Roberts Mountains allochthon and the western margin of the Cordilleran miogeocline in the Northern Ritter Range pendant, eastern Sierra Nevada, California

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ABSTRACT

The truncated southwestern edge of the Roberts Mountains allochthon is exposed in the Northern Ritter Range pendant in the eastern Sierra Nevada, structurally overlying parautochthonous rocks of the Cordilleran miogeocline. The Northern Ritter Range pendant exposes units that have the same stratigraphic affinities and structural relationships as rocks of the Antler orogenic belt in Nevada.

Paleozoic metasedimentary rocks exposed in the pendant consist of two major units: (1) a structurally complex, disrupted chert and argillite unit interpreted to be correlative with the Roberts Mountains allochthon; and (2) a stratigraphically coherent siliceous and calcareous unit, the Rush Creek sequence, that is interpreted to be part of a transitional outer shelf and slope assemblage of the lower Paleozoic Cordilleran miogeocline. In the Northern Ritter Range pendant, the Roberts Mountains allochthon structurally overlies the Rush Creek sequence along a north-striking, steeply dipping fault zone that may be a preserved remnant of the Roberts Mountains thrust, which in north-central Nevada emplaced the allochthon over outer shelf and slope strata of the Cordilleran miogeocline during the Late Devonian–Early Mississippian Antler orogeny.

These stratigraphic and structural belts are truncated on the southwest side of the pendant by the Gem Lake shear zone, a northwest-trending dextral strike-slip fault associated with the Cretaceous Sierra Nevada batholith. The Northern Ritter Range pendant thus defines both the southwestern limit of the Antler orogenic belt and the westernmost exposures of parautochthonous miogeoclinal rocks in the central Cordillera.

INTRODUCTION

A number of roof pendants and wall rock septa of Paleozoic metasedimentary rocks are preserved within the Mesozoic Sierra Nevada batholith in the eastern Sierra Nevada of California (Fig. 1). These pendants contain an important record of stratigraphic and structural relations along the Paleozoic Cordilleran continental margin, relations that elsewhere in eastern California have been obscured by voluminous Mesozoic plutonism or buried by Cenozoic strata.

Numerous hypotheses for the late Paleozoic and early Mesozoic tectonic evolution of this region have been proposed, including accretion of allochthonous terranes (Nokleberg, 1983), sinistral truncation of the Paleozoic continental margin and southward offset of Paleozoic rocks (e.g., Davis et al., 1978; Stone and Stevens, 1988; Walker, 1988), and east-vergent contractional deformation superimposed on an original promontory in the continental margin (Dickinson, 1981; Oldow, 1984). Subsequent Cretaceous dextral displacement of Paleozoic rocks was proposed by Schweickert and Lahren (1990), Stevens et al. (1992), and Kistler (1993), among others. Important to all these models is the geographic extent of autochthonous or parautochthonous miogeoclinal rocks of the Cordilleran continental margin, and the location and nature of the boundary between these miogeoclinal rocks and allochthonous eugeoclinal rocks to the north and west.

The focus of this paper is the Northern Ritter Range pendant, which is located in the east-central Sierra Nevada (Fig. 2) at the eastern edge of Yosemite National Park. The pendant consists of a 3–5-km-wide septum of Paleozoic metasedimentary rocks and Mesozoic metavolcanic rocks that extends 20 km northwest from the larger Ritter Range pendant (Kistler, 1966a, 1966b; Huber and Rinehart, 1965; Greene, 1995). Strata in the Northern Ritter Range pendant generally strike northwest and dip steeply to the southwest (Fig. 3). All pre-Tertiary rocks in the Northern Ritter Range pendant have been metamorphosed under greenschist to epidote-amphibolite facies conditions.

In this paper we describe the western limit of parautochthonous miogeoclinal rocks of the Cordilleran continental margin in the Northern Ritter Range pendant, and the fault contact that separates them from lower Paleozoic rocks that we correlate with the Roberts Mountains allochthon. Similar structural relations occur in north-central Nevada, where basinal rocks of the Roberts Mountains allochthon were emplaced over outer shelf and slope strata of the Cordilleran miogeocline during the Late Devonian–Early Mississippian Antler orogeny. We interpret the juxtaposition of basinal rocks and miogeoclinal rocks in the Northern Ritter Range pendant to indicate the southwestern limit of the Antler orogenic belt in the east-central Sierra Nevada.

PALEOZOIC STRATIGRAPHY

Previous studies grouped all Paleozoic metasedimentary rocks in the Northern Ritter Range pendant into one generalized unit termed the Lewis sequence (Kistler, 1966a, 1966b), which was thought to be late Paleozoic in age (Kistler and Nokleberg, 1979). New and more detailed mapping by Strobel (1986) and Greene (1995) allows division of the Lewis sequence

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GSA Bulletin, October 1997; v. 109; no. 10; p. 1294–1305; 10 figures; 2 tables.

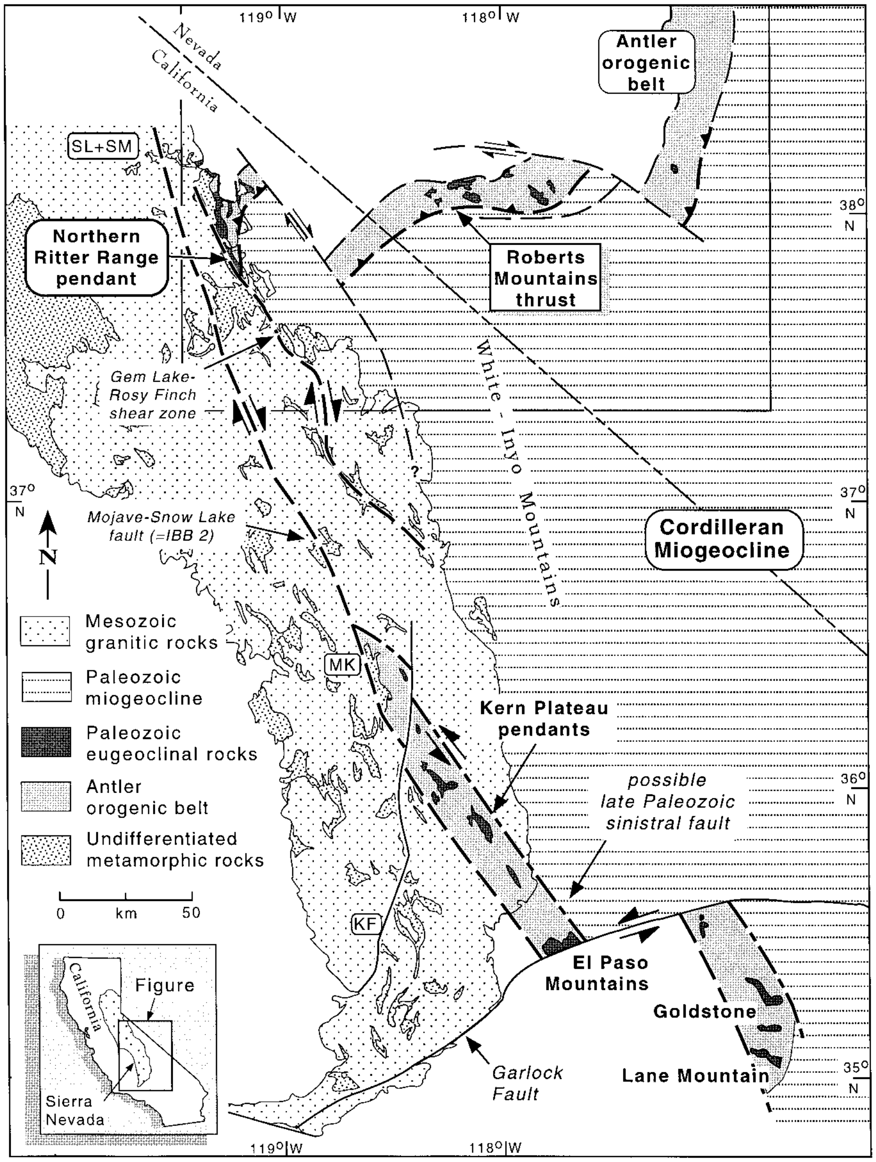

Figure 1. Generalized tectonic map showing the location of the Northern Ritter Range pendant and elements of the Antler orogenic belt from central Nevada to the Mojave Desert. Box indicates area of Figure 6. KF—Kern Canyon fault; MK—Mineral King pendant; SL + SM—Snow Lake and Sachse Monument pendants. Modified from Jennings (1977), Albers and Stewart (1972), and Kleinhampl and Ziony (1985); additional data are from Walker (1988), Dunne and Suczek (1991), and Schweickert and Lahren (1991).

