1991

Biostratigraphy of Upper Paleozoic rocks in the Mount Mossirson Roof Pendant, Sierra Nevada, California : evidence for its original paleogeographic position

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DOI: <https://doi.org/10.31979/etd.s9dz-mm3a>
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**Biostratigraphy of Upper Paleozoic rocks in the Mount
Morrison roof pendant, Sierra Nevada, California: Evidence for
its original paleogeographic position**

Willahan, Daune Erin, M.S.

San Jose State University, 1991

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BIOSTRATIGRAPHY OF UPPER PALEOZOIC ROCKS IN THE
MOUNT MORRISON ROOF PENDANT, SIERRA NEVADA, CALIFORNIA:
EVIDENCE FOR ITS ORIGINAL PALEOGEOGRAPHIC POSITION

A Thesis

Presented to

The Faculty of the Department of Geology
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

By

Daune Erin Willahan

August, 1991

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ACKNOWLEDGEMENTS

This manuscript was greatly improved by the many discussions with and thoughtful reviews from the members of the thesis committee. I especially want to thank my advisor, Dr. Cal Stevens, for suggesting the project, for helping in the field and the laboratory, and having patience with a new mother during the writing of the manuscript. Special thanks are given to Dr. David Andersen for his reviews of the manuscript and helpful suggestions, which especially improved the quality of the illustrated figures, and to Dr. Warren Nokleberg for his advice and help in obtaining the relevant articles and maps. Also, I want to thank all my field assistants, but especially Mary Long, who assisted me the entire first summer of field work, Joel Willahan, who assisted in the second summer, and Karen Hicks, whose help in measuring the stratigraphic sections was invaluable. This work is dedicated to my husband, who supported me (emotionally and financially!) throughout the project, and last but not least, to "Rainier," a loyal and loving four-legged friend who carried his share of rock samples for me and now runs free in the mountains of the sky.

TABLE OF CONTENTS

	Page
ABSTRACT.....	x
INTRODUCTION.....	1
STRATIGRAPHY.....	6
Bright Dot Formation.....	7
Lithology.....	7
Fossils and Age.....	18
Depositional Environment.....	18
Mount Baldwin Marble.....	20
Lithology.....	20
Fossils and Age.....	25
Depositional Environment.....	31
Mildred Lake Hornfels.....	31
Lithology.....	31
Depositional Environment.....	33
Lake Dorothy Hornfels.....	33
Lithology.....	33
Depositional Environment.....	39
Bloody Mountain Formation.....	41
Lithology.....	41
Fossils and Age.....	48
Depositional Environment.....	48
STRUCTURE.....	51

	Page
DEPOSITIONAL HISTORY.....	57
REGIONAL COMPARISON OF UPPER MISSISSIPPIAN TO	
PERMIAN AGE ROCKS.....	60
PALEOZOIC TECTONIC HISTORY OF THE REGION.....	69
Regional History.....	69
Position of the Bloody Mountain Block	
during the Late Paleozoic.....	74
CONCLUSIONS.....	79
REFERENCES CITED.....	80
APPENDIX A: MEASURED SECTIONS.....	84
Section 1.....	84
Section 2.....	87
Section 3.....	90

LIST OF ILLUSTRATIONS

Figure	Page
1. Map of the Mount Morrison and Other Roof Pendants.....	2
2. Structural Blocks of the Mount Morrison Pendant.....	4
3. Geologic Map of the Study Area.....	8
4. Chert with Shale in the Bright Dot Formation.....	11
5. Interbedded Hornfels of the Upper Bright Dot Formation	12
6. Calcareous Unit within the Upper Bright Dot Formation	13
7. Soft-sediment Deformation in the Upper Bright Dot Formation.....	15
8. Debris-flow Deposits of Upper Bright Dot Formation.....	16
9. Conglomerate Bed in Upper Bright Dot Formation	17
10. Chesterian Conodonts from the Upper Bright Dot Formation.....	19
11. Typical Appearance of Mount Baldwin Marble...	21
12. Argillaceous Marble Beds and Chert Nodules in the Lower Mount Baldwin Marble.....	23

Figure		Page
13.	Graded Bed in Mount Baldwin Marble.....	24
14.	Debris-flow Conglomerate in Mount Baldwin Marble.....	26
15.	Contact between Bright Dot Formation and the Mount Baldwin Marble.....	27
16.	Morrowan Conodonts from the Lower Mount Baldwin Marble.....	29
17.	<u>Omphalotrochus?</u> at Top of the Mount Baldwin Marble	30
18.	Outcrop of Mildred Lake Hornfels.....	32
19.	Contact between the Mount Baldwin Marble and the Mildred Lake Hornfels.....	34
20.	The Lake Dorothy Hornfels with Typical Stripes.....	36
21.	Soft-sediment Deformational Features in the Upper Lake Dorothy Hornfels.....	37
22.	Debris-flow Deposit in the Lake Dorothy Hornfels.....	38
23.	Contact between the Lake Dorothy Hornfels and the Mildred Lake Hornfels.....	40
24.	Outcrop of the Bloody Mountain Formation.....	42
25.	Marble within the Bloody Mountain Formation	43

Figure		Page
26.	Debris-flow Conglomerate in the Bloody Mountain Formation.....	45
27.	Change in the Weathered Color of the Bloody Mountain Formation.....	46
28.	Crinoidal Marble Bed in the Bloody Mountain Formation.....	47
29.	Contact between the Bloody Mountain Formation and the Underlying Lake Dorothy Hornfels.....	49
30.	Deformed Bright Dot Formation.....	55
31.	Deformed Mount Baldwin Marble.....	56
32.	Location of Mount Morrison Pendant Relative to the Inyo Mountains.....	61
33.	Correlations between the Bloody Mountain Block and the Inyo Mountains.....	62
34.	Map of Area in Southeastern California.....	65
35.	Late Paleozoic Continental Margin in California and Nevada.....	70
36.	Map of East-central California Showing Pennsylvanian and Permian Rocks.....	71
37.	Present location of the Snow Lake and Mount Morrison Blocks and the Position of the Mount Morrison Pendant.....	76
38.	Inferred Original Paleogeographic Position of the Bloody Mountain Block.....	78

