Stratigraphy, depositional history, and tectonic evolution of Paleozoic continental-margin rocks in roof pendants of the eastern Sierra Nevada, California

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ABSTRACT

The major roof pendants of the eastern Sierra Nevada, including the Bishop Creek, Pine Creek, Mount Morrison, Deadman Pass, Gull Lake, and part of the Northern Ritter Range and Log Cabin Mine pendants, are composed of continental-margin rocks ranging in age from Middle(?) Cambrian to middle(?) Permian. This group of pendants apparently is separated from all other exposures of Paleozoic rocks by faults, forming a geologic and geographic entity here referred to as the Morrison block. Here, for the first time, a common stratigraphy, consisting of 10 formational units, one named herein, is recognized throughout the pendants of the Morrison block, providing a basis for new correlations and regional interpretations.

Middle(?) Cambrian through Ordovician rocks of the Morrison block compare closely with rocks exposed south of Miller Mountain in west-central Nevada, suggesting paleogeographic continuity along an originally linear belt. In both areas rocks of this age are represented by deep-water, continental-margin sequences that contrast significantly with the dominantly platform deposits in the White-Inyo Range to the east. Devonian rocks, which in the Morrison block are represented by a submarine-fan system, can be traced into submarine channels in the western Inyo Mountains and thence onto the shelf in the eastern Inyo Mountains, providing a tie between these areas.

Eugeoclinal rocks now composing the Antler belt are distal equivalents of rocks in the Morrison block that were deposited and deformed during the Late Devonian–Early Mississippian Antler orogeny at a considerable distance to the west. Later, in post-Early Permian time, rocks of the Morrison block were deformed, rocks of the Antler belt were emplaced against the Morrison block, and the facies boundaries and structural belts defined here were offset on northwest-trending dextral faults.

INTRODUCTION

Paleozoic metasedimentary rocks are present in numerous roof pendants and wall-rock septa in the eastern Sierra Nevada of east-central California. These rocks have been mapped and generally described in a number of previous investigations, but the regional stratigraphy, lateral variations, and correlation with strata in other areas have not been previously documented. As a result, the paleogeographic and tectonic significance of these rocks has remained unclear. New mapping and stratigraphic investigations throughout the eastern Sierra Nevada have shown that a consistent stratigraphy, representing a common geologic history, is present in a series of pendants extending about 115 km northwestward from the southern end of the Bishop Creek pendant to just south of Conway Summit (Fig. 1). The stratigraphy of these pendants can be correlated with or linked by facies with continental-margin rocks in west-central Nevada, miogeoclinal rocks in the White-Inyo Range to the east, and eugeoclinal rocks in the Roberts Mountains allochthon (Antler belt) to the west (Fig. 1). These relationships provide a basis for a better understanding of the nature of the North American continental margin during Paleozoic time, and allow recognition of facies belts that can be employed in restoration of the original early Paleozoic continental margin.

Although Paleozoic rocks in the eastern Sierra Nevada pendants can now be correlated with rocks in surrounding areas, they are separated from them by faults, inferred faults beneath more recent deposits, or faults thought to have been present prior to intrusion of Mesozoic granitic rocks. These rocks therefore are interpreted to form a discrete structural block, although they do not constitute a terrane as defined by Howell et al. (1985). We refer to these rocks collectively as the Morrison block because the most complete stratigraphic sequence is exposed in the Mount Morrison pendant. The concept of the Morrison block is somewhat similar to that of the Owens terrane proposed by Nokleberg (1983), but we believe that differences in the definition would be large enough to cause confusion if the name Owens terrane or block were applied here. The Morrison block includes pendants that we have mapped and studied in detail, including the Bishop Creek pendant (Fig. 2), Mount Morrison pendant (Fig. 3), Gull Lake pendant (Fig. 4), and part of the Log Cabin Mine pendant (Fig. 5). It also includes areas that we have studied in less detail, including the Pine Creek, part of the Northern Ritter Range, and Deadman Pass pendants, and several smaller outcrops including a limestone mass south of Conway Summit, calcareous sandstone near Big Springs Campground, shale near Arcularius Ranch, and limestone in the hills south of Bishop (Fig. 1). Rocks in the Big Pine Creek pendant (Fig. 1) are not included in the Morrison block because the rocks exposed there are very similar to coeval rocks in the White-Inyo Range, and they are older than any rocks in the other roof pendants, making comparison impossible. Rocks in the Big Ram Mine area northwest of Independence (Fig. 1) also are excluded from the Morrison block because they compare most closely with rocks of the central Inyo Mountains.

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Data Repository item 9952 contains additional material related to this article.

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REGIONAL SETTING

Today the Morrison block is located between the mostly shallow-water lower Paleozoic miogeoclinal rocks to the east in the White-Inyo Range and deep-water eugeoclinal rocks represented by the Roberts Mountains allochthon (Antler belt) to the west (Fig. 1). Although these three rock sequences are now separated from one another by faults, their original relative positions are thought to be unchanged because rocks of the Morrison block are transitional between those of the eugeocline and the miogeocline. Many of the rocks of the Morrison block are eugeoclinal in character, but they are intercalated with beds or sequences of beds composed of sediment derived from the miogeocline.

The pendants of the Morrison block generally are relatively small, representing only fragments of the original depositional systems mostly destroyed by intrusion of the Sierra Nevada batholith. Original bedding features, mostly parallel bedding with uncommon cross bedding, generally are well preserved, especially in the highly siliceous units and in interbedded limestone and chert sequences; metamorphism has not obliterated the original character of the rocks. Pelitic rocks in the Mount Morrison pendant some distance from any pluton contain biotite, muscovite, quartz, K-feldspar, and andalusite or cordierite, the mineral composition yielding maximum pressures of 2.0–2.2 kbar at temperatures of 600–615 °C (data of J. Ferry via S. Sorensen, 1988, personal commun.).

The nature of deformation of the pendants has been controversial. The section in the Mount Morrison pendant was interpreted by Russell and Nokleberg (1977) as being structurally thickened by isoclinal folding, and the oldest regional deformation was stated by them and by Nokleberg and Kistler (1980) to have been Devonian and Mississippian in age. Wise (1996) analyzed the structure of the Mount Morrison pendant and concluded that only one folding event is recognizable and that the section was thickened by thrust faulting in Late Devonian(?) time. Stevens and Greene (1997) indicated that thrust faults in the Mount Morrison pendant involve Early Permian rocks and that some thrusts are truncated by the Laurel-Convict fault, which is intruded by a 225 ± 16 Ma dike (Greene et al., 1997b), suggesting that most deformation was post–Early Permian and pre–Late Triassic.

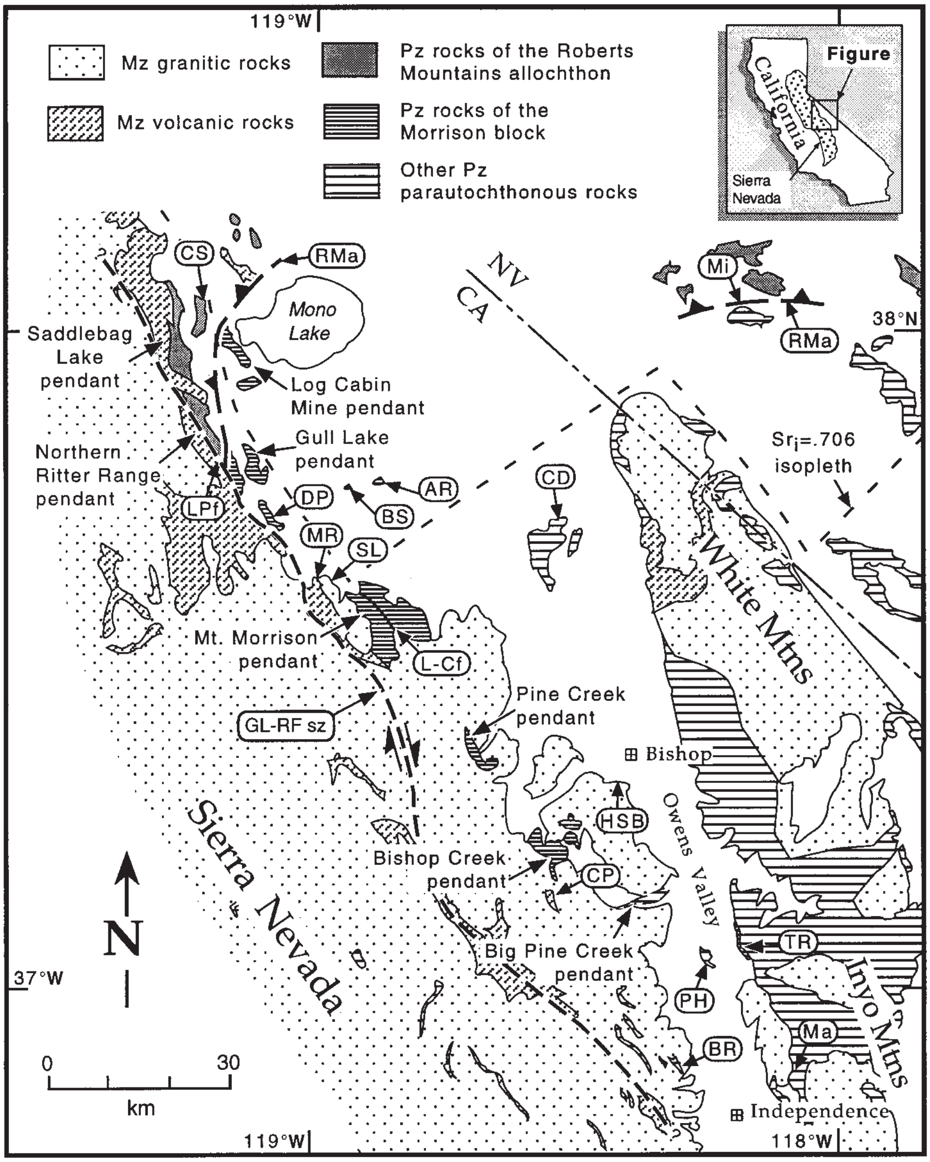

Figure 1. Regional index map showing locations mentioned in the text and the distribution of Paleozoic (Pz) and Mesozoic (Mz) rocks in eastern California (modified from Bateman, 1992). AR—Arcularius Ranch; BR—Big Ram Mine; BS—Big Springs Campground; CD—Casa Diablo; CP— Chocolate Peak; CS—Conway Summit; DP—Deadman Pass pendant; GL-RF sz—Gem Lake–Rosy Finch shear zone; HSB—hills south of Bishop; L-Cf—Laurel-Convict fault, an exposed part of IBB3 of Kistler (1993); LPf—late Paleozoic fossils; Ma—Mazourka Canyon; Mi—Miller Mountain; MR—Mammoth Rock; PH—Poverty Hills; RMa— interpreted margin of Roberts Mountains allochthon; SL—Sherwin Lakes; TR—Tinemaha Reservoir. Note that outcrops of rocks of the Morrison block at Big Springs Campground, Chocolate Peak, Conway Summit, and hills south of Bishop are so small they can not be separated from other units on the scale of this map.