(here abandoned) into three separate units: (1) a chert and argillite unit correlated with part of the Roberts Mountains allochthon (Schweickert and Lahren, 1987; Greene et al., 1989); (2) a siliceous and calcareous unit named the Rush Creek sequence (Strobel, 1986), correlated with Ordovician through Devonian continental slope and rise facies of the Cordilleran miogeocline (Stevens and Greene, 1994; 1995); and (3) rare fault slices of upper Paleozoic marble correlated with the Pennsylvanian Mount Baldwin Marble and indicating local development of a late Paleozoic carbonate platform (Greene and Dutro, 1991; Stevens and Greene, 1994; Greene and Schweickert, 1995).

Chert-Argillite Unit

The chert-argillite unit in the Northern Ritter Range pendant is structurally complex and consists predominantly of black chert that grades into siliceous argillite and locally to slate (Fig. 4). These rocks are thin bedded, dark rusty orange weathering, black to dark gray, and locally pyritic. Light gray–weathering phosphatic lenses, thin stringers, and nodules are locally abundant in the chert (Greene, 1995). Discontinuous, 1–2-m-thick lenses of sandy, highly cleaved marble are present at a few locations, and thin-bedded quartz siltstone is locally abundant in the northern part of the pendant. The chert-argillite unit commonly appears well bedded in outcrop, but individual layers are discontinuous on a scale of 1–5 m (Fig. 5A). Locally, disrupted layering, intraclast breccia beds, and chaotic units suggest that significant syndepositional deformation has occurred (Fig. 5B).

Very fine grained, thin-bedded to finely laminated, calc-silicate hornfels is present locally in the chert-argillite unit. The calc-silicate rocks form isolated lenses, 2–100 m thick and as long as 900 m, that are folded and deformed with the enclosing chert and argillite. The calc-silicate rocks are more competent than surrounding rocks, and the discontinuous nature of the intercalated lenses suggests large-scale boudinage and tectonic disruption of internal stratigraphy.

The predominance of chert and argillite in this unit indicates that deposition occurred in a basinal environment. The presence of continentally derived sandy limestone and quartz siltstone suggests that the chert-argillite unit was deposited in a continental margin basin probably adjacent to North America, as has been shown by Finney et al. (1993) for similar rocks of the Roberts Mountains allochthon in central Nevada.

Correlation and Age. No fossils have been recovered from the chert-argillite unit in the Northern Ritter Range pendant. The unit is, however, continuous northward from the Northern Ritter Range pendant into the Saddlebag Lake pendant (Kistler, 1966a; Greene, 1995), where it was correlated by Schweickert and Lahren (1987) with an Ordovician chert and shale unit in the Candelaria Hills in west-central Nevada (Fig. 6). In this section we discuss the evidence supporting this correlation and its tectonostratigraphic implications.

In the Saddlebag Lake pendant, the chert-argillite unit consists of highly deformed black chert and siliceous argillite, interbedded siltstone and calc-silicate hornfels, and minor lenses of quartzite, basalt, and limestone (Schweickert and Lahren, 1987; 1993). The unit there is unconformably overlain by as much as 30 m of lithic sandstone and chert-pebble conglomerate containing limestone clasts with Permian conodonts, which are assigned to the Diablo Formation (Schweickert and Lahren, 1987). These rocks are overlain by as much as 950 m of thinly bedded siltstone and fine sandstone locally containing chert and shale clasts and chert-pebble to chert-cobble conglomerate. These rocks are assigned to

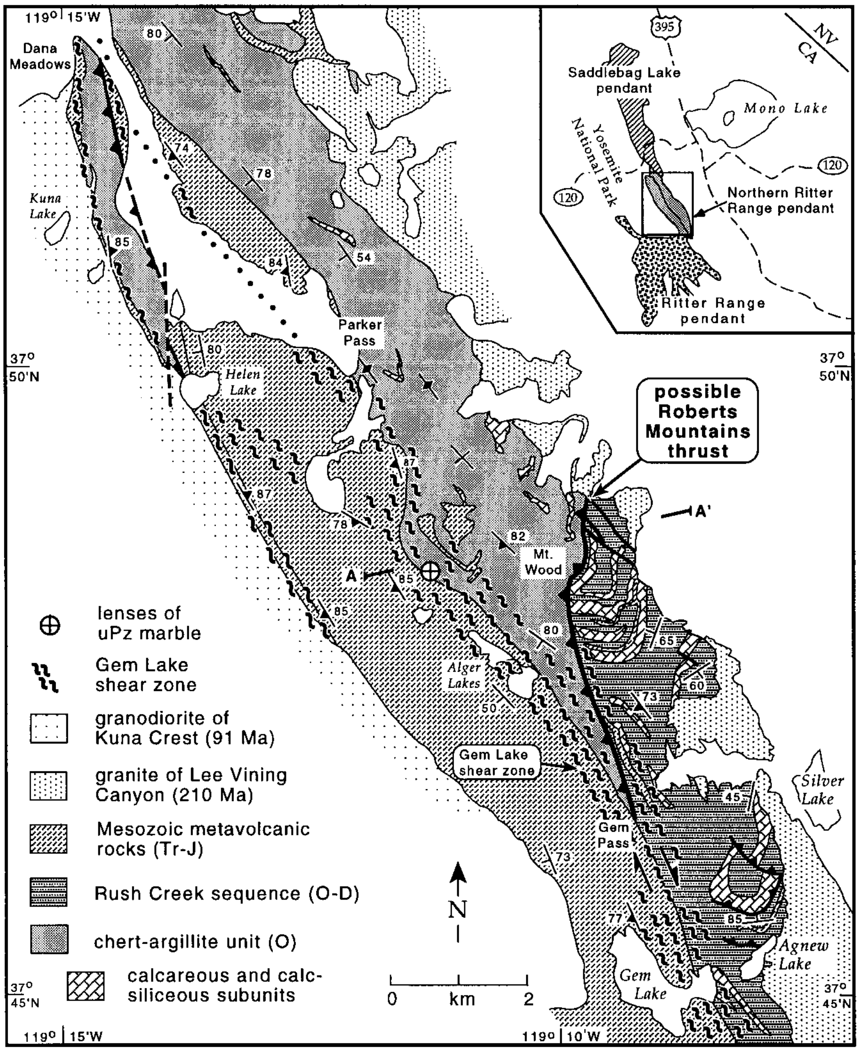

Figure 2. Generalized geologic map of the Northern Ritter Range pendant. Line A–A′ indicates location of the cross section shown in Figure 3. Simplified from Greene (1995).

the Candelaria Formation (Schweickert and Lahren, 1987).

In the Candelaria Hills, the stratigraphically lowest unit consists of thin-bedded, dark gray to black chert interbedded with dark gray siliceous argillite and laminated phyllitic shale, and structurally interleaved with sandy limestone and calcareous quartz sandstone (Stanley et al., 1977; Stewart, 1979). Locally abundant graptolites in the phyllitic shale indicate an Ordovician age (Ross, 1961; Stewart, 1979), whereas the calcareous quartz sandstone contains Devonian conodonts (Stanley et al., 1977; Stewart, 1979). The chert and shale unit is unconformably overlain by the Permian Diablo Formation, which consists of as much as 25 m of thinly interbedded, medium- to coarse-grained sandstone and chert-pebble conglomerate (Speed et al., 1977). The Diablo Formation is overlain by the Lower Triassic Candelaria Formation, consisting of more than 975 m of green to brown shale and sandy shale, massive brown sandstone, and interbedded sandstone and chert-pebble conglomerate (Ross, 1961; Albers and Stewart, 1972).