Plate

1. Geologic Map of the Bloody Mountain Block
Study Area..... in pocket
2. Measured Sections 1 and 2 in pocket
3. Measured Section 3 in pocket

ABSTRACT

Upper Paleozoic metasedimentary rocks in the Mount Morrison roof pendant in the eastern Sierra Nevada have chronologic and lithologic similarities to Upper Mississippian-Lower Permian rocks about 130 km to the southeast in the southwestern Inyo Mountains. The pendant rocks represent basin/base of slope deposits as do those in the southwestern Inyo Mountains. In addition, the sequence of lithologic changes is similar. In the pendant, Chesterian (Late Mississippian) conodonts from a faunally mixed sample have been extracted from the siliciclastic upper Bright Dot Formation, and early Morrowan (Early Pennsylvanian) conodonts have been found near the base of a marble sequence in the overlying Mount Baldwin Marble. These latter conodonts occur just above calcareous beds containing chert nodules or "golfballs" similar to those occurring in the Morrowan part of the Pennsylvanian-Permian Keeler Canyon Formation in the Inyo Mountains. The similarity in the rocks, inferred depositional environments, and timing of major lithologic changes between the Upper Mississippian to Permian rocks of the Mount Morrison pendant and the Inyo Mountains suggests that the Mount Morrison pendant originated as part of North America approximately 130 km southeastward from its present position.

INTRODUCTION

The Mount Morrison roof pendant (Rinehart and Ross, 1964) is one of a series of pendants east of the crest of the Sierra Nevada (Fig. 1), consisting mainly of multiply-deformed Paleozoic metasedimentary and Mesozoic metavolcanic rocks (Kistler and Nokleberg, 1980). These pendants, which form a discontinuous, 140-km-long, northwest-trending belt, are preserved within a complex of granitic plutons of Mesozoic age.

There has been considerable controversy over the origin of these pendants and their possible relationship, if any, to the Paleozoic North American continent. One interpretation is that the rocks in these pendants are allochthonous, representing a collage of tectono-stratigraphic terranes that were accreted along a tectonically active continental margin (Nokleberg, 1983). Other workers (Lahren and Schweickert, 1989; Stevens and others, submitted 1991) have suggested that these pendants represent displaced pieces of Proterozoic and Paleozoic North America. However, convincing chronologic and lithologic correlations have been difficult because of a lack of close age constraints and detailed stratigraphic studies. This is due in part to contact metamorphism, which has tended to obliterate the fossils, and deformation that has disrupted the sedimentary sequences. In addition, these

Figure 1. Generalized map of the central Sierra Nevada, California, showing the location of the Mount Morrison and other roof pendants (modified from Russell and Nokleberg, 1977).

pendants occupy very rugged terrain; most are located at elevations above 2700 m, making field work difficult.

The 62-km² Mount Morrison pendant contains two sequences of metamorphic rocks; Paleozoic miogeoclinal metasedimentary rocks form the eastern two-thirds of the pendant, and metavolcanic rocks of Mesozoic age occupy the western third of the area (Fig. 2). Granitic rocks of Mesozoic age enclose and intrude the pendant rocks. These are predominantly quartz monzonite and granodiorite, although scattered bodies of granite, aplite, diorite and gabbro are present locally (Rinehart and Ross, 1964).

The Paleozoic sequence has been divided by major faults into three structural blocks (Fig. 2), which originally were named and described by Rinehart and Ross (1964). From east to west, these are the McGee Mountain, Convict Lake and Bloody Mountain blocks. The McGee fault separates the McGee Mountain and Convict Lake blocks, the Laurel-Convict fault separates the Convict Lake and Bloody Mountain blocks, and an unnamed fault separates the Bloody Mountain block from the adjacent Mesozoic volcanic sequence.

There are two main objectives to this study. The first is to obtain better age constraints for the units in the Mount Morrison pendant by recovering fossils, especially conodonts, that have withstood metamorphism. The second is to describe the stratigraphy in detail in order to ascertain

Figure 2. Structural blocks of the Mount Morrison roof pendant (modified from Rinehart and Ross, 1964). Uncolored areas are underlain by igneous rocks or alluvium.

how much lithologic similarity there is with rocks of Paleozoic North America east of Owens Valley.

Research was restricted to a 19-km² area within the Mount Morrison pendant exclusively within the Bloody Mountain block (Fig. 2). This area was mapped on two 7.5-minute topographic base maps: the Bloody Mountain quadrangle and the Convict Lake quadrangle.

STRATIGRAPHY

All of the rocks in the Mount Morrison pendant have been metamorphosed to the hornblende-hornfels facies (Rinehart and Ross, 1964), but the protoliths can be interpreted. In the following descriptions the metamorphic rock names are used except in the discussions of depositional environments where protolith names for the metasedimentary rocks are used. The most common rocks in the pendant are two types of microgranular hornfels: siliceous hornfels and calc-silicate hornfels. Siliceous hornfels is a quartz-mica-feldspar rock in which quartz constitutes 40 to 80 percent of the rock and calc-silicate minerals are minor or absent (Rinehart and Ross, 1964). Parent sedimentary rocks probably were carbonaceous mudstone and/or siltstone with some interlaminated shale. Calc-silicate hornfels is composed of feldspar, quartz, and calc-silicate minerals, typically tremolite and diopside, which exceed 25 percent of the rock. Mica is sparse to absent. The parent rock probably was calcareous siltstone (Rinehart and Ross, 1964).

To determine thickness of rock units and the sequence of rock types, each formation was measured. Locations of measured sections are shown on Plate 1. All of the measured sections are illustrated on Plates 2 and 3 with accompanying descriptions in Appendix A. An altimeter and/or tape were

used to establish the positions of points on the slopes. The compass was used to obtain the strike and dip of beds as well as to determine the bearing of the line along which the section was measured. The altimeter was calibrated approximately every half hour against known elevations to assure accuracy. Trigonometric formulae were then used in calculating the thickness of rock units.

The Bloody Mountain block contains five formations: in order of decreasing age and from east to west they are the Bright Dot Formation (Fig. 3), here assigned a Late Mississippian age; the Mount Baldwin Marble, here considered Pennsylvanian to Early Permian in age; and the Mildred Lake Hornfels, Lake Dorothy Hornfels, and Bloody Mountain Formation, all of which are considered to be Permian in age. The Bright Dot Formation is truncated at its base by the Laurel-Convict fault. The upper part of the Bloody Mountain Formation is intruded by the Cretaceous Round Valley Peak Granodiorite, which has removed an unknown amount of section.