PREVIOUS WORK IN THE MORRISON BLOCK

Rocks in the Morrison block have been studied and mapped in various degrees of detail. Of the four major pendants we have studied extensively, the Bishop Creek pendant was mapped by Bateman (1965) and Bateman and Moore (1965), the Mount Morrison pendant was studied by Rinehart and Ross (1964), and the Log Cabin Mine and Gull Lake pendants were mapped by Kistler (1966). In all these studies informal rock units were used, except in the Mount Morrison pendant, where Rinehart and Ross (1964) formally described 10 formations of the 27 Paleozoic units they mapped.

The ages of most rocks in the Morrison block have been poorly known. The exception was the Mount Morrison pendant, where Rinehart and Ross (1964) reported on fossils from 21 localities; more recently, Willahan (1991) recovered diagnostic conodonts from two previously poorly dated formations in this pendant. The only other significant fossils previously reported were graptolites from the Bishop Creek pendant (Moore and Foster, 1980; Frazier et al., 1986) and the Log Cabin Mine pendant (Stewart, 1985).

STRATIGRAPHY OF THE MORRISON BLOCK

Introduction

Our work in the Morrison block supports the use of 8 of the 10 formations originally defined in the Mount Morrison pendant by Rinehart and Ross (1964). These are, from older to younger, the Mount Aggie Formation, the Convict Lake Formation, the Mount Morrison Sandstone, the Bright Dot Formation, the Mount Baldwin Marble, the Mildred Lake Hornfels, the Lake Dorothy Hornfels, and the Bloody Mountain Formation.

The Hilton Creek Marble of Rinehart and Ross (1964) is here interpreted to be a structural repetition of the Mount Baldwin Marble. The Buzztail Spring Formation of Rinehart and Ross (1964) is interpreted to be equivalent to rocks included in the lower part of the type section of the Mount Aggie Formation, so we herein reduce the rank of this unit to an informal member of the Mount Aggie Formation. In addition, we here subdivide rocks of the Mount Aggie Formation overlying the Buzztail Spring member into the informally named Salty Peterson and Coyote Ridge members. We restrict the name Convict Lake Formation and propose a new formational name, Aspen Meadow Formation, for rocks that Rinehart and Ross (1964) originally included in the upper part of the Convict Lake Formation. The Mount Morrison Sandstone is here restricted to the unbroken calcareous sandstone interval in the lower part of the original type section, and the name Sevehah Group is formally proposed to include the Mount Morrison Sandstone and the overlying Squares Tunnel Formation, a unit originally named for rocks in the western Inyo Mountains (Stevens et al., 1996). This latter unit is now correlated with rocks included in the upper part of the original type section of the Mount Morrison Sandstone, as well as various other units mapped by Rinehart and Ross (1964).

In this paper we describe the new and revised units discussed above, and redescribe previously named units for which we have made new observations. Permian units younger than the Mount Baldwin Marble are not redescribed here because we have few new data to report.

Revisions of lower Paleozoic units are necessary because the complicated distribution of different lithologic units in the Mount Morrison pendant, interpreted by Rinehart and Ross (1964) to be primarily the result of rapid facies changes, is shown by our work to be the result of structural repetition. In several places fragments of various stratigraphic units have been folded or faulted into what Rinehart and Ross (1964) interpreted to be normal stratigraphic sequences (e.g., in Sevehah Cliff, Fig. 6). At numerous localities, however, intact stratigraphic sections are preserved (e.g., the ridge north of Convict Lake in the Mount Morrison pendant, Fig. 7) and provide the framework for unraveling the complex structural relations in more deformed areas. The stratigraphic column utilized here is shown in Figure 8.

Mount Aggie Formation

The Mount Aggie Formation, the oldest unit recognized in the Morrison block, was named by Rinehart and Ross (1964). This unit, which had not been reported previously beyond the Mount Morrison pendant, is now also recognized in the Bishop Creek pendant. It is characterized by 1500 m or more (Rinehart and Ross, 1964) of very dark gray, laminated to thin-bedded, siliceous argillite interbedded with variable amounts of thin-bedded, medium gray, fine-grained limestone, and brown-weathering, very dark gray argillite. The statement of Rinehart and Ross (1964) that the Mount Aggie Formation contains calcareous quartz sandstone is incorrect. The large exposure of calcareous sandstone in upper McGee Creek in the Mount Morrison pendant (Fig. 3), believed by Rinehart and Ross (1964) to belong to the Mount Aggie Formation, for example, actually is an infold of the much younger Mount Morrison Sandstone.

In the type section northwest of Convict Lake, the Mount Aggie Formation can be divided into three informal members. From older to younger, they are the Buzztail Spring member, the Salty Peterson member, and the Coyote Ridge member.

Buzztail Spring Member

The name Buzztail Spring Formation was proposed by Rinehart and Ross (1964) for a highly folded and faulted stratigraphic sequence on the north side of lower McGee Creek (Fig. 3). We correlate these rocks with the lowest unit of the Mount Aggie Formation exposed at its type section near Convict Lake and therefore lower the rank of the Buzztail Spring to member and assign it to the Mount Aggie Formation. This member has been identified only in the Mount Morrison pendant.

On the ridge northwest of Convict Lake, the Buzztail Spring member consists of 600+ m (Wise, 1996) of alternating beds of dark gray argillite, commonly one to a few centimeters thick, and very fine grained, medium bluish-gray limestone, generally a few centimeters thick. In some parts of the section, limestone may compose as much as 30% of the rocks. Conodont sample 13732, collected by Ketner (1998) from the upper part of this unit, has yielded conodonts indicating an age close to that of the Cambrian-Ordovician boundary. Because this unit consists of very fine grained, thin-bedded, dark-colored argillite and limestone lacking a fauna other than conodonts, it is interpreted as a moderately deep-water deposit formed far from a sediment source. This unit is conformably overlain by the Salty Peterson member. The upper contact is placed below the lowest limestone unit in this part of the section with a minimum thickness of 4 m.

Salty Peterson Member

This member of the Mount Aggie Formation, named herein for a prospect in the eastern part of the Bishop Creek pendant (Fig. 2), also has been identified in the Mount Morrison pendant and in the hills south of Bishop. It differs from the Buzztail Spring member in containing limestone-rich units consisting of alternating beds of pure limestone, 2–8 cm thick, and argillaceous limestone, 1–2 cm thick, commonly light and dark gray, respectively. In the Bishop Creek pendant there are at least two major limestone units within the member (Fig. 2); the upper limestone is 110 m thick. The base of the Salty Peterson member is not exposed there, but its thickness is greater than 200 m. On the ridge northwest of Convict Lake in the Mount Morrison pendant this unit is 34 m thick. Conodonts from sample 13762, collected by Keith Ketner (1996, personal commun.) nearby, indicate an age close to that of the Cambrian-Ordovician boundary.

This unit probably was deposited in an environment similar to that of the Buzztail Spring member (i.e., relatively deep water, far from shore), but at a time when argillaceous material was not continuously available. Limestone beds thin rapidly northwestward from the Bishop Creek pendant, suggesting increasingly deeper water farther from shore in a northwest direction.

The Salty Peterson member is conformably overlain by the Coyote Ridge member of the Mount Aggie Formation. The upper contact, exposed both along Coyote Creek in the Bishop Creek pendant and on the ridge northwest of Convict Lake in the Mount Morrison pendant, is placed above the highest limestone more than 1.5 m thick.

Coyote Ridge Member

This member of the Mount Aggie Formation is named for exposures east of Coyote Ridge along Coyote Creek in the Bishop Creek pendant (Fig. 2). It has been identified only in the

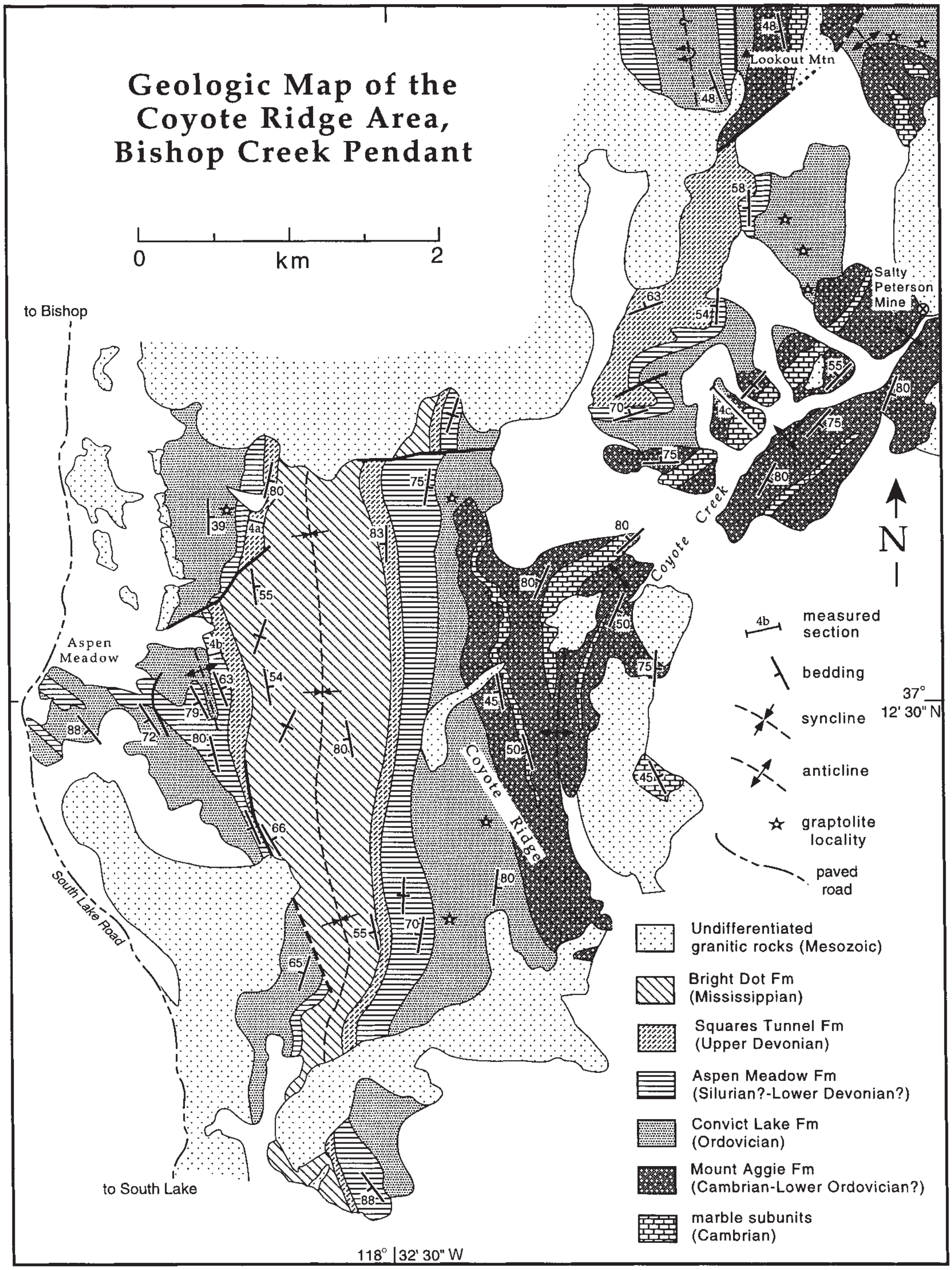

Figure 2. Geologic map of most of the Bishop Creek pendant. This figure represents new mapping for this project, incorporating some data from Bateman (1965). Marble subunits in the Mount Aggie Formation belong to the Salty Peterson member; rocks above the higher limestone subunit belong to the Coyote Ridge member.