Correlation of the Paleozoic succession in the Candelaria Hills with that in the Saddlebag Lake and Northern Ritter Range pendants is further strengthened by notable similarities in their structural geometries. Both areas consist of structurally disrupted sections of predominantly chert and argillite unconformably overlain by relatively intact upper Paleozoic strata. Two major generations of mid-Paleozoic structures were recognized in lower Paleozoic rocks in the Candelaria Hills by Oldow (1984). First-generation, tight to isoclinal folds with well-developed axial planar cleavage are overprinted and reoriented by second-generation folds with predominantly northeast-striking, upright axial surfaces. These structures are similar to those

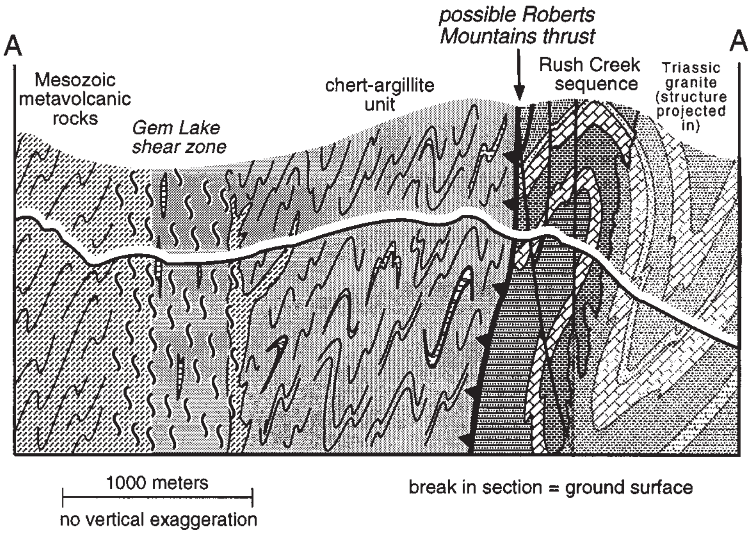

Figure 3. Diagrammatic cross section of the Northern Ritter Range pendant. Paleozoic metasedimentary rocks of the Rush Creek sequence are structurally overlain by the chert-argillite unit, which is faulted against Mesozoic metavolcanic rocks of the Koip sequence. The location of section line is shown in Figure 2.

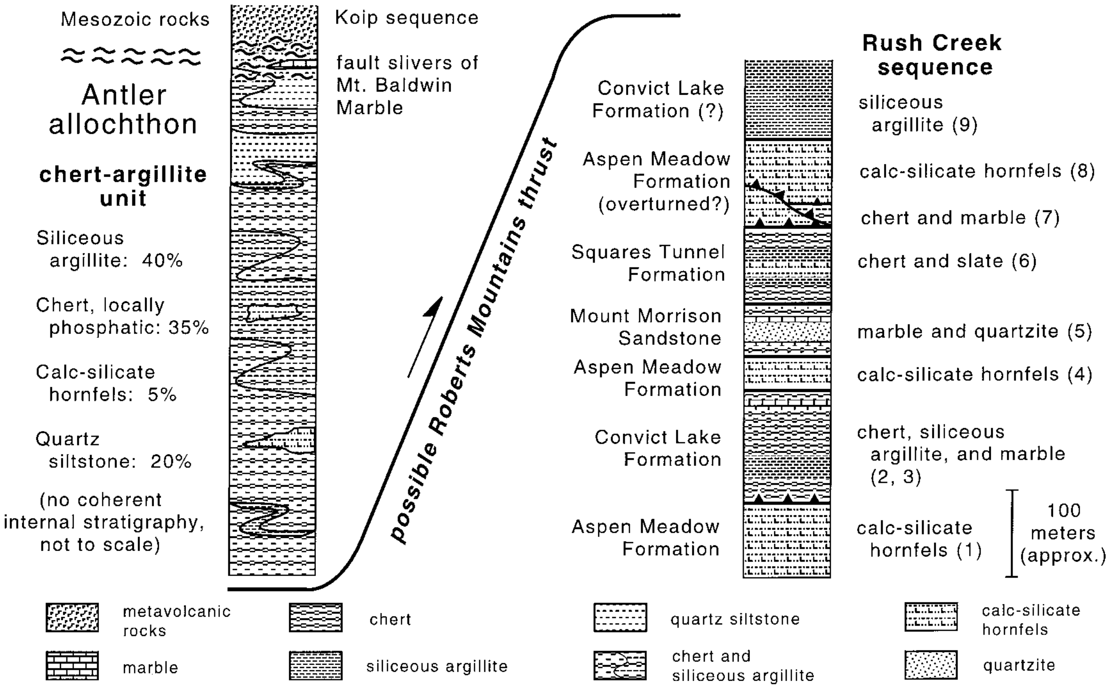

Figure 4. Diagrammatic lithologic columns of the chert-argillite unit and the Rush Creek sequence, showing lithology, structural relations, and proposed correlations. Lithologic column of the Rush Creek sequence is from the area north of Agnew Lake and is modified from Strobel (1986). Numbers in parentheses are the unit designations of Strobel (1986). Lithologic column of the chert-argillite unit is diagrammatic, and is not to scale.

recognized in the Northern Ritter Range pendant, which include first-generation tight to isoclinal folds and upright second-generation folds interpreted to have been predominantly northeast trending prior to reorientation during third-generation folding. These structures are described in detail in a later section.

In summary, significant similarities in lithology, structural style, and stratigraphic succession between the Candelaria Hills in west-central Nevada and the Saddlebag Lake and Northern Ritter Range pendants in the eastern Sierra Nevada support correlation of the Paleozoic successions in these three areas.

Tectonostratigraphic Nomenclature. The chert and shale unit in the Candelaria Hills was originally assigned to the Palmetto formation by Ferguson et al. (1954), and that name was used by Schweickert and Lahren (1987, 1993) and Greene (1995) for the correlative rocks in the Saddlebag Lake and Northern Ritter Range pendants. Other workers, however (e.g., Ross, 1961; Stewart and Poole, 1974; Stewart, 1980; Stevens and Greene, unpub. data), have noted marked differences between the chert and shale unit in the Candelaria Hills and the Palmetto Formation in the Palmetto Mountains (Fig. 6). In the Palmetto Mountains, rocks mapped as Palmetto Formation locally appear to depositionally overlie the Cambrian Emigrant Formation (Buckley, 1971; Albers and Stewart, 1972; Stewart, 1980). Those rocks closely resemble siliceous and calcareous rocks of the Ordovician Convict Lake Formation in the eastern Sierra Nevada, which we interpret as deeper water equivalents of autochthonous Ordovician shelf carbonates to the south (Stevens and Greene, 1995; unpub. data). The chert and shale unit in the Candelaria Hills, in contrast, is structurally complex and contains structurally interleaved Ordovician and Devonian strata with rare interstratified mafic volcanic rocks (Stewart, 1980). Such assemblages in north-central Nevada are generally considered to be part of the Roberts Mountains allochthon, and correlative with units such as the Vinini Formation (Stewart, 1980; Oldow, 1984; Finney and Perry, 1991).

We therefore support the correlation of black chert and siliceous argillite in the Saddlebag Lake and Northern Ritter Range pendants with the chert and shale unit in the Candelaria Hills (Schweickert and Lahren, 1987, 1993), and we interpret both these areas as exposures of the Roberts Mountains allochthon. Because of the ambiguities in previous usage, we prefer not to use the term Palmetto Formation and instead refer to the chert and argillite in the Northern Ritter Range pendant informally as the "chert-argillite unit."

In summary, eugeoclinal rocks of the Roberts Mountains allochthon are exposed in the Candelaria Hills, in the Saddlebag Lake pendant, and in the Northern Ritter Range pendant. The Roberts Mountains allochthon thus extends from central Nevada as far southwest as the Northern Ritter Range pendant on the eastern edge of the Sierra Nevada, implying that, as in central Nevada, structurally underlying parautochthonous rocks of the Cordilleran miogeocline should lie to the southeast, either within or southeast of the Northern Ritter Range pendant.

Rush Creek Sequence

The Rush Creek sequence was informally defined by Strobel (1986) to include a stratified succession of siliceous, calc-silicate and calcareous metasedimentary rocks exposed north of Agnew Lake (Fig. 4). The Rush Creek sequence has since been expanded to include similar rocks exposed for 9 km along the southeast edge of the Northern Ritter Range pendant (Fig. 2) (Greene, 1995).

The Rush Creek sequence includes five major rock types: calc-silicate hornfels, siliceous argillite, bedded chert, sandy marble, and calcareous quartzite (Table 1). These are interbedded on both meter scale and 10–100 meter scale, giving exposures of the Rush Creek sequence a distinctive banded appearance (Fig. 7). The rocks generally are fine grained and thin bedded. Rare sedimentary structures, developed primarily in the calc-silicate hornfels, include fine plane laminations, cross laminations, graded beds, and small scour and fill structures. No syndepositional deformational features were observed, whereas in the chert-argillite unit such features are relatively common. Calcareous rocks make up about 50% of the Rush Creek sequence, in contrast to the chert-argillite unit, in which calcareous rocks compose less than 5% of the section. Although the overall sequence is substantially deformed by thrust faults and tight mesoscopic to macroscopic folds (Fig. 2), individual strata in the Rush Creek sequence can be traced for as much as 1 km.