Bright Dot Formation

Lithology

The Bright Dot Formation, named by Rinehart and Ross (1964), is characterized by dark-reddish-brown-weathering siliceous rocks ranging from metachert to siliceous

Figure 3. Generalized geologic map of the study area.

layers that are interbedded with greyish-green chert layers that are <3 cm thick. These two rock types alternate with very thin, medium- to dark-grey layers within which phosphatic lenses occur. These lenses are <1 cm thick and generally hornfels. The maximum exposed thickness of the Bright Dot Formation is approximately 610 m (Rinehart and Ross, 1964), but repetitious folding makes this estimated thickness questionable.

The Bright Dot Formation is divided into two members; the lower unit, reported to be 300 to 450 m thick, consists of massive metachert and siliceous hornfels, and the upper unit, probably 150 to 300 m thick, is composed of distinctly bedded siliceous and calc-silicate hornfels (Rinehart and Ross, 1964). Both the metachert and siliceous hornfels of the lower member are dark grey to black on fresh surfaces, weathering to a dark reddish brown. The metachert is interbedded or gradational with the siliceous hornfels, and in the field it is difficult to distinguish between the two. Locally the metachert has a vitreous luster on fresh surfaces, whereas the hornfels typically is dull. The metachert is microgranular and according to Rinehart and Ross (1964) is more than 80% quartz; it also contains biotite, muscovite, feldspar and opaque minerals, predominantly pyrite, which account for the unit's rusty appearance where weathered. Weathered surfaces locally have

a well-bedded or layered appearance that is not visible on fresh surfaces. Abundant ribbon chert with shale partings occurs at one locality near the Laurel-Convict fault (Fig. 4). Bedding is defined by 3- to 6-cm-thick, black chert range from 0.5 to 3 cm in length with rare ones up to 6 cm long. Radiolarians recovered from a sample of the black chert are unidentifiable (B. Murchey, pers. comm., 1990). Sponge spicules are abundant in this sample.

The following description is based on the uppermost 86 m of the upper member of the Bright Dot Formation that was measured (Appendix A, Section 1, Plate 2). Lower beds in this member are too deformed to be included in the measured section. This part of the upper member is composed of a distinctively interbedded siliceous and calc-silicate hornfels (Fig. 5). The siliceous hornfels weathers dark to moderate reddish brown, whereas the calc-silicate hornfels weathers very pale orange. These alternating beds range in thickness from 2 cm up to 1 m. On fresh surfaces this microgranular hornfels ranges from very light to dark grey. Some of the siliceous beds contain lenses of calcareous material which, when weathered out, give a pock-marked appearance to the rock. Locally abundant calcareous beds and lenses occur within the hornfels. These fine-grained calcareous units typically are light to dark grey on both fresh and weathered surfaces (Fig. 6). Relict bedding is

Figure 4. Chert with shale partings in the Bright Dot Formation. Knife is 9 cm long.

Figure 5. Typical interbedded siliceous (orange) and calc-silicate (pale-orange) hornfels of the upper Bright Dot Formation. Hammer is 38 cm long.

Figure 6. Fine-grained calcareous unit (below hammer) within the upper Bright Dot Formation.

distinguished by changes in grain size, and soft-sediment-deformational features are common in the thicker calcareous units (Fig. 7). Also associated with these calcareous units are debris-flow deposits, containing poorly sorted and ungraded chert-pebble and limestone-pebble conglomerates. These debris-flow conglomerates occur primarily near the top of the upper member (Fig. 8). The conglomerate beds are 1 to 3 m thick and contain clasts ranging from 2 mm to 5 cm, with local clasts up to 15 cm (Fig. 9). The clasts are subangular to subrounded and consist of chert, marble and hornfels. The matrix is siliceous and the conglomerate is predominantly clast-supported, although locally it is matrix-supported. At one locality, the conglomerate is interlayered with a coarse-grained calcareous bed containing poorly sorted, bioclastic detritus (pelmatozoans, corals and brachiopods) and chert pebbles. At another locality, chert is rhythmically interbedded with unfossiliferous, medium- to coarse-grained, marble beds, as well as conglomerate beds with abundant chert pebbles in a calcareous matrix.

The Bright Dot Formation is in fault contact with the Ordovician-Silurian Sevehah Cliff Formation along its entire exposed length (Rinehart and Ross, 1964). This fault was named the Laurel-Convict fault by Rinehart and Ross (1964).

Figure 7. Soft-sediment deformation in a calcareous bed in the upper Bright Dot Formation.

Figure 8. Calcareous debris-flow bed near top of upper Bright Dot Formation.

Figure 9. Chert- and limestone-pebble conglomerate bed in upper Bright Dot Formation.

Fossils and Age

The Bright Dot Formation was tentatively assigned a Pennsylvanian age by Rinehart and Ross (1964). To further constrain the age, samples were collected and processed for conodonts. An age-diagnostic conodont assemblage was recovered from one locality (Loc. Y, Plate 1) and identified and dated by Charles Sandberg (written comm., 1989) and the author. This assemblage includes Chesterian (Late Mississippian) fossils (Fig. 10), along with Kinderhookian (Early Mississippian) and Early, Middle and Late Devonian specimens that are interpreted to be reworked.

Sample BD-43

Polygnathus aff. P. communis communis

Pseudopolynathus aff. P. oxypageus

Gnathodus aff. G. commutatus commutatus

Gnathodus aff. G. bilineatus?

On the basis of these new fossil data the upper Bright Dot Formation can now be assigned to the Upper Mississippian.

Depositional Environment

The Bright Dot Formation is interpreted to have been deposited in a basinal environment. The chert and siltstone of the lower member reflect deposition in quiet water, probably on a basin plain, either by slow hemipelagic processes or by rapid fallout from dilute turbidity

Figure 10. Chesterian conodonts (Gnathodus aff. G. commutatus commutatus) from the upper part of the Bright Dot Formation.

currents. The interbedded siliceous and calcareous mudstones that characterize the upper member also may represent transportation and deposition by dilute turbidity currents. The coarse-grained, sediment-gravity-flow deposits in the upper member may be the consequence of relatively rare events bringing coarser sediment farther out into the basin than usual.