Bishop Creek pendant, where it is 186 m thick, and in the Mount Morrison pendant, where it is 94 m thick. This member is characterized by alternating 0.5–1-cm-thick beds of black and orange or black and white chert and siliceous argillite, similar to some sequences in the lower part of the Buzztail Spring member.

No fossils have been recovered from this unit, but its age is considered to be Early Ordovician because conodonts representing a time close to the Cambrian-Ordovician boundary have been recovered from the underlying Salty Peterson member and Early (but not earliest) Ordovician graptolites have been recovered from the overlying Convict Lake Formation. The lack of a fauna in the thinly bedded cherty rocks that compose most of this member suggests deposition in a quiet, deep-water environment.

This unit is concordantly overlain by the Convict Lake Formation. The upper contact is placed above the highest thinly banded, cherty rocks that typify this member.

Convict Lake Formation (Restricted)

The Convict Lake Formation was named by Rinehart and Ross (1964) for a unit consisting of two parts: a thick lower part, consisting predominantly of dark gray argillite and hornfels with some very dark gray slate and medium gray,

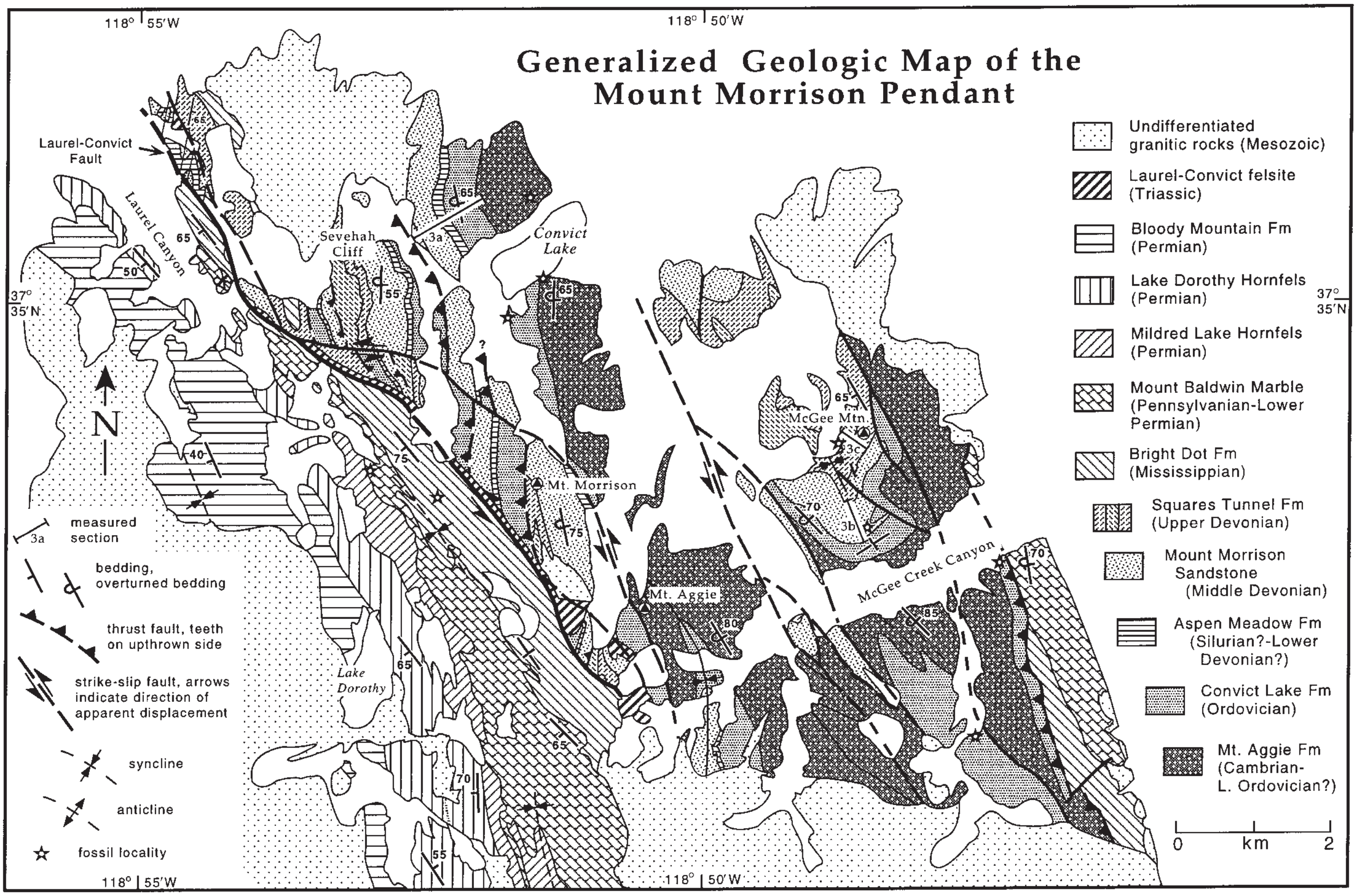

Figure 3. Geologic map of the Mount Morrison pendant. Figure is based on the map of Rinehart and Ross (1964) with extensive new mapping and reassignment of many rock units. Mapping of Wise (1996) was incorporated in the northeastern part of the area.

siliceous quartzite, and a much thinner upper part, consisting of light-colored calcareous hornfels. Here, we restrict the name Convict Lake Formation to the thick lower part of the unit as described by Rinehart and Ross (1964), and reassign the upper part to the newly named Aspen Meadow Formation because both units are mappable, easily separated and identified, and important for correlation within several of the eastern Sierra Nevada pendants. The Convict Lake Formation, as redefined here, is widely exposed in the Morrison block, occurring throughout the eastern part of the Mount Morrison pendant and in the Bishop Creek, Log Cabin Mine, Northern Ritter Range, and Deadman Pass pendants, as well as near Arcularius Ranch.

The Convict Lake Formation as restricted here consists primarily of dark gray, commonly rusty-weathering argillite and fine-grained siliceous hornfels with some very dark gray slate and resistant ribs of medium- to coarse-grained, medium to light gray-weathering, noncalcareous quartzite. Beds of dark gray, cherty argillite with phosphatic lenses and blebs are common near the top of the formation in both the Log Cabin Mine and Bishop Creek pendants. The Convict Lake Formation, as restricted here, is 336 m thick in its type section on the ridge north of Convict Lake (Figs. 3 and 7).

Graptolites are well represented in the Convict Lake Formation and all known graptolite localities in the Morrison block are in this unit. Rinehart and Ross (1964) reported graptolites from several of their map units, but our mapping shows that all of their localities, except locality D, are within the Convict Lake Formation. We believe that locality D was mislocated by Rinehart and Ross (1964) because Upper Devonian conodonts occur at about the same stratigraphic level. We found one new graptolite locality in the Mount Morrison pendant and two new localities yielding probable graptolites.

Graptolites are most numerous in the Bishop Creek pendant. Moore and Foster (1980) reported graptolites from two localities, and Frazier et al. (1986) reported on nine other collections. During the course of this study, we (including San Jose State University students) discovered 10 additional localities. From the Log Cabin Mine pendant, one graptolite was reported by Stewart (1985), another locality was discovered during the present work with the help of Stan Finney, and probable graptolites were recovered from a third area. Graptolites also were collected from rocks assigned to the Convict Lake Formation near Arcularius Ranch (Fig. 1).

Graptolites in the Mount Morrison pendant represent at least zones 6 to 15 (Early to Late Ordovician) of Berry (1960). In the Bishop Creek pendant the fossils span graptolite zones 3–7 to at least zone 14 and probably 15, and rocks from near Arcularius Ranch have yielded zone 5 graptolites. The Convict Lake Formation, therefore, represents all except the earliest part of the Ordovician.

The presence of pelagic graptolites, the only fossils recovered from the Convict Lake Formation, and the regularly banded, dark-colored, argillaceous rocks suggest deposition in rather deep, probably oxygen-deficient water. The quartzites, of which several in the Mount Morrison pendant appear to be channel-form, probably filled channels on a deep-water, sand-poor submarine fan.

The Convict Lake Formation is conformably overlain by the Aspen Meadow Formation except on McGee Mountain, where it is unconformably overlain by the Mount Morrison Sandstone. The upper contact is placed below the lowest sequence of light-colored, thin-bedded, calc-silicate beds of the overlying Aspen Meadow Formation.

Aspen Meadow Formation

The name Aspen Meadow Formation is proposed herein for a distinctive 150-m-thick unit of thinly banded, light-colored calcareous hornfels and fine-grained, siliceous rocks widely exposed in the Bishop Creek, Mount Morrison, Deadman Pass, Gull Lake, Northern Ritter Range, and Log Cabin Mine pendants. The type section on the ridge above Aspen Meadow in Bishop Creek Canyon (Fig. 2) consists mostly of very light gray and light green hornfels in bands about 5 and 1 cm thick, respectively (Fig. 9). The type section is described in detail in the Data Repository.[1]

No fossils have been recovered from the Aspen Meadow Formation, but a Silurian to Early Devonian age is inferred from the ages of the enclosing rocks. Deposition is interpreted to have been in relatively deep, quiet water far from shore because the unit is typically very thin bedded, very fine grained, and mostly undisturbed by an infauna.