Correlation and Age. No age-diagnostic fossils have yet been discovered in the Rush Creek

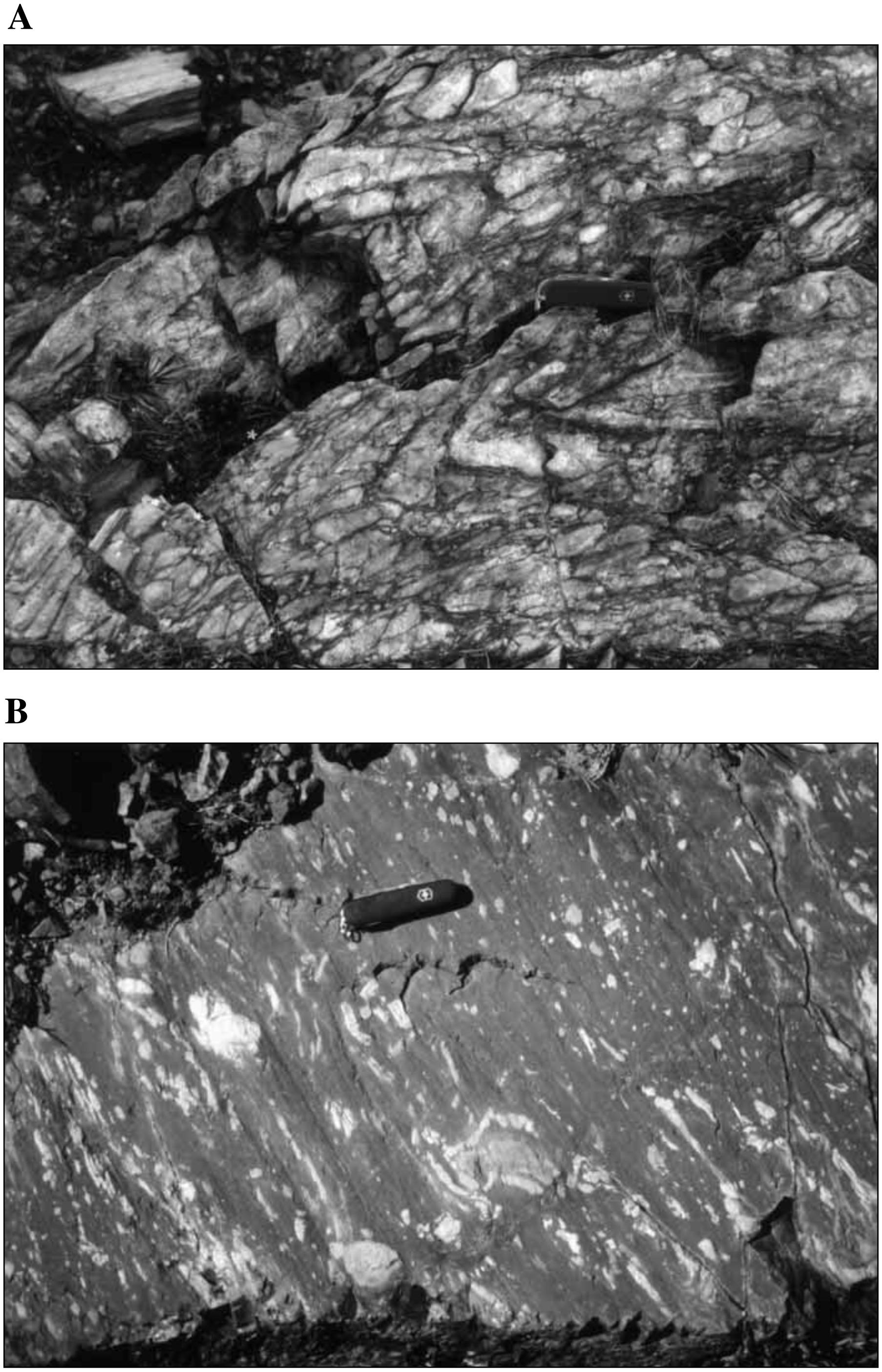

Figure 5. (A) Tight folds and dismembered bedding in quartz siltstone of the chert-argillite unit. (B) Disaggregated quartz-rich laminae in a siliceous argillite matrix suggest chaotic soft sediment deformation; chert-argillite unit, Parker Pass. Knife is 9 cm in length.

sequence. Nineteen chert and marble samples processed for conodonts yielded only one unidentifiable fragment (J. Repetski, 1991, personal commun.), and rare trace fossils are nondiagnostic. The Rush Creek sequence is here considered to be Ordovician through Devonian in age, on the basis of lithologic correlation with a distinctive stratigraphic succession of lower Paleozoic rocks that is present in many of the roof pendants in the eastern Sierra Nevada (Rinehart and Ross, 1964; Greene and Stevens, 1994; Stevens and Greene, 1994, 1995; Wise, 1996).

In the cliffs north of Agnew Lake (Fig. 7), Strobel (1986) described a section of the Rush Creek sequence consisting of nine units with an aggregate thickness of more than 600 m (Fig. 4). The lower part of this section consists of thin-bedded, green and white banded calc-silicate hornfels. The middle part of the section consists of interbedded black chert, siliceous argillite and marble, overlain by thin-bedded, green and white banded calc-silicate hornfels. These beds are overlain by a distinctive 65-m-thick unit of calcareous sandstone and sandy marble that forms a prominent white marker horizon in cliff exposures (Fig. 7), and is overlain by black phosphatic chert and slate. The upper part of the section consists of thin-bedded, green and white banded calc-silicate hornfels overlain by siliceous argillite.

The middle part of this stratigraphic section bears a marked resemblance to the Ordovician to Devonian stratigraphic sequence in the Mount Morrison pendant. The chert, argillite, and marble probably are correlative with the Convict Lake Formation, the green and white banded calc-silicate hornfels with the Aspen Meadow formation, the calcareous quartz sandstone with the Mount Morrison Sandstone, and the overlying black chert and slate with the Squares Tunnel Formation (Fig. 4).

We interpret the calc-silicate hornfels at the base of the section in the Rush Creek sequence and the calc-silicate hornfels and siliceous argillite units in the upper part of the section as thrust repetitions of Convict Lake and Aspen Meadow formations, as indicated in Figures 4 and 7. The thrust faults, however, are generally cryptic in outcrop, and direct evidence of thrust faulting was recognized only in a cliff face exposing black chert truncated and structurally overlain by calc-silicate hornfels (Fig. 7).

In summary, the Rush Creek sequence is interpreted to be correlative with Ordovician through Devonian strata in the Mount Morrison pendant, and with similar rocks exposed in pendants both north and south of the Northern Ritter Range pendant. These Ordovician through Devonian strata are deeper water equivalents of slope and platform facies rocks in the Inyo Mountains (Stevens and Greene, 1994, 1995). We interpret the Rush Creek sequence as part of the transitional, outer continental shelf and slope assemblage of the Cordilleran miogeocline.

Upper Paleozoic Limestone

Isolated lenses of gray marble and silicified marble are exposed 1.5 km northwest of Alger Lakes (Fig. 2) (Brook et al., 1979; Greene, 1995). We interpret these lenses to be fault slices within the Gem Lake shear zone (Greene and Dutro, 1991; Greene and Schweickert, 1995). Fossiliferous, silicified marble is exposed as subcrop and