Mount Baldwin Marble

Lithology

The Mount Baldwin Marble was named by Rinehart and Ross (1964) for a light- to dark-bluish-grey marble, containing fine- to coarse-grained, fossiliferous and unfossiliferous beds (Fig. 11). The formation is about 152 m thick at the type locality (Rinehart and Ross, 1964), and these workers noted that the intense folding in the formation made thickness measurements unreliable away from this locality. An incomplete thickness of approximately 189 m was calculated for the formation (Appendix A, Section 1, Plate 2) south of the type locality. It should be noted that repetition of beds was not observed in the measured section at this locality, suggesting that the formation may thicken somewhat southward.

At the base of the formation, a debris-flow deposit is represented locally by a conglomerate containing subangular

Figure 11. Typical appearance of Mount Baldwin Marble (note large recrystallized crinoid stems at right in fossiliferous bed).

to subrounded clasts of chert, 2 mm to > 15 cm long, supported by a calcareous matrix. The lower part of the Mount Baldwin Marble contains scattered to abundant dark brown to black chert beds. The chert occurs in nodules that range from 0.3 to 8 cm in diameter and as thin beds or irregular masses 10 to 50 cm thick. Interbedded with the chert-bearing zones are light-brown, argillaceous marble beds; dark-grey, pyritic, very fine-grained marble (Fig. 12); and marble beds with abundant crinoidal debris. The chert and argillaceous beds, which are 4 cm to more than 1 m thick, are erosionally resistant, forming ledges that stand out from the bluish-grey marble. Within this interval, bedding is defined by chert lenses, beds, and aligned nodules. Above this distinctive basal unit, coarsely recrystallized medium-grey marble beds, 6 to 30 cm thick, are interbedded with fine-grained, light- to dark-grey marble beds that are 4 to 15 cm thick. These fine-grained beds are interbedded with light- to medium-grey, fossiliferous beds containing gastropods and pelmatozoan detritus. Relict bedding features are represented by changes in grain size and color. Bouma Tab sequences, although not easily identified due to metamorphism of the formation, were observed locally (Fig. 13). Bouma Ta is defined by 6- to 30-cm-thick, graded beds of pelmatozoan debris and large grains of calcite, 0.5 to 3 mm in length.

Figure 12. Typical appearance of argillaceous marble beds and chert nodules in the lower part of the Mount Baldwin Marble.

Figure 13. Graded bed in Mount Baldwin Marble. Up direction at top of photo.

These beds grade upward into thinly laminated, fine-grained beds ranging from 4 to 15 cm thick, which are inferred to represent the Bouma Tb interval.

Irregular chert lenses occur randomly near the top of the formation, but are less abundant than at the base. At one locality, a short distance below the contact with the overlying Mildred Lake Formation, a debris-flow deposit was observed. This poorly sorted, ungraded, 1.5-m-thick conglomerate contains chert and calcium carbonate clasts ranging from 2 to 20 cm in length (Fig. 14). The calcium carbonate clasts, composed of white and black, fine-grained marble, and medium-grey, crinoidal marble, are supported in a light- to medium-grey, calcareous matrix.

The Mount Baldwin Marble conformably overlies the Bright Dot Formation. The contact between the two formations (Fig. 15) is placed at the top of the highest bed of siliceous hornfels. This contact also corresponds with the lowest occurrence of marble in most of the area studied. The boundary is gradational at a few localities where interlayering of hornfels and marble occurs over a few meters.

Fossils and Age

The Mount Baldwin Marble was assigned a Pennsylvanian age on the basis of brachiopods collected from the lower

Figure 14. Debris-flow conglomerate at top of Mount Baldwin Marble. Note 10-cm-long black chert clast to right of person's knee.

Figure 15. Contact between the reddish-brown Bright Dot Formation and the light-grey Mount Baldwin Marble near right edge of photo.

part of the formation by Rinehart and Ross (1964). In addition to these fossils, abundant crinoid columnals occur throughout the formation. Further constraints on the age of the formation have been made possible by the extraction of Morrowan (Early Pennsylvanian) conodonts (Fig. 16) from near the base of the formation (Locs. W, X, Plate 1) during this work. The conodonts were identified and dated by Charles Sandberg (written comm., 1989) and the author.

Sample MB-26a

Adetognathus aff. A. lautus

Idiognathoides aff. I. noduliferus

Sample MB-94

Adetognathus aff. A. lautus

Rhacistognathus aff. R. muricatus?

Idiognathoides aff. I. noduliferus

Idiognathoides aff. I. sulcatus sulcatus?

Idiognathoides aff. I. sinuatus?

In addition to the conodonts, a distinctive gastropod 4 cm in diameter (Fig. 17) was found at the top of the formation (Loc. V, Plate 1). This large specimen has been tentatively identified as belonging to the genus Omphalotrochus (C. Stevens, pers.comm., 1990). This genus is restricted to the Wolfcampian (Early Permian), so the upper portion of the Mount Baldwin Marble has been assigned tentatively to the Lower Permian.

Figure 16. Morrowan conodonts (Adetognathus aff. A. lautus) from the lower part of the Mount Baldwin Marble.

Figure 17. Omphalotrochus? or possibly a bellerophontid gastropod 4 cm in diameter, from top of the Mount Baldwin Marble.

Depositional Environment

The Mount Baldwin Marble represents a major change in the depositional regime: basinal siliceous mudstone and siltstone are abruptly overlain by dominantly carbonate rocks. The sediment-gravity-flow deposits and fine-grained and argillaceous limestone observed within the formation suggest that the sediment was deposited in a lower-slope environment, probably seaward of a carbonate platform.