The Aspen Meadow Formation is conformably overlain by the Mount Morrison Sandstone except in the Bishop Creek pendant, where the Mount Morrison Sandstone is not present and the Aspen Meadow Formation is conformably overlain by the Squares Tunnel Formation. In the McGee Mountain area the Aspen Meadow Formation is missing due to submarine channeling prior to deposition of the Mount Morrison Sandstone. The upper contact of the Aspen Meadow Formation is placed at the base of the lowest calcareous sandstone in the Mount Morrison Sandstone or black argillite or chert of the Squares Tunnel Formation where the Mount Morrison Sandstone is missing.

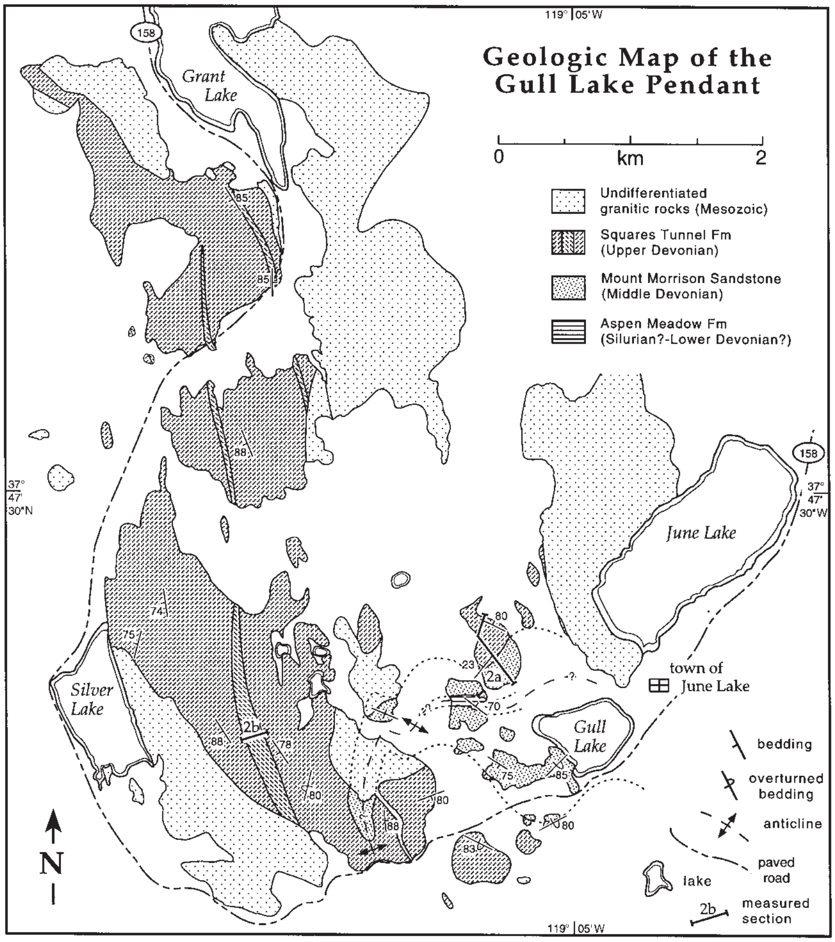

Figure 4. Geologic map of the Gull Lake pendant. The outcrop pattern is based on the map of Kistler (1966), but all of the Paleozoic rocks were remapped for this project.

Sevehah Group

A thick sequence of calcareous quartz sandstone and sandy limestone complexly interbedded with black argillite and chert, commonly containing light gray, phosphatic blebs and lenses, overlies the Aspen Meadow Formation. This succession is here named the Sevehah Group.

The most distinctive rock type in the Sevehah Group is calcareous quartz sandstone. Such sandstones in the eastern Sierran roof pendants are restricted to this group, so the name Sevehah Group can be utilized in areas of incomplete stratigraphy where calcareous quartz sandstone, not assignable to a specific formation, crops out. The Sevehah Group consists of two formations: the lower Mount Morrison Sandstone (restricted) and the upper Squares Tunnel Formation. The stratigraphic complexities within this unit are illustrated in Figure 10.

Mount Morrison Sandstone (Restricted)

The Mount Morrison Sandstone was named by Rinehart and Ross (1964) for rocks exposed on the summit and east flank of Mount Morrison. The Mount Morrison Sandstone has been recognized in the Gull Lake, Deadman Pass, Northern Ritter Range, and Log Cabin Mine pendants, as well as in the Mount Morrison pendant. It is not represented in the Bishop Creek pendant due to nondeposition. A very thin unit exposed near Tinemaha Reservoir at the foot of the Inyo Mountains (Fig. 1), which consists of conglomerate essentially identical to that in the Mount Morrison Sandstone exposed on McGee Mountain, also is assigned to this formation.

The type section of the Mount Morrison Sandstone originally included a unit of hornfels and marble almost 100 m thick. Here we consider this

[1]GSA Data Repository item 9952, supplemental data, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301. E-mail: editing@geosociety.org. Web: http://www.geosociety.org/pubs/ftpyrs.htm. Data Repository item contains descriptions of measured sections and faunal lists for all paleontologic samples, including 2 from the Mount Aggie Formation, 25 from the Convict Lake Formation, 5 from the Mount Morrison Sandstone, 4 from the Squares Tunnel Formation, 1 from the Bright Dot Formation, 14 from the Mount Baldwin Marble, 1 from the Bloody Mountain Formation, 1 from the Vaughn Gulch Limestone, 1 from the Kearsarge Formation, and 1 from the Keeler Canyon Formation(?).

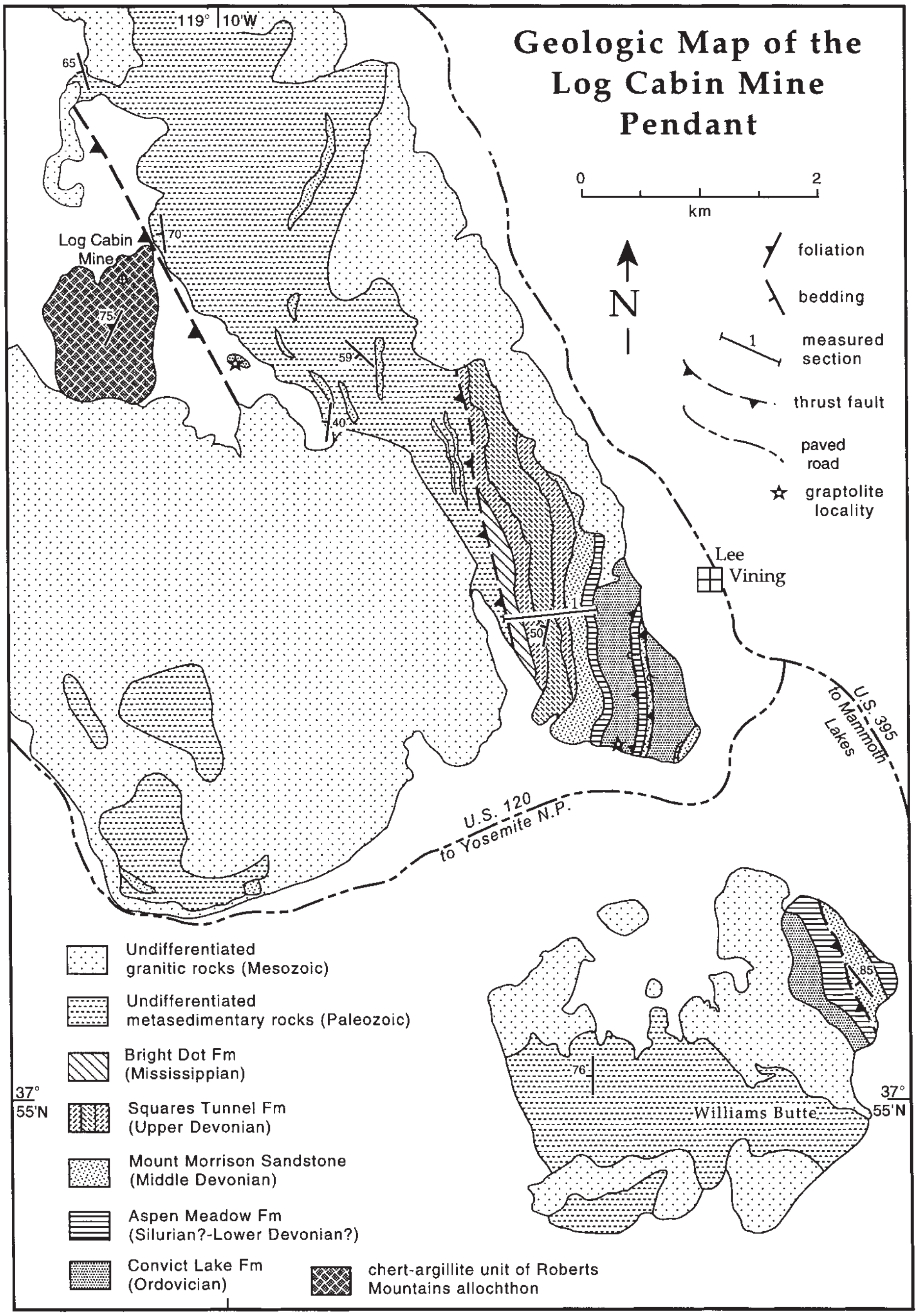

Figure 5. Geologic map of the southeastern part of the Log Cabin Mine pendant. This figure utilized original mapping of Kistler (1966), but the Paleozoic rocks along the eastern part of the pendant were completely remapped. Lenses of calcareous sandstone in western part of pendant could belong to the McGee member of the Squares Tunnel Formation rather than Mount Morrison Sandstone as shown.

unit and the overlying sandstone and argillite to be part of the overlying Squares Tunnel Formation. Thus, we restrict the name Mount Morrison Formation to the lower unbroken succession of calcareous quartzite in the type section exposed along the ridge northwest of Convict Lake. By this definition the Mount Morrison Formation consists of 177 m of fine- to coarse-grained, light to medium gray, calcareous, bimodal quartz sandstone in beds one to many meters thick. Black chert or argillite clasts, mostly about 0.5 cm, but to 25 cm across, commonly are suspended in the sandstone (Fig. 11). Dish structures (Fig. 12) are present in a medium-grained sandstone at the southwest end of Convict Lake, and small- and medium-scale cross-bedding has been observed elsewhere.