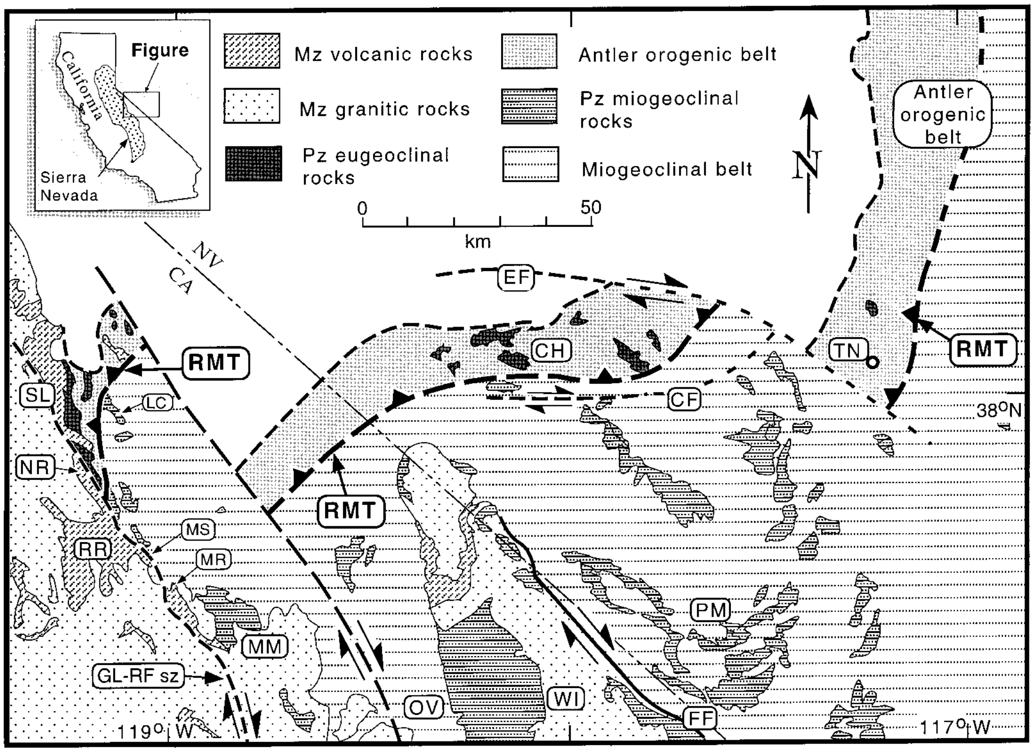

Figure 6. Generalized geologic map of the Antler orogenic belt from central Nevada to the Sierra Nevada. Abbreviations: CF—Coaldale fault; CH—Candelaria Hills; EF—Excelsior fault; FF—Fish Lake Valley fault; GL-RF sz—Gem Lake–Rosy Finch shear zone; LC—Log Cabin Mine pendant; MM—Mount Morrison pendant; MS—Minaret Summit; MR—Mammoth Rock; NR—Northern Ritter Range pendant; OV—Owens Valley; PM—Palmetto Mountains; RMT—Roberts Mountains thrust; RR—Ritter Range pendant; SL—Saddlebag Lake pendant; TN—Tonopah; WI—White-Inyo Mountains. Paleozoic eugeoclinal rocks may be present locally as klippes in and northwest of the Palmetto Mountains (e.g., McKee, 1968b). The dextral fault in Owens Valley is based on reconstruction of Devonian submarine fan facies offset between the White-Inyo Mountains and the Mount Morrison pendant (Stevens et al., 1995; Stevens and Greene, unpub. data). Figure is modified from mapping of Albers and Stewart (1972), Kleinhampl and Ziony (1985), and Bateman (1992); additional data are from Stewart (1985) and Schweickert and Lahren (1990).

talus within a 300-m-long, northwest-striking zone that appears to be structurally imbricated with the chert-argillite unit. The silicified marble is locally brecciated, but the contained fossils are otherwise undeformed; there is no evidence of cleavage or ductile deformation. This contrasts sharply with the surrounding chert and argillite, which are highly cleaved, tightly folded, and contain evidence of at least three phases of penetrative, ductile deformation (described in a following section).

Lenses of dark gray, coarsely recrystallized, variably silicified crinoidal marble 20 to 100 m in length and containing locally abundant black chert nodules are exposed a few hundred meters to the west. These lenses of marble are imbricated with chert and siliceous argillite in a zone of intense shearing and alteration along the contact between the chert-argillite unit and overlying metavolcanic rocks of the Late Triassic to Early Jurassic Koip sequence.

Correlation and Age. The fossil assemblage in the marble lenses is dominated by large crinoid columnals, and contains productoid and spiriferoid brachiopods, possibly including the genera *Dictyoclostus* and *Martinia*. The assemblage also includes tabulate corals and stenoporoid bryozoans. Identifications are tentative, but the fossils indicate a general age range of Late Mississippian through mid-Permian (J. T. Dutro, 1988, written commun.).

Isolated fault blocks of fossiliferous marble very similar to those at Alger Lakes are exposed at Minaret Summit and at Mammoth Rock, 20 km and 28 km south of Alger Lakes, respectively (Fig. 6). The fossiliferous marble at these locations has been correlated with the Pennsylvanian Mount Baldwin Marble in the Mount Morrison pendant (Rinehart and Ross, 1964; Huber and Rinehart, 1965), which is a dark gray marble characterized by large crinoid columnals, nodular chert, and a macrofossil assemblage including productoid brachiopods similar to *Dictyoclostus* (Rinehart and Ross, 1964). The Mount Baldwin Marble was deposited in a relatively shallow water carbonate platform environment and indicates localized uplift probably associated with the Antler orogeny (Stevens and Greene, 1994; unpub. mapping).

We have proposed (Greene and Dutro, 1991; Greene and Schweickert, 1995) that the marble lenses in the Northern Ritter Range pendant are correlative with the Mount Baldwin Marble, and were displaced northwestward from the vicinity of the Mount Morrison pendant in middle Cretaceous time by the dextral Gem Lake shear zone. These marble lenses do not date the chert-argillite unit or the Rush Creek sequence, as suggested previously (Kistler and Nokleberg, 1979).

STRUCTURE

Chert-Argillite Unit

Paleozoic Structures. Contrasting styles of Paleozoic deformation help distinguish the chert-argillite unit from the structurally underlying Rush Creek sequence (Table 2). Paleozoic structures typical of the chert-argillite unit include locally abundant syndepositional deformational

TABLE 1. DESCRIPTIONS OF LITHOLOGIC UNITS IN THE RUSH CREEK SEQUENCE

Lithology	Description	Mineralogy	Protolith
Calcsilicate hornfels (35%)	Off-white to tan when weathering, gray-green when fresh, commonly banded in outcrop, very fine-grained to microcrystalline, very thin- to thin-bedded, finely laminatedin part, varies from dominantly siliceous to dominantly calcareous.	Quartz, tremolite, feldspar, clinozoisite, calcite, sericite, opaques	Variably argillaceous and calcareous chert and quartz siltstone
Siliceous argillite (30%)	Red-brown rusty when weathering, dark gray to black when fresh, very fine-grained, very thin- to thin-bedded, laminated in part, varies from dominantly siliceous to dominantly argillaceous.	Quartz, mica, feldspar, opaques	Siliceous shale
Metachert (20%)	Dark orange rusty when weathering, black to dark gray when fresh, very fine-grained to cryptocrystalline, very thin- to thin-bedded, locally contains white weathering phosphatic streaks and nodules.	Quartz, mica, opaques	Chert to argillaceous chert
Marble (10%)	Light to dark gray when weathering, dark gray when fresh, fine- to medium-grained, medium- to thick-bedded, commonly contains fine to medium detrital quartz grains, locally contains abundant black chert nodules.	Calcite, quartz, hornblende, opaques	Variably carbonaceous and sandy marble
Quartzite (5%)	White to light gray when weathering, light gray when fresh, thin-bedded to massive, with medium- to coarse-grained, well-rounded detrital quartz grains in a varied calcareous matrix grading to sandy marble.	Quartz, feldspar, calcite	Quartz arenite, feldspathic and/or calcareous in part

features (D_0) (Fig. 5B); intrafolial isoclinal folds and bedding-parallel cleavage (D_1); and tight, northwest-plunging folds with variably oriented axial surfaces and foliation (D_2) (Fig. 8).

Slaty cleavage (S_1) is characteristic of D_1 deformation and is well developed in slates and argillaceous interbeds in chert, where it typically parallels bedding. Dark streaks and laminae in the hinges of F_1 folds in chert suggest the local development of axial surface S_1 spaced cleavage in the chert layers. Folds that are definitely assignable to F_1 are rare, and are typically rootless, intrafolial, isoclinal folds of decimeter scale. Bedding in the chert-argillite unit generally is dismembered and discontinuous on a scale of 1 to 5 m (Fig. 5), which we interpret to result primarily from bedding transposition during D_1 deformation. In the Rush Creek sequence, in contrast, D_1 structures were not observed, and individual layers can commonly be traced for tens to many hundreds of meters.

Second-generation structures (D_2) in the chert-argillite unit consist predominantly of uncommon tight folds of bedding and S_1 foliation. Most F_2 folds are 1–2 m in amplitude, have northwest-trending, steeply plunging hinge lines, and variably striking, steeply dipping hinge surfaces (Fig. 8). Axial surface cleavage (S_2) generally consists of poorly developed spaced cleavage in the hinge zones of F_2 folds. F_2 folds are generally larger in wave length than F_1 folds, and are close to tight rather than isoclinal. It is probable that large map-scale F_2 folds are also present in the chert-argillite unit in the Northern Ritter Range pendant, as reported by Brook (1977) in the Saddlebag Lake pendant. However, the lack of coherent stratigraphic markers in the chert-argillite unit makes identification of such structures difficult, and none was observed in this study.

