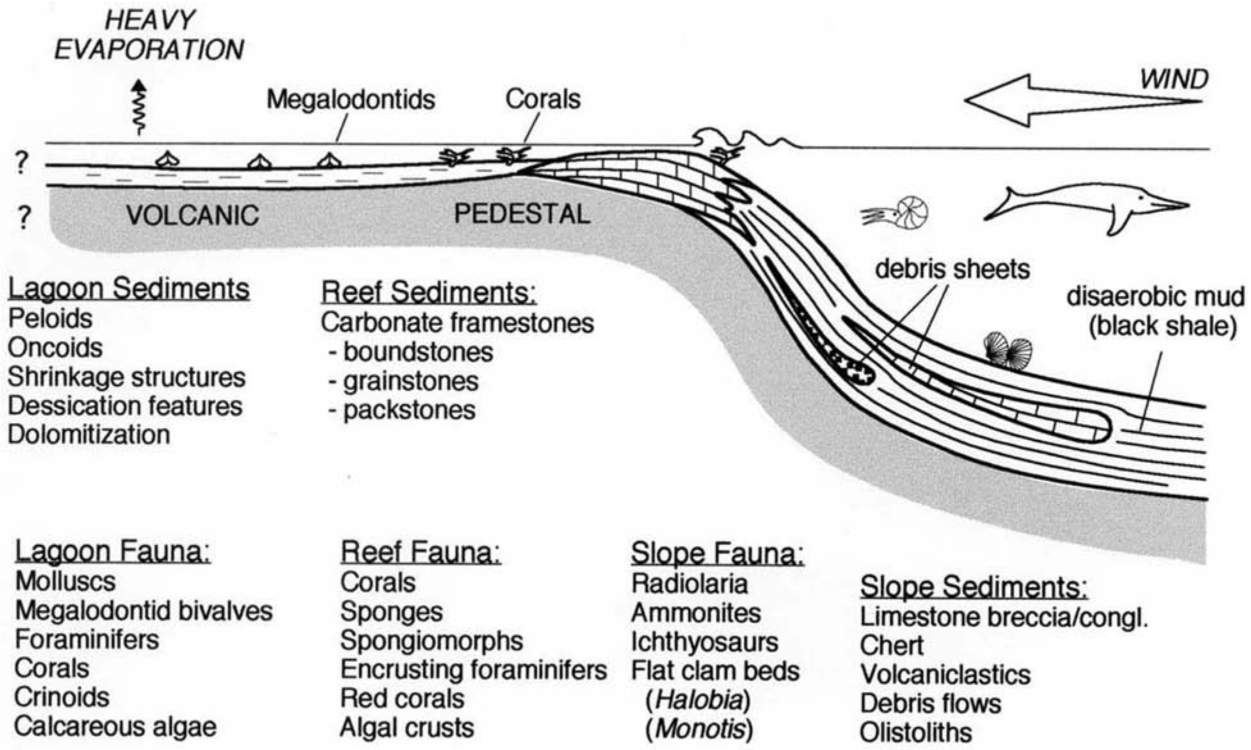

Figure 20. Generalized "cartoon" model for the Martin Bridge lithofacies and members showing sediment types and biotic compositions. In this model one can appreciate how lithofacies and biotic types can laterally change rapidly in the island arc setting of the Wallowa terrane. Also note that the reef belt (best developed on the windward side) is much narrower relative to the more extensive lagoon.

basinal dysaerobic black-shale and mudstone facies. The end of the Martin Bridge deposition was characterized by the drowning of the carbonate platform with a transition to deeper-water turbiditic sedimentation before a Late Triassic (middle Norian) transition into the overlying Hurwal Formation.

The Hurwal Formation contains some carbonate intervals, but most of the rock types (shales, spicular mudstones, and turbidite deposits) are clearly of deeper-water origin and indicate drowning of the platform. Chaotic carbonate breccias and conglomerate deposits in the Hurwal record yet another phase of younger carbonate platform development later in middle to late Norian time somewhere outside of the present outcrop area. Conglomerate and breccia, referred to as the Deadman Lake and Excelsior Gulch units in the northern and southern Wallowa Mountains respectively (Nolf, 1966; Follo, 1992), show an abundance of corals, sponges, spongiomorphs, and a variety of other reef organisms within limestone clasts ranging from a few centimeters to tens or perhaps as much as 100 m in length. Follo (1992) interpreted limestone clasts of the Deadman Lake unit to have been derived from a northern source whereas limestone and volcanic rock fragments and chert of the Excelsior Gulch unit were derived from a uplifted southern source (Baker terrane?). Although the exact source of the two distinctive chaotic deposits and their relationships to each other are unclear, they are important in suggesting the presence of a subaerial land source and the existence of younger (middle–late Norian?) carbonate platforms from which reef debris was shed downslope into the adjacent basin.

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