On McGee Mountain a quite different facies of Mount Morrison Sandstone, 575 m thick, is composed of medium- to coarse-grained, calcareous sandstone, containing variable amounts of floating lithoclasts (generally dark-colored argillite or chert), and conglomerate with clasts of medium gray limestone, black chert, rust-weathering argillite, and light brown or light gray sandstone and calcareous siltstone as much as 1 m across in a coarse-grained, calcareous, quartz-sandstone matrix (Fig. 13). About one-third of the unit is composed of conglomerate. Sandstone lenses to 4 m long, probably erosional remnants left by repeated cut and fill, occur within some of the conglomerate sequences. Conodonts are rare in the Mount Morrison Sandstone. One assemblage from a clast in the lower part of the unit at McGee Mountain is Emsian (Early Devonian) in age. Another assemblage from a limestone turbidite at the top of the Mount Morrison Sandstone near Tinemaha Reservoir is Givetian (late Middle Devonian) in age, and a third assemblage from sample 13756 collected by Keith Ketner from the Convict Lake area is reported to be Middle Devonian to early Frasnian (early Late Devonian) (Anita Harris, 1999, personal commun.). The most likely age of the Mount Morrison Sandstone, therefore, apparently is Givetian.

Stevens et al. (1995) interpreted the Mount Morrison Sandstone as representing a deep-water, submarine-fan system on the basis of the close association of this unit with black argillite and chert of a deep-water aspect, and sedimentary features, including dish structures, ripple laminations at the tops of some beds, and numerous large chert and argillite clasts floating in sandstone. Each sandstone bed, typically massive and as thick as several meters, probably represents a single sediment-gravity flow.

The Mount Morrison Sandstone is conformably overlain by the Squares Tunnel Formation. The upper contact is placed below the lowest black chert or argillite unit in the Sevehah group.

Squares Tunnel Formation

The Squares Tunnel Formation was named by Stevens et al. (1996) for Upper Devonian rocks in the western Inyo Mountains near Independence (Fig. 1). At the type locality the Squares Tunnel Formation is composed of dark gray to black argillite and chert commonly with light gray phosphatic blebs or stringers 2 to 8 mm thick and 2 to 6 cm long. This unit is now recognized in the Log Cabin Mine pendant where it is 280 m thick, in the Coyote Creek pendant where it is 120 m thick, and in the Gull Lake, Mount Morrison, Deadman Creek, and Northern Ritter Range pendants.

In the Morrison block, the Squares Tunnel Formation consists of black chert and argillite with light gray, phosphatic blebs, generally intercalated with individual beds to thick sequences of calcareous sandstone. The exception is the Bishop Creek pendant, where this type of sandstone is lacking. Conglomerate composed largely of black chert clasts in a calcareous sandstone matrix also composes a substantial part of a 200-m-thick calcareous sandstone unit within the Squares Tunnel Formation on McGee Mountain. This unit is herein named the McGee Mountain Member.

Conodonts and radiolarians from the Squares Tunnel Formation in the Inyo Mountains (Stevens et al., 1996) and conodonts from the McGee Mountain Member indicate that this formation is in part, at least, Famennian (Late Devonian) in age. The presence of black, radiolaria-bearing chert and argillite suggests deposition in relatively deep water. The calcareous sandstones are similar to those in the Mount Morrison Sandstone, and are similarly interpreted as submarine-fan deposits.

The Squares Tunnel Formation is concordantly overlain by the Bright Dot Formation in both the Log Cabin Mine and Bishop Creek pendants. In the Mount Morrison pendant, rocks typical of the McGee Mountain Member of the Squares Tunnel Formation and the overlying Bright Dot Formation are interbedded. The contact between the two formations is placed above the highest black chert, very dark gray argillite, or calcareous sandstone of the Squares Tunnel Formation.

Bright Dot Formation

The Bright Dot Formation, named by Rinehart and Ross (1964), is here recognized in the Mount Morrison, Bishop Creek, Pine Creek, and Log Cabin Mine pendants. Rocks in the Pine Creek pendant that we place in this unit originally were assigned to the Mildred Lake Formation by Bateman (in Rinehart and Ross, 1964), probably on the basis of a supposed syncline (Bateman, 1965). The structure in the Pine Creek pendant appears synclinal from a distance, but a conglomerate-filled channel on the west limb of the supposed syncline shows that the west-dipping rocks are upright rather than overturned, and therefore underlie rather than overlie the Mount Baldwin Marble farther west.

The lower part of the Bright Dot Formation is marked by beds of fine-grained sandstone. Higher in the section Rinehart and Ross (1964) reported a 300–450-m-thick unit of microgranular, muscovite-rich, siliceous hornfels and metachert, overlain by 150–300 m of well-layered siliceous and

Figure 6. View to west of Sevehah Cliff, Mount Morrison pendant showing complexly folded and faulted Convict Lake, Aspen Meadow, Mount Morrison, and Squares Tunnel formations. These rocks originally were mapped as the informally named sandstone and hornfels of Sevehah Cliff (Rinehart and Ross, 1964).

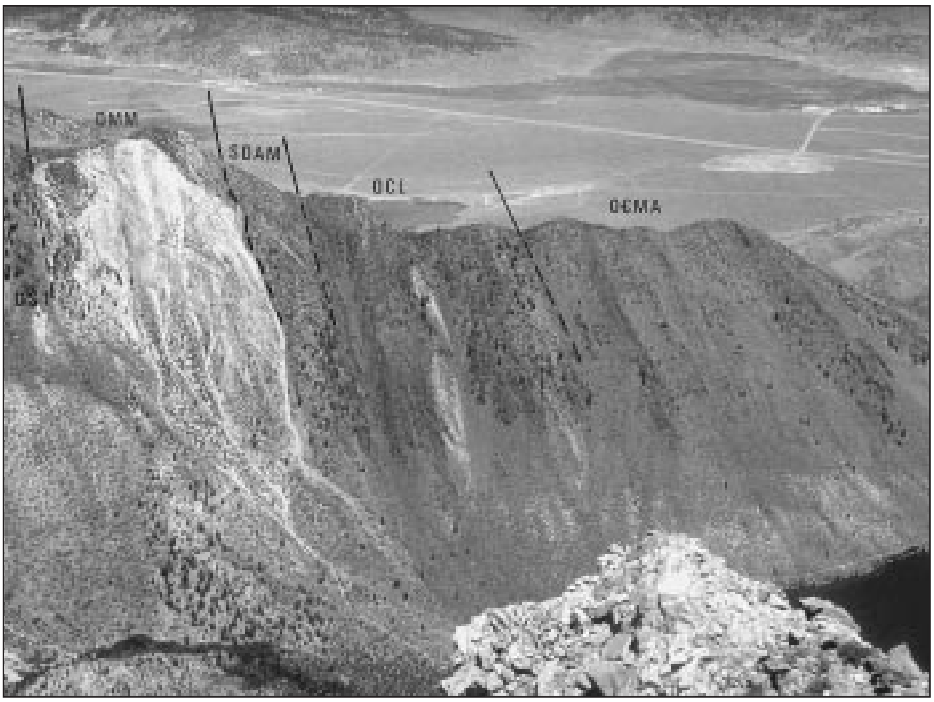

Figure 7. View to north of ridge north of Convict Lake showing the type sections of the Mount Aggie Formation (OЄMA), Convict Lake Formation (OCL), and Mount Morrison Sandstone (DMM) (restricted). Beds are overturned and dip steeply to the east. SDAM—Aspen Meadow Formation.

Age	Unit	Approx. thickness (m)	Lithology and inferred depositional environment
Permian	Bloody Mountain Formation *	1200+	Massive to thick-bedded siliceous and calc-silicate hornfels; dark reddish-brown-weathering, rare conglomeratic interbeds. Base of slope.
Permian	Lake Dorothy Hornfels	300	Thin-bedded, banded, siliceous hornfels. Base of slope.
Permian	Mildred Lake Hornfels	150-300	Light gray, massive, siliceous hornfels. Relatively deep water, hemipelagic.
Penn.	Mount Baldwin Marble *	150-190	Gray, fossiliferous marble. Shallow-water carbonate platform.
Miss.	Bright Dot Formation *	450+ - 600+	Dark gray siliceous hornfels; locally contains andalusite, muscovite, and chert-pebble conglomerate. Shallowing-upward sequence, dominantly or entirely marine.
Devonian	Sevahah Group – Squares Tunnel Fm	0-1000+?	Black chert with phosphatic nodules. Deep water, hemipelagic.
Devonian	Sevahah Group – Squares Tunnel Fm – McGee Mtn Mbr * *	0-200	Calcareous quartz sandstone. Submarine fan.
Devonian	Sevahah Group – Squares Tunnel Fm	80-285+	Black chert with phosphatic nodules. Deep water, hemipelagic.
Devonian	Sevahah Group – Mt. Morrison Sandstone *	50-570	Calcareous quartz sandstone; massive, fine to coarse grained, light gray. Submarine fan.
Silurian	Aspen Meadow Formation	80-150	Green and white banded calcsilicate hornfels. Relatively deep water, hemipelagic.
Ordovician	Convict Lake Fm * * *	340	Dark gray siliceous argillite, slate, and quartzite; graptolites common. Sand-poor submarine fan or apron.
Ordovician	Mount Aggie Fm – Coyote Ridge Mbr	90-190	Laminated siliceous argillite. Deep water, hemipelagic.
? Cambrian	Mount Aggie Fm – Salty Peterson Mbr *	30-200+	Thick interbeds of limestone and argillite. Moderately deep water, hemipelagic.
Cambrian	Mount Aggie Fm – Buzztail Springs Mbr *	1400+	Thinly interbedded, alternating dark gray argillite and thinly bedded blue-gray limestone. Limestone less common in lower part. Deep water, hemipelagic.

Figure 8. Stratigraphy of the Morrison block. Thicknesses are approximate due to original variability and unresolved structural complications in some areas. Asterisks indicate fossil collections.

calcareous hornfels in layers 1 cm to 1 m thick. Several calcareous lenses associated with chert- and limestone-pebble conglomerate (Willahan, 1991) in the upper part of the formation have yielded a largely reworked conodont fauna including Lower, Middle, and Upper Devonian and Lower and Upper Mississippian forms (Willahan, 1991). In the Bishop Creek pendant there are several beds of fine-grained conglomerate composed largely of black chert clasts. The Bright Dot Formation probably is entirely Mississippian in age as it is underlain by Upper Devonian and overlain by Lower Pennsylvanian rocks.

The nature of the depositional environment of the Bright Dot Formation is obscure. Sedimentary structures other than parallel laminae and small scours in sandstone at the base of the section have not been noted. Fossil-bearing, debris-flow deposits near the top of the section in the Mount Morrison pendant suggest deposition in a marine environment near the base of a moderately steep slope, and a conglomerate-filled channel in the Pine Creek pendant may have formed subaerially. Because the underlying Squares Tunnel Formation is interpreted as a relatively deep-water deposit, and the overlying Mount Baldwin Marble is a shallow-water, carbonate-bank accumulation, the Bright Dot Formation probably represents a shallowing-upward sequence.