D_1 and D_2 structures are middle to late Paleozoic in age, because they are not present in either the lower Koip sequence (222 Ma U/Pb age, Schweickert and Lahren, 1987) or the Permian Diablo Formation, which overlies the chert-argillite unit to the north in the Saddlebag Lake pendant (Schweickert and Lahren, 1987). D^1 structures are restricted to the chert-argillite unit and must therefore have formed prior to the fault juxtaposition of the unit with the Rush Creek sequence. These structures may represent preemplacement deformation within the Roberts Mountains allochthon, as suggested by Oldow (1984) for similar structures in the Candelaria Hills. The D_2 structures, which are also present in the Rush Creek sequence, are interpreted to have formed during the Late Devonian–Early Mississippian Antler orogeny, following previous interpretations of correlative structures in the Saddlebag Lake pendant by Brook (1977) and Schweickert and Lahren (1987, 1993). Whereas age constraints on these structures are permissive of development as late as the middle Permian, the only known orogenic episode in the region during this period is the mid-Paleozoic Antler orogeny.

Mesozoic Structures. The most prominent structural fabric in the chert-argillite unit formed during an important phase of mid-Mesozoic deformation (D_3), and is characterized by well-developed cleavage striking N30°–60°W, and by steeply northwest-plunging, tight, mesoscopic folds (Fig. 8). These structures are present throughout the Northern Ritter Range pendant in rocks as young as Early Jurassic (201 Ma U/Pb age; Schweickert et al., 1994), and are cut by plutons of the Late Cretaceous Tuolumne Intrusive Suite (91 Ma U/Pb age; Stern et al., 1981). D_3 structures developed after juxtaposition of the chert-argillite unit and the Rush Creek sequence, and commonly overprint and obscure D_1 and D_2 structures. We interpret the variable orientation of D_2 structures in the chert-argillite unit (Fig. 8) to be a result of reorientation by the northwest-trending D_3 structures, which are more strongly developed in this unit than in the Rush Creek sequence.

Rush Creek Sequence

Paleozoic Structure. Paleozoic structures in the Rush Creek sequence are characterized by tight, southwest- and northeast-trending mesoscopic folds with moderately plunging hinge lines (Figs. 8 and 9); map-scale, tight to isoclinal folds with extensive overturned limbs referred to here as “nappe folds” (Figs. 2 and 3); and major thrust imbrication (Fig. 7) (Greene, 1995). These structures are increasingly overprinted in northern and western areas by northwest-trending mid-Mesozoic structures. Axial surface foliation associated with D_2 folds consists of a locally well-developed, finely spaced, disjunctive cleavage filled by white quartz veins. Small-scale isoclinal folds and bedding-parallel cleavage equivalent to D_1 structures in the chert-argillite unit were not observed in the Rush Creek sequence. The oldest structures recognized are major nappe folds, including a northeast-trending anticline north of Agnew Lake, and large folds exposed on the south and east flanks of Mount Wood (Fig. 2). Nappe folds on the east side of the Northern Ritter Range pendant are north- to northeast-trending, but to the west are refolded into a northwest trend by later mid-Mesozoic folds. These large nappe folds cannot be traced continuously; the map pattern is inferred from exposed folds, bedding attitudes, and extrapolation of units across cover. More small thrust faults imbricate the section than can be resolved at this map scale, and the actual map pattern is more complex than shown.

Nappe folds and associated northeast-trending structures are cut by the 210 Ma granite of Lee Vining Canyon, indicating that these structures are Triassic or older. We interpret these structures to be mid- to late Paleozoic in age, probably cor-

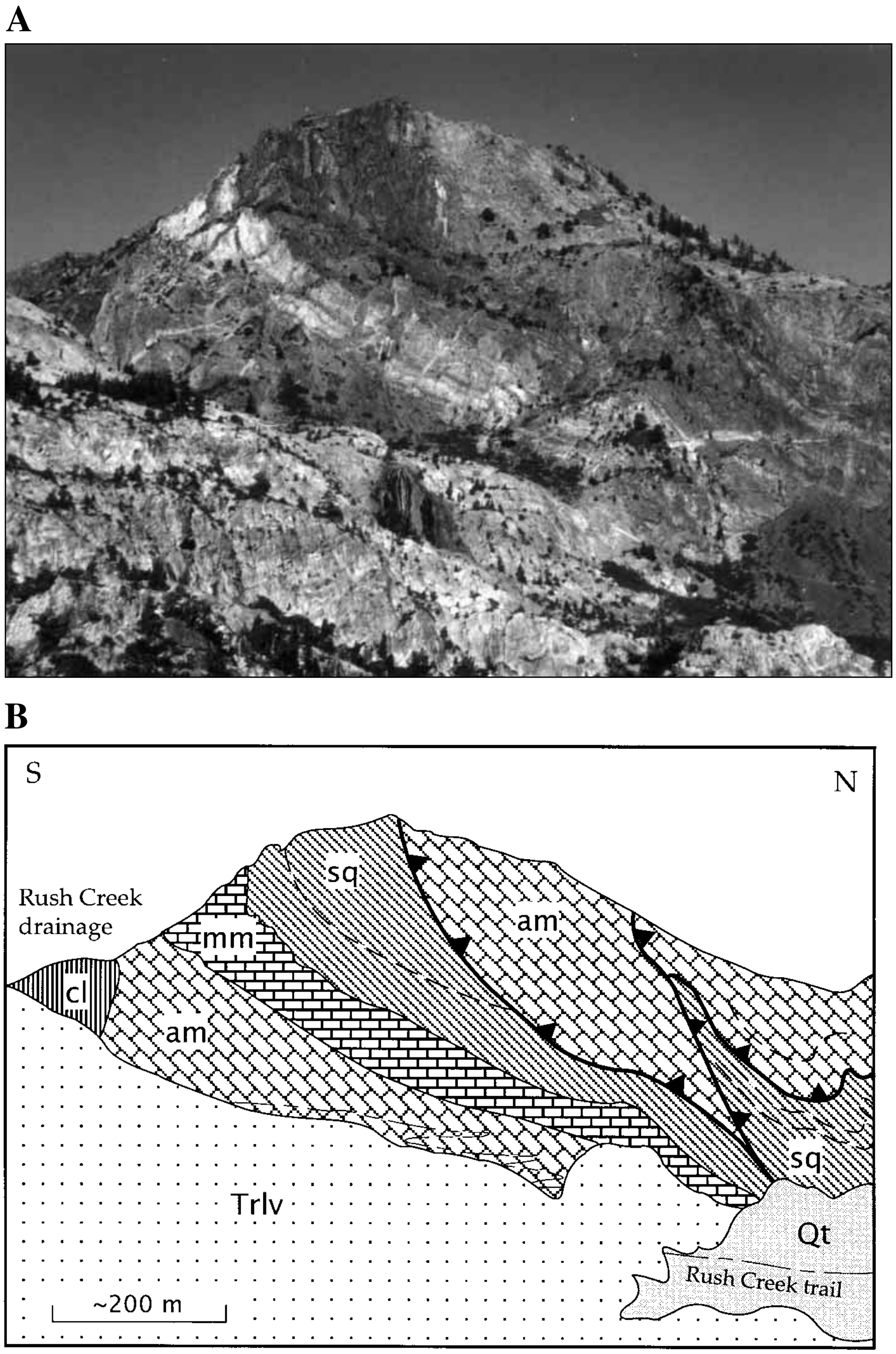

Figure 7. Photo (A) and line drawing (B) of the Rush Creek sequence north of Agnew Lake, viewed looking west from the town of June Lake. The prominent white band in the face is calcareous quartz sandstone correlated with the Mount Morrison Sandstone (mm). Dark unit above is chert and slate of the Squares Tunnel Formation (sq), separated from calc-silicate hornfels of the Aspen Meadow formation (am) on the right skyline by thrust faults. cl—Convict Lake Formation, Trlv—granite of Lee Vining Canyon, Qt—Quaternary talus.

relative with D_2 structures in the chert-argillite unit and possibly related to thrust emplacement of the Roberts Mountains allochthon during the Late Devonian–Early Mississippian Antler orogeny. Alternatively, some or all of these structures could be related to a period of Late Triassic contractional deformation recognized in the Saddlebag Lake pendant (Schweickert and Lahren, 1987, 1993) and the Log Cabin Mine pendant (Stevens and Greene, unpub. mapping). This is considered unlikely, however, because structures known to be associated with Triassic deformation trend north to northwest (e.g., Schweickert et al., 1988; Schweickert and Lahren, 1993), whereas the early structures in the Rush Creek sequence trend predominantly northeast (Fig. 8) (Strobel, 1986; Greene, 1995).

Mesozoic Structure. Mid-Mesozoic structures in the Rush Creek sequence are similar to, but less prominent than, those in the chert-argillite unit (Fig. 8), and are characterized by northwest-striking, steeply southwest-dipping foliation with rare, steeply northwest-plunging tight folds. These structures become progressively less well developed to the east in the Rush Creek sequence, where northeast-trending Paleozoic structures predominate (Strobel, 1986; Greene, 1995).