Mildred Lake Hornfels

Lithology

The Mildred Lake Hornfels, named by Rinehart and Ross (1964), consists of fine-grained, massive, siliceous hornfels. The formation is approximately 189 m thick (Appendix A, Section 2, Plate 2). Weathered surfaces typically are pale orange to reddish orange in color (Fig. 18), whereas fresh surfaces are light to medium grey. Locally abundant white to greenish-grey calc-silicate-hornfels beds ranging up to 3 m thick also occur. Bedding features are not visible on fresh surfaces; however, rare, reddish-brown laminations occur on weathered surfaces of outcrops of medium-grey, siliceous hornfels, giving these rocks a bedded appearance. Rinehart and Ross (1964) noted that relict clastic texture is only visible in thin section, with quartz grains 0.05 to 0.1 mm in diameter scattered

Figure 18. Typical outcrop of Mildred Lake Hornfels.

throughout a finer-grained matrix of granoblastic quartz, plagioclase and potassium feldspar, biotite and minor muscovite.

The Mildred Lake Hornfels conformably overlies the Mount Baldwin Marble (Fig. 19). The lithologic boundary between the two formations is commonly gradational over a few meters, and is represented by interlayering of marble and hornfels beds. In the field, the contact was placed at the top of the highest marble bed.

The Mildred Lake Hornfels tentatively was assigned an age of Pennsylvanian and/or Permian by Rinehart and Ross (1964). On the basis of the apparent age of the underlying Mount Baldwin Marble, this formation is here assigned to the Permian.

Depositional Environment

The deposits of the Mildred Lake Hornfels originally were dark, massive, very fine-grained, siliceous and calcareous siltstone and mudstone. These rocks are inferred to represent hemipelagic sedimentation, probably within a basinal environment.

Lake Dorothy Hornfels

Lithology

The Lake Dorothy Hornfels was named by Rinehart and

Figure 19. Contact between the light-grey Mount Baldwin Marble and the reddish-orange Mildred Lake Hornfels.

Ross (1964) for a sequence of very fine-grained, interbedded siliceous and calc-silicate hornfels. The formation is approximately 450 m thick (Appendix A, Section 2, Plate 2) and has a distinctively striped appearance; bands of dark-grey to greenish-black, siliceous hornfels alternate with yellowish- to greenish-grey beds of calc-silicate hornfels (Fig. 20). These alternating beds range from 2 to 4 cm in thickness. Weathering color ranges from reddish orange to greenish black. Fresh surfaces have a dull appearance; alternating beds can still be observed, but the differences are subtle. The calcareous composition of the lighter beds makes them less resistant; lenses and "eyes" weather out, imparting a pock-marked appearance to these beds.

The upper half of the Lake Dorothy Hornfels contains abundant sandy marble beds that range from 7 to 24 m thick. These beds weather a light-grey color and have primary features that include folds and convolute laminations interpreted to be of soft-sediment deformational origin (Fig. 21). Fresh surfaces are light to medium grey. A 4.6-m-thick debris-flow deposit within 60 m of the top of the formation contains subrounded to angular clasts of chert, siliceous hornfels, and fossiliferous, micritic and sandy marble supported by a siliceous matrix (Fig. 22). This conglomerate is ungraded and very poorly sorted.

The Lake Dorothy Hornfels conformably overlies the

Figure 20. The Lake Dorothy Hornfels showing its typical distinctive stripes.

Figure 21. Soft-sediment deformational features in sandy marble beds within the upper Lake Dorothy Hornfels.

Figure 22. Unsorted debris-flow deposit, containing clasts of chert, hornfels and marble, near the top of the Lake Dorothy Hornfels.

Mildred Lake Hornfels (Fig. 23). A transitional zone marked by a few-meter-thick sequence of interbedded rocks typical of each formation occurs between the two distinctive units. The contact is placed at the base of the lowest sequence of striped beds that characterizes the Lake Dorothy Hornfels. Where covered by scree or soil, the formational boundary is discerned by a color change; the Lake Dorothy Hornfels has a greenish hue, whereas the Mildred Lake Hornfels has an orange hue.

The Lake Dorothy Hornfels was tentatively assigned a Pennsylvanian and (or) Permian age by Rinehart and Ross (1964). On the basis of the probable Permian fossil in the Mount Baldwin Marble, this formation is here assigned to the Permian.

Depositional Environment

The Lake Dorothy Hornfels probably was deposited in a basinal/base of slope environment. The lower half of the formation is characterized by fine-grained, rhythmically interbedded packages of siliceous and calcareous siltstone and mudstone, interpreted here as basinal deposits. The upper half of the formation consists of calcareous sequences with abundant soft-sediment deformational features and sediment-gravity-flow conglomerates. According to Lowe (1972), mass-flow and slump units characterize a base-of-

Figure 23. Contact between the light greenish-grey Lake Dorothy Hornfels on the left and the underlying, reddish-orange Mildred Lake Hornfels.

slope setting, the instability of the slope being indicated by the abundance of these slumped beds.

Bloody Mountain Formation

Lithology

The Bloody Mountain Formation was named by Rinehart and Ross (1964) for a unit of massive, dense, siliceous and calc-silicate hornfels that weathers a dark reddish-brown (Fig. 24). An incomplete thickness of 1207 m was calculated for the formation (Appendix A, Section 3, Plate 3). On fresh surfaces the Bloody Mountain Formation is composed of very fine-grained, dark-grey to black siliceous hornfels, and light-grey calc-silicate hornfels. Weathered surfaces are variable in color; dark, reddish-brown colors predominate, although medium-grey and greenish-black colors also are common. At some locations the outcrops have a mottled reddish-brown appearance. The formation is unbedded to bedded; bedding is defined by subtle light-brown-colored laminae on weathered surfaces. The overall outcrop appearance is blocky with a vertical jointing pattern. Fine-grained, medium- to dark-grey, unfossiliferous, marble lenses less than 0.5 m thick are scattered throughout the section (Fig. 25); they are especially common within the lowermost part of the formation.

Debris-flow deposits and turbiditic marble beds are

Figure 24. Typical outcrop of the Bloody Mountain Formation.

Figure 25. Marble lens within the Bloody Mountain Formation.

interbedded with the hornfels within the upper half of the Bloody Mountain Formation. The thin-bedded, unfossiliferous marble is fine to medium grained, weathering to greyish brown. Fresh surfaces are medium grey. Associated with these marble beds are chert-pebble conglomerates containing subangular to subrounded clasts that range from 1 to 8 mm in length within a siliceous matrix.