The Bright Dot Formation appears to be overlain concordantly by the Mount Baldwin Marble, although Wise (1996) stated that the contact is unconformable. The upper contact is placed at the base of the lowest limestone in the Mount Baldwin Marble.

Mount Baldwin Marble

This formation was named by Rinehart and Ross (1964) for a 189-m-thick section of marble (Willahan, 1991) in the Mount Morrison pendant; Bateman (in Rinehart and Ross, 1964) correlated a similar marble unit in the Pine Creek pendant with it. Rocks here assigned to the Mount Baldwin Marble, in addition to the localities mentioned in Rinehart and Ross (1964), include outcrops near the mouth of McGee Creek, named Hilton Creek Marble by Rinehart and Ross (1964); banded, very coarse-grained marble on Chocolate Peak; fossiliferous lenses of altered limestone trapped along the Gem Lake shear zone in the Northern Ritter Range pendant (Greene and Schweickert, 1995); and a large limestone mass near Conway Summit (Fig. 1).

The Mount Baldwin Marble consists of almost pure, medium to dark gray to bluish-gray, fine-grained to very coarse grained marble. Black chert in nodules or nodular beds is locally abundant in the lower part of the formation.

Fossils reported by Rinehart and Ross (1964), including crinoidal debris, corals, and brachiopods, were interpreted by them to be Early Pennsylvanian in age. Willahan (1991) recovered Morrowan (Early Pennsylvanian) conodonts from two samples near the base of the formation, and during this study, two additional samples from near the type locality yielded identifiable conodonts. One sample from the middle of the formation is late Atokan–early Desmoinesian (Middle Pennsylvanian) in age, and the other, collected from the uppermost 2 m of the formation, yielded an Asselian (early Early Permian) fauna. Thus, the Mount Baldwin Marble spans earliest Pennsylvanian to earliest Permian time. The fauna, consisting of a variety of shallow-water calcareous fossils, and the rocks, composed of thick-bedded, pure limestone, suggest deposition on a shallow-water, carbonate bank. The contact between the Mount Baldwin Marble and the overlying Mildred Lake Hornfels is sharp but conformable.

Post-earliest Permian Formations

Rinehart and Ross (1964) divided the post-earliest Permian section in the Mount Morrison pendant, the top of which is not exposed, into three formations; from older to younger, these are the Mildred Lake Hornfels, the Lake Dorothy Hornfels, and the Bloody Mountain Formation. These units, which were described by Rinehart and Ross (1964) and Willahan (1991), consist primarily of fine-grained siliceous hornfels that locally are interbedded with coarse-grained debris-flow deposits bearing rare shallow-marine fossils. These rocks suggest a depositional environment at or near the base of a submarine slope.

REGIONAL CORRELATIONS AND INTERPRETATIONS

Rocks temporally correlative with those of the Morrison block are exposed to the east in west-central Nevada and the White-Inyo Range, and to the west in the Saddlebag Lake, western Log Cabin Mine, and Northern Ritter Range pendants (Fig. 1). Previously, with minimal dating of poorly understood stratigraphic units and differences in facies, relationships between the Paleozoic rocks of the Morrison block and those in these other areas were unclear. Now that the stratigraphy of the Morrison block has been clarified and most units

Figure 9. Typical interbedded light gray and light to medium green calcareous hornfels in the Aspen Meadow Formation. Photograph of an outcrop in the type section in the Bishop Creek pendant. Knife (right center) is 9 cm long.

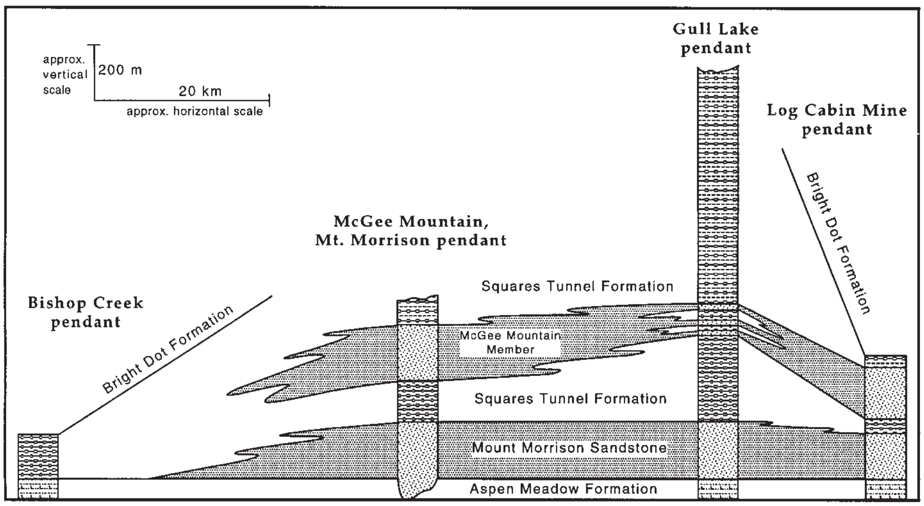

Figure 10. Stratigraphic cross section of the Sevehah Group from the Bishop Creek to the Log Cabin Mine pendant.

have been relatively well dated, the paleogeographic significance of the various lithofacies can be interpreted with confidence.

The oldest unit in the Morrison block, the Mount Aggie Formation, correlates lithologically and temporally with the Emigrant Formation in west-central Nevada and rocks mapped as Emigrant Formation by Nelson (1966) in the White Mountains (Fig. 14). The upper part of the Mount Aggie Formation has yielded conodonts suggesting an age close to that of the Cambrian-Ordovician boundary and the Emigrant Formation has been dated as Middle to Late Cambrian (Albers and Stewart, 1972). The age of the tops of these two formations is very similar; graptolite-bearing rocks immediately overlying the Mount Aggie and Emigrant Formations represent graptolite zones 4 or 5 and zones 3–8, respectively, according to William Berry (1996, personal commun.). The fine-grained, thin-bedded Mount Aggie and Emigrant Formations, which contrast greatly with the shallow-water dolomite, limestone, and shale (Monola Formation through Tamarack Canyon Dolomite) that accumulated concurrently in the White-Inyo Range, define an important facies boundary that represents the Middle to Upper Cambrian shelf margin of western North America (Fig. 15).

The highest member of the Mount Aggie Formation, the siliceous, thin-bedded Coyote Ridge member, is similar lithologically to the lower part of the Lower Ordovician Al Rose Formation in the western Inyo Mountains below beds that have yielded zone 4–6 graptolites (Ross, 1966). The Coyote Ridge member occurs below graptolite zone 4 or 5, so it may correlate temporally, as well as lithologically, with beds of the lower Al Rose Formation.

The deep-water Convict Lake Formation in the Morrison block and the lithologically similar Palmetto Formation in west-central Nevada have yielded graptolites representing at least zone 5 to 15 (within the Lower Ordovician to very high in the Ordovician rocks) and zones 3–8 to zone 14, respectively (William Berry, 1996, personal commun.). Thus, both units are of essentially identical age. Coeval units in the western Inyo Mountains were deposited primarily in shallow water. The upper part of the Al Rose Formation, which has yielded zone 4–6 graptolites, and the Barrel Spring Formation, which contains zone 12 graptolites (William Berry, 1996, personal commun.), are coeval with the lower and middle parts of the Convict Lake and Palmetto Formations. The Middle Ordovician Johnson Spring Formation, a Eureka Quartzite equivalent in the western Inyo Mountains (Ross, 1966), and the lower, Late Ordovician part of the Ely Springs Dolomite (Miller, 1975) correlate with the upper parts of the Convict Lake and Palmetto Formations. Deposition of both the Convict Lake and Palmetto Formations was characterized by slow accumulation of clay and silica occasionally interrupted by the influx of almost pure quartz sand. This sand almost surely represents the distal edge of the Eureka sand sheet that spread over the miogeocline as far west as the western Inyo Mountains (Stevens, 1986, 1991).

The Convict Lake Formation is overlain by the deep-water Aspen Meadow Formation, which represents part or all of the Silurian–Lower Devonian interval. This and younger Paleozoic units of the Morrison block have no temporal equivalents in either the parautochthonous rocks of west-central Nevada or the White Mountains because of post-Paleozoic erosion. In the western Inyo Mountains temporally equivalent units include the upper part of the shallow-water Ely Springs Dolomite, the overlying Vaughn Gulch Limestone, which contains transported reefal de-

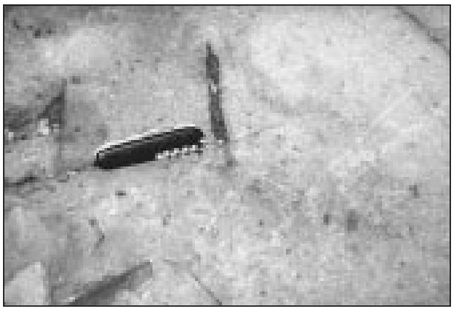

Figure 11. Coarse-grained, calcareous sandstone with “floating” argillite and chert clasts in the Mount Morrison Sandstone. Photograph of an outcrop along trail west of Convict Lake, Mount Morrison pendant. Knife is 9 cm long.

Figure 12. Dish structures in medium-grained sandstone in the Mount Morrison Sandstone. Photograph is of a displaced block along trail west of Convict Lake. Knife is 9 cm long.

Figure 13. Conglomerate composed largely of chert clasts in a coarse-grained sandstone matrix, Mount Morrison Sandstone. Photograph is of an outcrop on McGee Mountain in Mount Morrison pendant. Knife is 9 cm long.

bris, and, to the northwest, the basinal Sunday Canyon Formation. A contemporaneous carbonate-platform unit, the Hidden Valley Dolomite, is widely exposed in the southern Inyo Mountains and farther east (Stevens, 1986). Evidently this was a time of high calcium carbonate productivity on the shelf between times (Ordovician and Middle Devonian) of less carbonate production.

The Mount Morrison Sandstone in the Morrison block probably is of Givetian (late Middle Devonian) age and more or less temporally equivalent to the thin, quartz-rich Lippincott Member of the Lost Burro Formation (McAllister, 1974; Leatham et al., 1994) deposited on the shelf in the eastern Inyo Mountains and areas farther east. Snow (1992) pointed to a widespread unconformity represented mostly by nondeposition on the shelf in this part of the section, and Leatham et al. (1994) indicated that older rocks were subaerially exposed prior to deposition of the Lippincott Member. Thus, it seems probable that at this time excess amounts of quartz sand were available on the shelf. Channels in the western Inyo Mountains near Independence (Fig. 1) that are cut into lower Eifelian rocks and are filled with Famennian (Late Devonian) radiolarian chert (Stevens et al., 1996) are interpreted to have acted as conduits through which quartz sand was funneled from the shelf to the developing submarine fan in the Morrison block. The distinctive Givetian conglomerate that composes much of the Mount Morrison Sandstone near Tinemaha Reservoir (Fig. 1) probably represents the back fill of a major submarine channel. Another channel, interpreted as a continuation of that at Tinemaha Reservoir, is present at McGee Mountain. There the channel, which has cut out the Aspen Meadow Formation and much of the underlying Convict Lake Formation, is filled with a thick series of sandstone and conglomeratic rocks similar to those at Tinemaha Reservoir.