In the southern part of the pendant a right-lateral ductile shear zone of Cretaceous age, the Gem Lake shear zone (Strobel, 1986; Greene and Dutro, 1991; Greene and Schweickert, 1995), has cut out the chert-argillite unit and forms the contact between the Rush Creek sequence and Mesozoic volcanic rocks of the Koip sequence (Fig. 2). Mesozoic deformation in the Rush Creek sequence increases in intensity toward this shear zone, resulting in increasing foliation development and a loss of stratigraphic continuity.

POSSIBLE ROBERTS MOUNTAINS THRUST

The Rush Creek sequence is structurally overlain by the chert-argillite unit along a north- to northwest-striking, steeply west-dipping fault contact (Figs. 2 and 3). The fault trace is 5 km in length, and extends from Gem Pass to the north face of Mount Wood, in part following the location of a fault originally mapped by Kistler (1966a). Southeast of Alger Lakes, the fault merges with the Cretaceous Gem Lake shear zone, which has overprinted and obscured the earlier fault trace. North of Mount Wood, the fault is cut by the granite of Lee Vining Canyon (210 Ma U/Pb zircon age; Chen and Moore, 1982), indicating that the fault is no younger than Late Triassic time.

The fault trace is most clearly expressed at map scale as an abrupt truncation of northeast-striking marble and calc-silicate beds of the Rush Creek sequence against northwest-striking fabric in the chert-argillite unit. The fault trace, though poorly exposed, can be followed down the southwest face of Mount Wood (Fig. 10), where it is marked by a 25–50-m-wide zone of disrupted bedding and hydrothermal alteration. Rocks within this zone form disconnected lenses with anomalous orientations. Structures are ambiguous and no indicators of slip direction were ob-

TABLE 2. STRUCTURES IN THE NORTHERN RITTER RANGE PENDANT

Generation	Observed in	Structures	Orientation of foliation and hinge surfaces	Age (and age constraints)
D_5	All units	Spaced cleavage, rare open folds	Strike N30°–70°E, dip vertical	Jurassic or Early Cretaceous (post-201 Ma, pre-91 Ma)
D_4	All units	Thinly spaced cleavage, rare open folds	Strike N50°–90°W, dip vertical	Jurassic or Early Cretaceous (post-201 Ma, pre-91 Ma)
D_3	All units	Tight mesoscopic folds, well developed cleavage, map-scale folds, thrust faults	Strike N30°–60°W, steeply southwest-dipping	Jurassic or Early Cretaceous (post-201 Ma, pre-91 Ma)
D_2	Rush Creek sequence	Tight mesoscopic folds and local disjunctive cleavage, map-scale nappe folds and thrust faults	Strike N5°W–N60°E (avg. N30°E), steeply dipping	Syn- or post-Devonian, pre-Permian
D_2	Chert-argillite unit	Uncommon tight folds, poorly developed cleavage	Strike variable, steeply dipping	Syn- or post-Devonian, pre-Permian
D_1	Chert-argillite unit	Bedding-parallel cleavage, rare intrafolial isoclinal folds	Reoriented by later deformation	Mid-Paleozoic, possibly Devonian (post-Ordovician, pre-Permian)

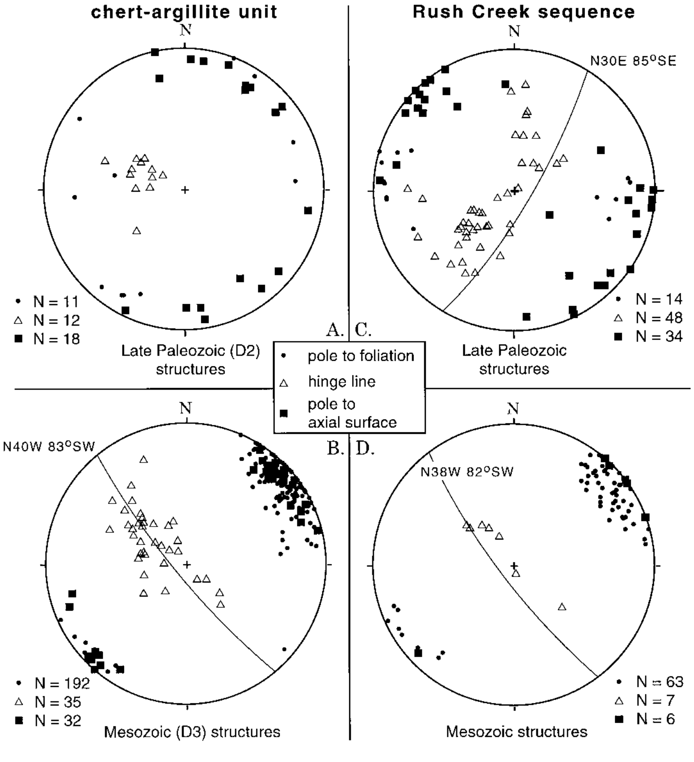

Figure 8. Equal area stereonets showing the orientation of mesoscopic structures in the chert-argillite unit and the Rush Creek sequence. Great circles indicate synoptic orientation of planar structures. (A) Late Paleozoic (D_2) structures in the chert-argillite unit, in part reoriented by D_3 deformation. (B) Mesozoic (D_3) structures in the chert-argillite unit. (C) Late Paleozoic structures in the Rush Creek sequence, probably equivalent to D_2 in the chert-argillite unit. (D) Mesozoic structures in the Rush Creek sequence, equivalent to D_3 in the chert-argillite unit. Some data in the Rush Creek sequence are from Strobel (1986).

served. At its northern end, the fault trace is parallel to northeast-trending bedding, mesoscopic folds, and major nappe folds in the Rush Creek sequence (Fig. 2). However, the fault truncates nappe folds to the south, indicating that the exposed fault postdates the earliest phase of folding in the Rush Creek sequence.

Correlation and Age. This fault contact in the Northern Ritter Range pendant juxtaposes the highly deformed, basinal chert-argillite unit of the Roberts Mountains allochthon against less-deformed siliceous, calc-silicate, and calcareous outer continental shelf and slope rocks of the Rush Creek sequence. Such juxtaposition is the defining characteristic of the Roberts Mountains thrust in north-central Nevada (Roberts et al., 1958), and we provisionally interpret this fault contact in the Northern Ritter Range pendant to be a remnant of the Roberts Mountains thrust, which developed during the Late Devonian–Early Mississippian Antler orogeny.

Mesozoic reactivation of the Roberts Mountains thrust is a common feature of the Antler orogenic belt, and Mesozoic faults are generally difficult to distinguish from the Paleozoic thrust (e.g., Ketner and Smith, 1982; Speed and Sleep, 1982). Available age constraints on this fault in the Northern Ritter Range pendant are permissive of displacement as young as Late Triassic time. It is thus possible that the exposed thrust fault in the Northern Ritter Range pendant was active during the Triassic, synchronous with the Lundy Canyon thrust and other Triassic thrust faults in the Saddlebag Lake pendant. The Lundy Canyon thrust was interpreted by Schweickert and Lahren

Figure 9. F_2 fold exposed in vertical cliff of calc-silicate hornfels, Rush Creek sequence, south face of Mount Wood. Hammer is 32 cm in length.

(1987, 1993) to be east vergent and to have a minimum displacement of about 10 km. The thrust duplicates Upper Triassic metavolcanic rocks and is cut by the 219 Ma Mt. Olsen pluton, indicating that it developed in the Late Triassic during the volcanic episode represented by the lower part of the Koip sequence. However, the development of contractional structures (D_2) in the Northern Ritter Range pendant that are not present in overlying Permian and Early Triassic units indicates that important late Paleozoic contractional deformation occurred in the Northern Ritter Range pendant, which is most reasonably interpreted to have resulted from the Antler orogeny (Nokleberg and Kistler, 1980; Schweickert and Lahren, 1987; Greene, 1995).

DISCUSSION: REGIONAL EXTENT OF THE ANTLER OROGENIC BELT

The Roberts Mountains thrust forms the leading edge of the Antler orogenic belt, which extends in a well-defined north-south belt from north-central Nevada to near Tonopah in west-central Nevada (Fig. 6). Southwest of Tonopah, the Antler orogenic belt apparently bends abruptly to the west, and is much less well defined. Many workers have proposed post-Antler structural complications in this region, including approximately 110 km of dextral displacement on the Excelsior and Coaldale faults (Stewart, 1985), 50 km of dextral displacement on the Fish Lake Valley fault (McKee, 1968b), large Cenozoic extension in the region between the Palmetto Mountains and the Candelaria Hills (Stewart and Diamond, 1990; Oldow et al., 1994), and 65 km of dextral displacement on a cryptic fault in the Owens Valley (Stevens et al., 1995). Restoration of these proposed displacements reduces the abrupt westward bend in the Antler orogenic belt, and would result in the Northern Ritter Range pendant being originally located substantially closer to previously defined parts of the orogenic belt (Stevens and Greene, unpub. data). The recognition of the southwestern limit of the Antler orogenic belt in the Northern Ritter Range pendant provides an important western anchor point for any attempt to reconstruct this section of the orogenic belt.