At one locality, a 70-m-thick, debris-flow conglomerate with clasts ranging from cobble to boulder size in a calcareous matrix is exposed. The clasts constitute a wide range of rock types: siliceous hornfels, fossiliferous and micritic marble, medium- to coarse-grained sandstone, and chert (Fig. 26). There is a dramatic change in the weathered color of the siliceous hornfels 45 m above this conglomerate (Fig. 27). The rock changes abruptly from reddish brown to greenish black. This greenish-black siliceous hornfels is 94 m thick, and within it there is an unusual 1.5-m-thick crinoidal marble bed containing chert pebbles (Fig. 28). The greenish-black unit is overlain by more of the reddish-brown-weathering hornfels that typifies the rest of the formation.

The Bloody Mountain Formation conformably overlies the Lake Dorothy Hornfels. The boundary is marked by a few meters of interlayered sandy, calcareous deposits typical of the Lake Dorothy Hornfels and the reddish-brown-weathering

Figure 26. Debris-flow conglomerate in the Bloody Mountain Formation with a variety of clasts, one containing gastropods.

Figure 27. Abrupt change in the weathered color of the Bloody Mountain Formation, on Bloody Mountain.

Figure 28. Crinoidal marble bed, 1.5 m thick, within the greenish-black-weathering unit in the Bloody Mountain Formation.

hornfels typical of the Bloody Mountain Formation (Fig. 29). The contact was placed at the top of the highest bed of sandy marble.

Fossils and Age

The Bloody Mountain Formation is assigned a Permian age based on a brachiopod and bryozoan fauna collected and identified by Rinehart and Ross (1964) and the presence of a probable Wolfcampian fossil in the older Mount Baldwin Formation. Conodonts extracted during the current research, are not identifiable.

Depositional Environment

The Bloody Mountain Formation represents deposition within a basin and/or base of slope environment. The very fine-grained, siliceous and calcareous sediment that characterizes the formation probably was deposited by hemipelagic processes, possibly at the basin margin. The sediment-gravity-flow deposits and turbiditic limestone beds within the upper half of the formation may record deposition in a basinal environment. The variety of shallow-shelf and deep-water limestone clasts within the 70-m-thick, debris-flow conglomerate is striking. In addition to these clasts, intraformational fragments of the Bloody Mountain Formation are present in the conglomerate. The presence of the latter clasts suggest that the debris flow, which probably

Figure 29. Contact between the slope-forming Bloody Mountain Formation and the underlying, resistant Lake Dorothy Hornfels.

originated in shallow water, incorporated pieces of slope sediment on its way to the base of the slope where it was deposited. The turbiditic limestone beds and associated chert-pebble conglomerates, interbedded with the hemipelagic sediment, may represent much smaller flows.

STRUCTURE

Structural studies in the Mount Morrison roof pendant have been conducted by Rinehart and Ross (1964), Russell and Nokleberg (1977), and Nokleberg (1983). Rinehart and Ross (1964) interpreted the pendant to be a thick, homoclinal sequence that may have been a remnant of the eastern limb of the Sierra Nevada synclinorium (Bateman and Eaton, 1967). According to Russell and Nokleberg (1977), the rocks within the Mount Morrison roof pendant have been greatly thickened by tight to isoclinal folding during three phases of deformation, each characterized by structures of a different style and orientation. These structures include folds, foliations, and lineations. Criteria used by these workers to recognize the multiple generations of structures included: superimposed relationships between structures, such as the refolding of earlier folds, foliations or lineations; differences in the style of folding, with successively younger folds generally being more open; different orientations of axial planes and foliations; and crossing of older axial planes and foliations by younger structures.

According to Russell and Nokleberg (1977), the first generation of structures is restricted to the McGee Mountain and Convict Lake blocks, located east of the Laurel-Convict fault. The axial planes of first-generation folds have an

average orientation of north-south, with gently plunging fold axes. Folds are tight to isoclinal, ranging in size from outcrop scale to folds with amplitudes and wavelengths of several hundred meters (Russell and Nokleberg, 1977). Second-generation structures occur in all rocks of the pendant, with fold sizes and styles differing across the Laurel-Convict fault. East of the fault, second-generation folds are open, have small amplitudes, and have moderately to steeply plunging fold axes and lineations. The average orientation for the axial planes of these folds is about N30°W (Russell and Nokleberg, 1977). West of the Laurel-Convict fault, the second phase of deformation has produced major and minor tight folds, with gently plunging fold axes and axial plane orientations comparable with those on the east side of the fault (Russell and Nokleberg, 1977). Although not abundant, third-generation structures occur in all rocks of the pendant. These consist of foliations, lineations, and small open folds. These folds have steeply plunging axes and steeply dipping axial-planar foliations that strike N60°W (Russell and Nokleberg, 1977).

The Laurel-Convict fault, the most prominent structure in the Mount Morrison roof pendant, has been recognized by all previous workers as dividing the pendant into two structural domains. The primary structural differences between the two domains are: (1) beds west of the fault are

right side up and strike about N30°W, whereas beds east of the fault generally are overturned and strike more nearly north (Rinehart and Ross, 1964), and (2) rocks east of the fault have undergone three episodes of deformation, whereas rocks west of the fault have been deformed only by the two younger generations (Russell and Nokleberg, 1977). The Laurel-Convict fault originally was interpreted by Rinehart and Ross (1964) and Russell and Nokleberg (1977) to represent a faulted angular unconformity. Because of exposure on steep canyon walls and talus-covered mountain slopes, the sense of displacement was not determined. The presence of reworked Devonian conodonts within sample BD43 of the Bright Dot Formation (Sandberg, written comm., 1989) suggests that the missing Devonian rocks between the Ordovician-Silurian Convict Lake block and the Mississippian Bright Dot Formation may be the result of an erosional event, supporting the interpretation that the Laurel-Convict fault represents a faulted angular unconformity. In his study of the wallrocks of the central Sierra Nevada, however, Nokleberg (1983) rejected the interpretation that the fault followed an unconformity, because nowhere in the eastern Sierra Nevada is such an unconformity documented. He postulated that the Laurel-Convict fault is a thrust fault, originally west-dipping at a moderate to shallow angle, and that it was rotated to a steeper angle during the

Nevadan Orogeny. He further suggested that the fault represents an accretionary suture between two tectonostratigraphic terranes.