The Squares Tunnel Formation, from which Famennian (Late Devonian) fossils have been recovered, is present in both the Morrison block and the western Inyo Mountains. The Lost Burro Formation was deposited concurrently on the carbonate platform in the eastern Inyo Mountains.

The type section of the Squares Tunnel Formation in the western Inyo Mountains is composed entirely of black radiolarian-bearing chert and shale. In the Morrison block, this unit consists of a major submarine-fan complex composed of calcareous sandstone and conglomerate encased in deep-water chert and argillite similar to that in the type Squares Tunnel Formation. This submarine-fan complex originated in a manner similar to that of the older Mount Morrison Sandstone.

The Mississippian Bright Dot Formation in the Morrison block is approximately equivalent in age and lithology to the Kearsarge Formation and Rest Spring Shale in the western Inyo Mountains (Stevens et al., 1996). The Bright Dot Formation in the Bishop Creek pendant includes a few beds of fine-grained, chert-pebble conglomerate composed of clasts similar to, but smaller than, those in the Kearsarge Formation. The source of chert pebbles in the Inyo Mountains, and perhaps most of those in the Morrison block as well, apparently was not the Antler belt, which was west of the Morrison block, but was instead an uplifted block postulated to have been exposed during Mississippian time between the Morrison block and the Inyo Mountains (Stevens, 1995; Stevens et al., 1997).

The Mount Baldwin Marble, a carbonate-platform accumulation that ranges from Early Pennsylvanian to Early Permian in age, is coeval with the Keeler Canyon Formation, a thick sequence of limestone turbidites in the Inyo Mountains (Stevens, 1991). Thus, at this time, or probably before, during Mississippian time, the regional slope in this region was reversed from that during early Paleozoic time. The source of limestone turbidites in the Inyo Mountains, however, probably was not the Mount Baldwin carbonate platform, but rather a carbonate shelf represented by the widespread Bird Spring Formation and equivalent units to the east (Stone and Stevens, 1988).

The general age and lithology of post–Mount Baldwin Marble Permian units in the Morrison block, including the Mildred Lake Hornfels, the Lake Dorothy Hornfels, and the Bloody Mountain Formation, suggest correlation with the Lower Permian Lone Pine Formation (lower part of the Owens Valley Group) in the southern Inyo Mountains. The presence of sediment-gravity-flow deposits not only in the Lone Pine Formation (Stone and Stevens, 1987), but also in the Morrison block, suggests generally deep-water deposition in a topographically diverse region.

RELATIONSHIP TO THE ANTLER BELT

Rocks representing the Antler orogenic belt (Roberts Mountains allochthon) have been recognized in both west-central Nevada and in the Sierra Nevada north and west of the Morrison block (Figs. 1 and 15). In the Saddlebag Lake pendant, Antler-belt rocks consist of highly deformed, interleaved units of phosphatic chert, shale, siltstone, and argillite with isolated bodies of quartzite, calcareous sandstone, basalt, and limestone (Schweickert and Lahren, 1987, 1993), that probably are Ordovician to Devonian in age. These rocks are overlain by as much as 30 m of Permian conglomerate, correlated with the Diablo Formation in west-central Nevada, and probable Triassic rocks correlated with the Candelaria Formation, also in Nevada (Schweickert and Lahren, 1987). The Antler belt contains most of the rock types represented in the lower Paleozoic section in the Morrison block, including calcareous quartzite indicative of the Sevehah Group submarine-fan deposits. The allochthonous rocks of the Antler belt, however, are much more deformed and contain fewer calcareous rocks. One of the most definitive attributes of the Antler belt rocks in this region is the presence of interbedded basalt or greenstone, which has not been confirmed in rocks of the Morrison block, but was reported by Schweickert and Lahren (1987) in rocks assigned to the Antler belt in the Saddlebag Lake pendant. The upper Paleozoic section in the Antler belt also is exceedingly different from that in the Morrison block. More than 2500 m of fine-grained upper Paleozoic rocks are present in the Mount Morrison pendant (Rinehart and Ross, 1964; Willahan, 1991), whereas only the thin Diablo Formation represents this age span in the Antler belt.

Using these criteria, the contact between Antler-belt rocks and the Morrison block can be constrained to be east of that part of the Saddlebag Lake pendant where deformed eugeoclinal rocks, including basalt, are overlain by Permian conglomerate, and west of the eastern Log Cabin Mine pendant, where Morrison-block rocks crop out. In the Northern Ritter Range pendant, the contact between the allochthonous Antler belt and its autochthon was mapped by Greene (1995) and Greene et al. (1997a).

The position of the frontal trace of the Roberts Mountains allochthon in west-central Nevada has been controversial. Schweickert and Lahren (1987) and others placed it south of all exposures of Ordovician black shale, whereas Stewart and Poole (1974), Stewart (1980), and Stevens et al. (1997) placed it in the Miller Mountain area (Fig. 15). Employing the criteria used for the roof pendants, we place the contact between the more or less intact lower Paleozoic sequence on the south slope of Miller Mountain, which is similar to that in the Morrison block in the Sierra Nevada, and the north side of Miller Mountain, where the highly disturbed lower Paleozoic rocks (Stewart, 1984), including amygdaloidal greenstone, are unconformably overlain by the Permian Diablo Formation. The position of this boundary in

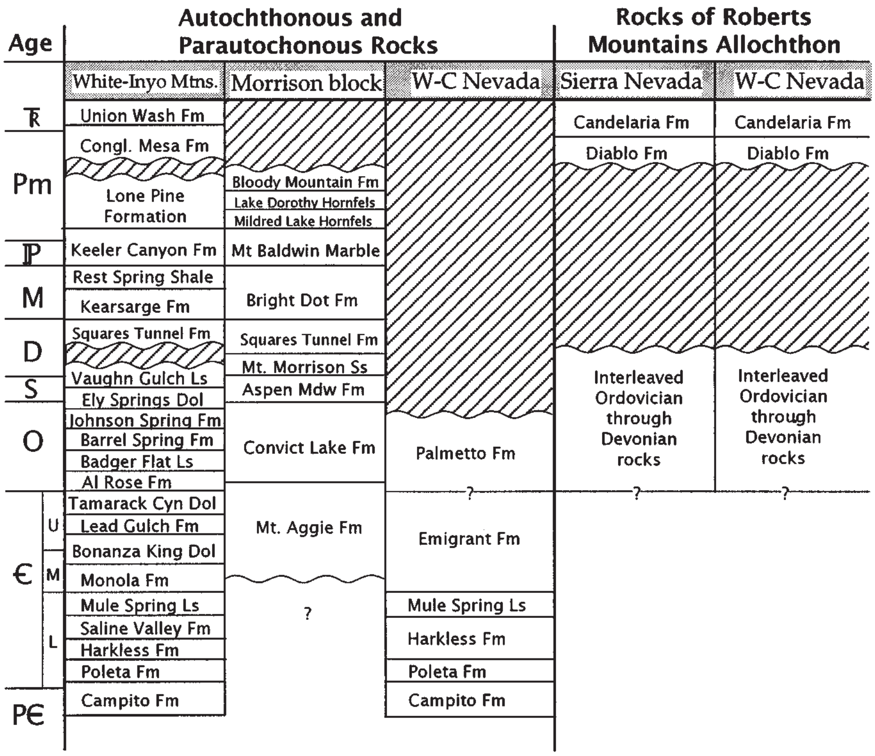

Figure 14. Correlation of units in the Morrison block with those in west-central Nevada and the White-Inyo Mountains, and rocks of the Roberts Mountains allochthon in the Sierra Nevada and west-central Nevada. In Morrison block, Mount Morrison Sandstone and Squares Tunnel Formation make up the Sevehah Group.

Miller Mountain is close to or at the position originally suggested by Stewart and Poole (1974). Thus, the lower Paleozoic rocks south of Miller Mountain, including the Emigrant and Palmetto Formations, and the similar Mount Aggie and Convict Lake Formations in the Morrison block, are here considered to originally have been part of the same facies belt. In addition, we suggest that the Antler-belt rocks deformed during the Antler orogeny were far from their present location at that time, and that they were emplaced into their present position against the Morrison block in post-middle Permian time, perhaps during emplacement of the Golconda allochthon in the early part of the Triassic (Schweickert and Lahren, 1987). Two lines of reasoning support this interpretation: (1) the Antler belt contains an upper Paleozoic sequence so different from that in the Morrison block that it is highly unlikely that they were deposited anywhere close to one another; and (2) there is no structural evidence that ties the Morrison block closely to the Antler belt in pre-Early Permian time.

DISPLACEMENT AND ROTATION OF FACIES AND STRUCTURAL BELTS

Both facies and structural belts and the $Sr_i = 0.706$ isopleth apparently change orientation from roughly north-south in central Nevada to roughly east-west in west-central Nevada (Figs. 1 and 15). Wetterauer (1977) coined the term Mina deflection to describe the change in orientation of these features, which has been variably ascribed to oroclinal folding in the region (Albers, 1967), to an original bend in the orientation of the continental margin (Oldow, 1984), to dextral displacement on east-west–trending faults (Stewart, 1985), and to dextral displacement on northwest-trending faults (Kistler, 1993).