Eugeoclinal rocks that are probably related to the Antler orogenic belt are also exposed in the Sachse Monument pendant (Lahren and Schweickert, 1994), which is located about 50 km northwest of the Northern Ritter Range pendant (Fig. 1). Lahren and Schweickert (1994) interpreted these rocks to structurally overlie miogeoclinal rocks exposed in the adjacent Snow Lake pendant, in a structural relationship similar to that in the Northern Ritter Range pendant. Both the Sachse Monument and Snow Lake pendants, however, probably originated in the present Mojave Desert region, and were transported to their present location by Cretaceous dextral displacement on the proposed Mojave–Snow Lake fault (Lahren and Schweickert, 1989, 1994). These rocks are therefore unrelated to the Paleozoic continental margin in the central Sierra Nevada region. Aside from these highly allochthonous exposures, eugeoclinal rocks of the Antler orogenic belt do not occur west of the Northern Ritter Range pendant. Instead, rocks of eugeoclinal affinities are exposed more than 150 km to the southeast, in the Mineral King and Kern Plateau pendants in the southern Sierra Nevada (Fig. 1) (Dunne and Suczek, 1991; Schweickert and Lahren, 1991).

These eugeoclinal rocks may have been offset southeastward from the main Antler orogenic belt by major sinistral strike-slip faulting that is proposed to have truncated the southwest-trending Cordilleran continental margin during late Paleozoic time (e.g., Davis et al., 1978; Stone and Stevens, 1988; Walker, 1988; Stevens et al., 1992). The presence of eugeoclinal rocks of the Antler orogenic belt in the Northern Ritter Range and Saddlebag Lake pendants constrains the location of the proposed sinistral truncation to be west of the Northern Ritter Range pendant, as noted by Schweickert and Lahren (1990, 1993). Alternatively, Dickinson (1981) proposed that the present trace of the Antler orogenic belt is the result of an original bend in the Cordilleran continental margin, suggesting that eugeoclinal rocks in the southern Sierra Nevada are not significantly displaced from their original position. In this case, the absence of eugeoclinal rocks between the Northern Ritter Range pendant and the southern Sierra Nevada would be the result of lack of preservation or removal by subsequent tectonism.

The Antler orogenic belt is currently truncated on the west side of the Northern Ritter Range pendant by the dextral Gem Lake–Rosy Finch shear zone (Tikoff and Teyssier, 1992; Greene and Schweickert, 1995), which was active in middle to Late Cretaceous time. The recognition of large dextral displacements along the axis of the Sierra Nevada batholith during Cretaceous time (e.g., Lahren and Schweickert, 1989; Kistler, 1993; Greene and Schweickert, 1995) suggests the possibility that the present gap between exposures of eugeoclinal rocks in the southern Sierra Nevada and the Northern Ritter Range pendant may be at least in part a

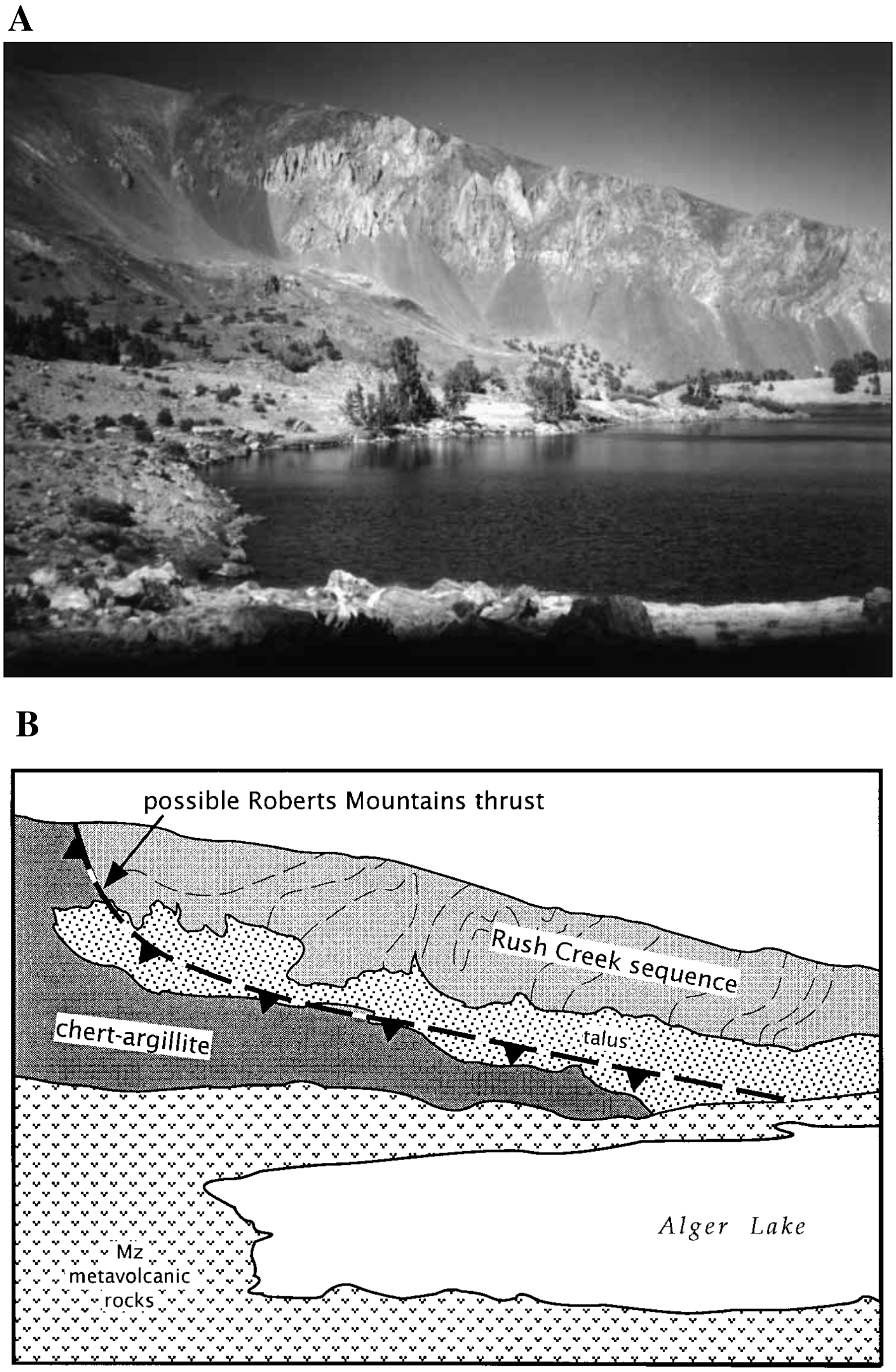

Figure 10. Photo (A) and line drawing (B) of the southwest face of Mount Wood, viewed looking east from Alger Lakes. Well-bedded calc-silicate hornfels, siliceous argillite, and marble of the Rush Creek sequence are juxtaposed against the dark-weathering chert-argillite unit to the northwest and along the base of the cliffs by the proposed Roberts Mountains thrust. View shows an oblique section through structure.

result of Mesozoic dextral truncation, and implies that displaced fragments of the Antler orogenic belt may also be present north of the Northern Ritter Range pendant, as suggested for the eugeoclinal rocks in the Sachse Monument pendant by Lahren and Schweickert (1994).

ACKNOWLEDGMENTS

This research was supported in part by National Science Foundation grants EAR-92-18174 to Stevens and EAR-87-07312 to Schweickert, and by a Sigma Xi Grant-in-Aid of Research to Greene. R. J. Strobel gave a helpful introduction to the Rush Creek area. R. W. Kistler provided assistance in relocating the fossil locality near Alger Lakes, and J. T. Dutro examined fossils from that locality. J. E. Repetski processed samples from both the chert-argillite unit and the Rush Creek sequence in an unfortunately unsuccessful search for conodonts. Helpful reviews were provided by M. Brandon, G. C. Dunne, P. H. Cashman, D. M. Herring, R. B. Miller, and J. H. Trexler.

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MANUSCRIPT RECEIVED BY THE SOCIETY MARCH 25, 1996
REVISED MANUSCRIPT RECEIVED FEBRUARY 26, 1997
MANUSCRIPT ACCEPTED MARCH 21, 1997

Printed in U.S.A.