My observations west of the Laurel-Convict fault indicate that the Bright Dot Formation and Mount Baldwin Marble are the most strongly deformed of the five units within the Bloody Mountain block (Plate 1). The Bright Dot Formation is juxtaposed against the fault, which probably accounts for its strong deformation (Fig. 30); deformation in the overlying Mount Baldwin Marble probably resulted both from its proximity to the fault and its relative incompetence (Fig. 31). Although folds are observed within the other units in the block, the intensity of deformation diminishes away from the fault.

Figure 30. Intensely deformed Bright Dot Formation
near the Laurel-Convict fault.

Figure 31. Deformed Mount Baldwin Marble.

DEPOSITIONAL HISTORY

The Mississippian through Permian rocks of the Bloody Mountain block record deposition in marine basin and slope environments. The oldest rock represented, probably Late Mississippian in age, is the hemipelagic siliceous mudstone of the lower member of the Bright Dot Formation, deposited in a basinal environment.

Within the upper member of the formation, calcareous siltstone is interbedded with siliceous mudstone similar to that in the lower member. During deposition of the upper member, an influx of a relatively large amount of fine-grained calcareous sediment occurred. These fine-grained beds are intercalated with several calcareous and siliceous sediment-gravity-flow deposits, including debris-flow deposits dated by conodonts as Late Mississippian (Chesterian) in age. The presence of reworked Early Mississippian and Devonian conodonts in these sediment-gravity-flow deposits suggests that the source was an uplifted structural block composed of older rocks. The sudden appearance of calcareous sediment in the upper Bright Dot Formation probably records the initial development of a carbonate shelf in the region.

The Mount Baldwin Marble represents an abrupt change in deposition from siliceous to carbonate sediment. During Early Pennsylvanian (Morrowan) time, deposition of cherty

limestone began. The presence of turbidites and other sediment-gravity-flow deposits in this section suggests deposition in a lower slope or basinal environment. This sediment probably was derived from a large, well developed carbonate shelf.

The limestones of the Mount Baldwin Marble are overlain by the dominantly siliciclastic Mildred Lake, Lake Dorothy, and Bloody Mountain formations, deposited in a deep basinal and/or base of slope environment. This change in sediment type probably occurred in the Early Permian (Wolfcampian). The hemipelagic deposits of the Mildred Lake Hornfels and lower part of the Lake Dorothy Hornfels are suggestive of sedimentation from suspension within a basinal environment. The calcareous turbidites and soft-sediment-deformation features in the upper Lake Dorothy Hornfels reflect instability on the slope and deposition of the sediment masses at the base of the slope. The lower half of the Bloody Mountain Formation records continued hemipelagic deposition, probably at the basin margin. Interbedded with the hemipelagic sediment in the upper half of the formation are sediment-gravity-flow conglomerates that may represent base-of-slope deposits that accumulated in or at the mouths of submarine channels. These conglomerates contain a variety of shallow-shelf and deep-water clasts, including siliceous mudstone and siltstone, fossiliferous and micritic

limestone, medium- to coarse-grained sandstone, and chert. These deposits may record an uplift of the source area, resulting in the erosion and subsequent transport of lithified sediment to the basinal/base of slope depositional site.

REGIONAL COMPARISON OF UPPER
MISSISSIPPIAN TO PERMIAN AGE ROCKS

Rocks similar in age and lithology to those in the Bloody Mountain block crop out east of the Owens Valley in the southern Inyo Mountains approximately 130 km to the southeast (Fig. 32). In both areas the Mississippian is characterized by mostly fine-grained siliciclastic rocks, the Pennsylvanian to Early Permian is represented by limestone, and the later Permian is characterized by fine-grained siliciclastic rocks with minor coarse-grained sediment-gravity-flow deposits. Thus, the stratigraphy of the Bloody Mountain block is comparable to that of the southwesternmost Inyo Mountains, as shown in Figure 33.

The youngest conodonts yielded by the Bright Dot Formation are Late Mississippian, the inferred age of this unit. In the Inyo Mountains region the coeval Upper Mississippian Perdido Formation is divided into three major facies belts: a southeastern calcareous facies belt; a central facies belt characterized by quartzose siltstone; and a northwestern facies belt, consisting of black shale, pebble to boulder conglomerate, and limestone and quartz siltstone turbidites (Stevens, 1986). Rocks in the northwestern facies belt, which occur in the western Inyo Mountains, are most similar to the rocks of the Upper Mississippian Bright Dot Formation, especially the upper

Figure 32. Generalized map of part of California and Nevada showing location of Mount Morrison pendant relative to the Inyo Mountains.

Figure 33. Chronologic and lithologic correlations between the formations of the Bloody Mountain block and the southwestern Inyo Mountains.

member (Fig. 33). This member contains interbedded calcareous and siliceous siltstone interpreted as distal turbidites and hemipelagic deposits, and debris-flow deposits represented by chert- and limestone-pebble conglomerates. Both the Bright Dot Formation and the northwestern facies of the Perdido Formation (Stevens, 1986) apparently were deposited in similar, relatively deep-marine depositional environments.

The Rest Spring Shale, which overlies the western facies of the Perdido Formation (Stevens, 1986), was deposited in late Late Mississippian time in the Inyo Mountains. A lithologic correlative of this formation has not been recognized in the study area where the Bright Dot Formation is overlain by the Mount Baldwin Marble. However, in the Pine Creek pendant, located 15 km to the south (Fig. 1), a thick argillaceous sequence that underlies the Mount Baldwin Marble (Bateman, 1965) may be an equivalent of the Rest Spring Shale, which for some unknown reason is not present at Mount Morrison.

The next higher unit at Mount Morrison, the Lower Pennsylvanian to Lower Permian (?) Mount Baldwin Marble, is correlated with the Keeler Canyon Formation in the Inyo Mountains (Fig. 33). These formations probably represent the same age range. Common to both areas is the abrupt change from siliceous sediment of Late Mississippian age to

limestone of Early Pennsylvanian age. Morrowan conodonts have been recovered from close to the base of the Keeler Canyon Formation (Stone, 1984) near Tinemaha Reservoir (Fig. 34), and near the base of the Mount Baldwin Marble (Locs. W, X, Plate 1). In addition to the conodonts, a distinctive gastropod found in a carbonate debris-flow deposit at the top of the Mount Baldwin Marble, tentatively identified as Omphalotrochus, suggests that this part of the formation may be Wolfcampian, the same age as the top of the Keeler Canyon Formation in the Inyo Mountains (Stone and Stevens, 1987). Both the Keeler Canyon and Mount Baldwin formations consist of bioclastic and micritic limestone and argillaceous limestone turbidites. Most striking, however, is the presence of abundant beds and zones of nodular and lenticular chert in the lower parts of each formation. Both formations are interpreted to have been deposited in a lower-slope environment.