Observations made during this study suggest to us that the change in orientation of the facies and structural belts is not an original feature of the continental margin. The similarity of the lithologic units between the east-west–trending continental-margin sequence in west-central Nevada and the more or less north-south–trending segment in the Sierra Nevada is most easily explained by deposition along an originally straight margin. Especially important is the position of the major Middle to Late Devonian submarine channel and fan complex in the Sierra Nevada that is more consistent with an originally straight margin. If the Mina deflection had been an original feature, the main channel at McGee Mountain (5a in Fig. 15) would have been located essentially on a peninsula rather than in the bight in west-central Nevada (within the Mina

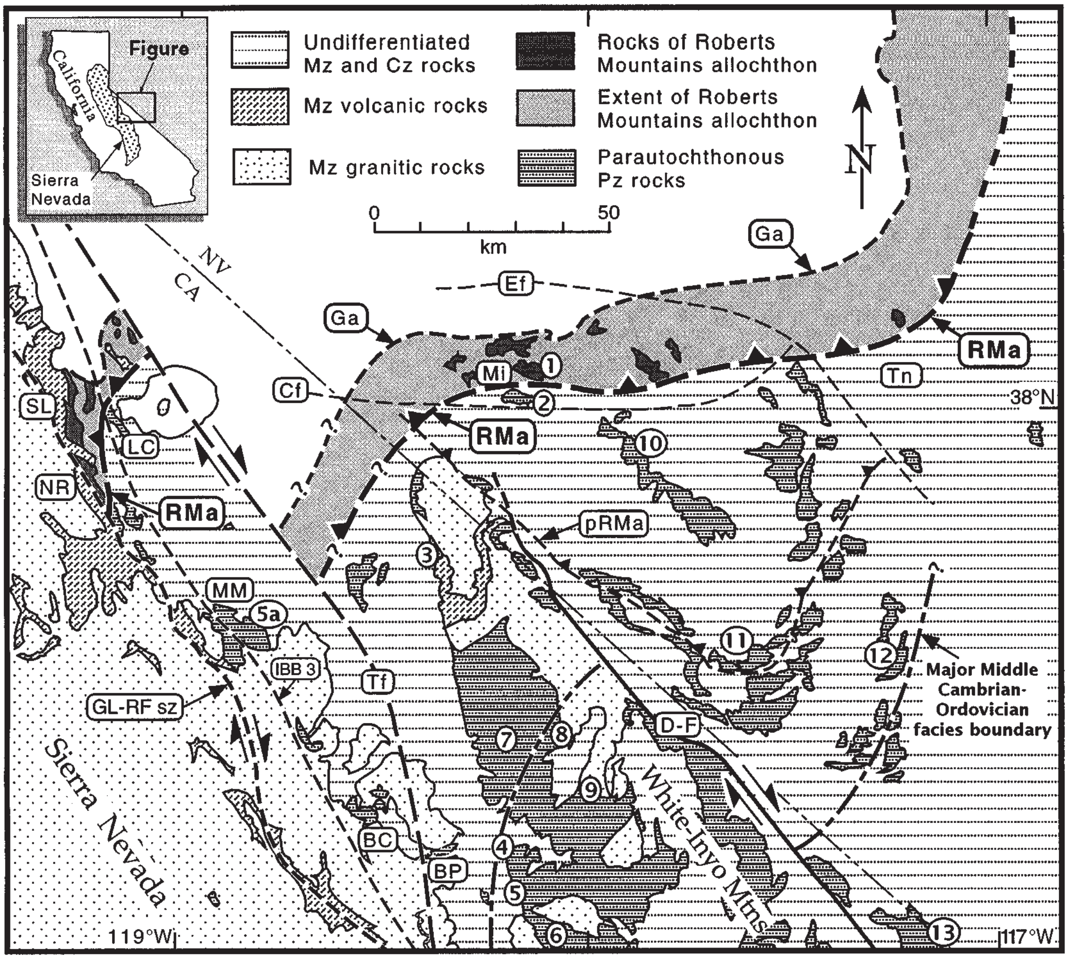

Figure 15. Generalized geologic map of east-central California and west-central Nevada showing major structural features involved in our reconstruction, locations of places referred to in the text, and data points important for recognition of the position of a major Middle and Upper Cambrian facies boundary. Pz is Paleozoic, Mz is Mesozoic, and Cz is Cenozoic. Pendants are: BC—Bishop Creek; BP—Big Pine Creek; LC—Log Cabin Mine; MM—Mount Morrison; NR— Northern Ritter Range; SL—Saddlebag Lake. Faults or shear zones are: Cf—Coaldale fault; D-F— Death Valley–Furnace Creek fault zone; Ef—Excelsior fault; GL-RF sz—Gem Lake–Rosy Finch shear zone; Tf—Tinemaha fault. Mi—Miller Mountain; Tn—Tonopah; Ga—southeastern margin of Golconda allochthon; RMa and pRMa—our placement and an alternative placement, respectively, of the southeastern margin of Roberts Mountains allochthon. 1—Roberts Mountains allochthon (Ordovician-Devonian rocks); 2—parautochthonous Lower Cambrian units including Poleta(?) Formation; 3—basinal Ordovician(?) rocks; 4, 8, 9—shallow-water Middle and Upper Cambrian rocks (e.g., Tamarack Canyon Dolomite); 5—Ordovician moderately deep-water rocks including Badger Flat Limestone and Middle Devonian submarine channel; 5a—offset Middle and Upper Devonian submarine channel present at 5. 6—Pennsylvanian Keeler Canyon Formation; 7, 10, 12—moderately deep-water Middle and Upper Cambrian Emigrant Formation; 11—deep-water Ordovician Palmetto Formation; 13—shallow-water Upper Cambrian Nopah Formation. Based primarily on Bateman (1992) and Albers and Stewart (1972).

deflection), where it would be expected to have been located.

If the facies and structural belts have been reoriented, displacement would have been accomplished by dextral displacement on faults and/or rotation of crustal blocks. Previously proposed strike-slip faults in the area that could have produced the Mina deflection are the Death Valley–Furnace Creek fault zone, the Intrabatholithic Break 3 (IBB3), the Tinemaha fault, the Coaldale fault, and the Excelsior fault (Fig. 15).

Stewart (1985, 1988) showed that the Death Valley–Furnace Creek fault zone displaces two Lower Cambrian facies boundaries by about 35 km (and considerably more if facies lines are straightened out) along the northern part of the fault zone near the Mina deflection (Fig. 15). In Death Valley, the amount of displacement is about 80 km (Stevens et al., 1991). Restoration of about 70 km of dextral faulting and rotation straightens out the major Middle(?) Cambrian–Ordovician regional facies boundary recognized here (Fig. 15).

Kistler (1993) considered the Laurel-Convict fault in the Mount Morrison pendant to be an exposed segment of the IBB3 upon which considerable right-lateral displacement had occurred, on the basis of offset of the Sr_i = 0.706 isotopic isopleth farther north. We have shown (Greene et al., 1997b), however, that the latest displacement on the Laurel-Convict fault was sinistral and pre-latest Triassic in age. This fault, therefore, did not accommodate the dextral displacement indicated by offset of the Sr_i = 0.706 isopleth (Fig. 1). A cryptic fault in Owens Valley, called the Tinemaha fault by Stevens et al. (1997) (Fig. 15), however, could account for both the 65 km of apparent dextral displacement of the $Sr_i = 0.706$ isopleth and the apparent displacement of a major Middle Devonian submarine channel from Tinemaha Reservoir at the foot of the Inyo Mountains to McGee Mountain in the Sierra Nevada (5 and 5a, respectively, Figs. 15 and 16). Displacement on this fault apparently is constrained as pre–late Late Triassic in age because the Wheeler Crest Granodiorite of late Late Triassic age (Bateman, 1992) lies across the inferred fault trace.

The Coaldale fault of Stewart (1985), based on the apparent termination of the Death Valley–Furnace Creek and Owens Valley–White Mountains faults and 60–80 km of displacement of the eastern edge of a sandy limestone facies (Sevehah Group) in the region, probably is not important because after displacement on the Tinemaha fault is restored, rocks of the Sevehah Group are no longer displaced. The Excelsior fault, proposed by Stewart (1985) as an east-trending dextral fault, is difficult to evaluate because it would cut pre-Tertiary outcrop belts at a low angle.

We suggest that the original trends of both facies and structural belts in the region were slightly west of south, and we interpret most of the apparent change in orientation of these belts to be due to dextral displacement of about 65 km on the Tinemaha fault and about 70 km of dextral displacement involving faulting and rotation of the east-trending segment of the Antler belt in westernmost Nevada related to displacement on the Death Valley–Furnace Creek fault zone farther south. This zone of deformation may have been active throughout much of Mesozoic as well as Cenozoic time (e.g., Stewart, 1988), with a considerable amount of deformation in this region having occurred in early Mesozoic time. Restoration of a total of 135 km of dextral displacement of the frontal trace of the Antler allochthon involving faulting and rotation straightens out that trace (Fig. 16) and the apparent margin of the North American sialic crust. We realize, however, that other solutions for restoration of the original trends are possible. This northeast-trending mid-Paleozoic North American continental margin, as reconstructed here (Fig. 16), appears to have been truncated west of the region under consideration, probably during late Paleozoic time (e.g., Stone and Stevens, 1988).

SUMMARY

The Morrison block, which consists of roof pendants extending about 115 km from the Coyote Creek pendant northwestward to north of the Log Cabin Mine pendant, is shown here to have a consistent stratigraphy. Ten formations have been mapped in the four largest pendants, and are recognized also in many of the smaller pendants.

The lower Paleozoic rocks in the Morrison block and those in west-central Nevada are very similar, and are deep-water equivalents of the well-known miogeoclinal rocks of the White-Inyo Range to the east. The new understanding of the nature of this deep-water facies belt combined with recognition of an early Mesozoic fault with a large amount of dextral displacement in the Owens Valley area suggests to us that the continental margin originally was linear and north-northeast trending. We propose, therefore, that the present configuration of facies and structural belts in the Mina deflection is due mainly to Mesozoic and Cenozoic dextral displacement and rotation of crustal blocks.

West of the region under consideration, the distal parts of the lower Paleozoic depositional system represented by the rocks of the Morrison block were deformed into the Antler orogenic belt during the Late Devonian to Early Mississippian Antler orogeny. The contrast between the upper Paleozoic rocks of the Morrison block and those overlying the deformed lower Paleozoic rocks in the Antler belt, and the minimal effects of the Antler orogenic event on the rocks of the Morrison block, however, suggest that these two blocks were far apart during most of Paleozoic time. These two quite different blocks most likely were juxtaposed between Early Permian and Late Triassic time.

ACKNOWLEDGMENTS

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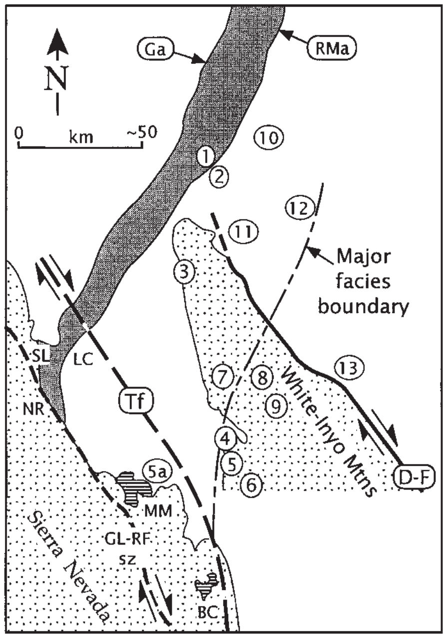

Figure 16. Restored structural and facies belts in west-central Nevada and east-central California. See Figure 15 for numbers and abbreviations.

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