The Mildred Lake and Lake Dorothy formations are correlated with the Lower Permian (Wolfcampian) Lone Pine Formation in the Inyo Mountains (Fig. 33). Like the Mildred Lake and Lake Dorothy formations, the Lone Pine Formation conformably overlies a similar limestone sequence, and both sequences are similar lithologically. The Lone Pine Formation has been divided into four members by Stone and Stevens (1987): Members A, B, C, and the Reward Conglomerate

Figure 34. Map of area in southeastern California showing location of Mount Morrison pendant relative to the southern Inyo Mountains and localities discussed in text. See Figure 32 for location of area (modified from Stone and Stevens, 1987).

Member. Member A is composed primarily of thin-bedded to laminated calcareous mudstone interbedded with siltstone and very fine- to fine-grained sandstone (Stone and Stevens, 1987). It is correlated with the Mildred Lake Hornfels and the lower half of the Lake Dorothy Hornfels on the basis of lithology. Member B of the Lone Pine Formation consists of interbedded mudstone, siltstone and fine-grained sandstone with locally abundant beds of limestone, some containing soft-sediment deformational features and others containing bioclastic debris. Similar rock types and deformational features occur in the upper half of the Lake Dorothy Hornfels, in which there are locally abundant marble beds with convolute laminations and soft-sediment folds.

Approximately 20 km southeast of Independence, in the Reward Mine-Union Wash area (Fig. 34), the Lone Pine Formation has been metamorphosed by numerous intrusive bodies (Stone and Stevens, 1987). Metamorphism has altered and silicified Member A into reddish-brown-weathering, thin-bedded, siliceous hornfels, siltite, and very fine-grained quartzite, and Member B into a greenish-grey, thin-bedded calc-hornfels and calcareous siltite interbedded with layers of marble. The Mildred Lake and Lake Dorothy formations (Fig. 23), which also have been extensively contact metamorphosed, are very similar. Correlation between the Bloody Mountain Formation and Member C of the Lone Pine

Formation (Fig. 33) is speculative, primarily because of a lack of good age control. In the Reward Mine-Union Wash area, Member C is composed of massive, dark-brown-weathering hornfels interbedded with minor fine- to coarse-grained quartzite and chert-pebble conglomerate (Stone and Stevens, 1987). These characteristics are generally similar to those of the Bloody Mountain Formation, which conformably overlies the Lake Dorothy Hornfels.

In the Inyo Mountains the Reward Conglomerate conformably overlies Member C of the Lone Pine Formation, and the Upper Permian Conglomerate Mesa Formation unconformably overlies the Reward Conglomerate (Stone and Stevens, 1987). Correlatives of the Reward Conglomerate and Conglomerate Mesa Formation have not been found in the study area, possibly having been removed by the intrusive rocks, and/or by faulting and erosion.

During middle to late Wolfcampian time, contemporaneous subsidence and thrust faulting occurred at the eastern margin of the basin in which the Lone Pine Formation was deposited (Stone and Stevens, 1988). If the Bloody Mountain Formation correlates in part with the upper part of the Lone Pine Formation, it is possible that its much greater thickness is due to its occurrence in an area of greater subsidence, or it might have occurred in a higher thrust plate, originating in a deeper part of the basin. The

variety of shelf- and deep-water-derived clasts in the 70-m-thick, debris-flow conglomerate near the top of the formation, as well as in the other sediment-gravity-flow deposits in the upper half of the Bloody Mountain Formation, may have been derived from a source on the west side of the basin. Such a nearby source also could help explain why the unit is so thick.

PALEOZOIC TECTONIC HISTORY OF THE REGION

Regional History

The tectonic history of the late Paleozoic continental margin in east-central California in the region bounded by the Sierra Nevada to the west, the Garlock fault to the south, and the Death Valley-Furnace Creek fault to the east (Fig. 35) is discussed here to set the geologic framework for interpreting whether or not the Mount Morrison pendant originated along the North American margin, and, if so, where.

Between the Early Ordovician and middle Late Mississippian, the western margin of the North American continent slowly subsided (Stevens, 1986). Immediately east of the Inyo Mountains (Fig. 36), about 2300 m of subsidence occurred between Early Ordovician and Middle Pennsylvanian time. Subsidence increased westward to >3500 m at the eastern edge of the Owens Valley. The rate of subsidence generally was greater than that of sedimentation and, according to Stevens (1986), the water depth at the western part of the region may have increased to 3000 m in the Late Mississippian. The effect of the Early Mississippian Antler orogeny upon this area is still uncertain, although its development near here led to a substantial amount of subsidence.

Figure 35. Location of the Late Paleozoic continental margin and the Late Devonian-Mississippian Antler orogenic belt in California and Nevada (modified from Stevens, 1986; Stone and Stevens, 1988).

Figure 36. Map of east-central California showing outcrops of Pennsylvanian and Permian rocks (black) and localities discussed in text. See Figure 35 for location of area.

By Late Mississippian time, the region southeast of the Inyo Mountains was represented by a broad carbonate shelf, but throughout the Inyo Mountains to the northwest and for some unknown distance farther west, deposition of siliciclastic sediment occurred in a relatively deep-water basin. On the northwest side of the basin in which this sediment was deposited there may have been a southern extension of the Antler orogenic belt (Fig. 35) which was well developed in central Nevada at this time.

Tectonic activity in the Pennsylvanian and Permian caused great paleogeographic changes in the region. During the Early Pennsylvanian, carbonate sediment began to be deposited throughout eastern California (Stevens, 1986). Then, in the late Middle Pennsylvanian (Desmoinesian) and into the earliest Permian (early Wolfcampian), the western part of the former shelf underlain by Early to Middle Pennsylvanian carbonate shelf deposits subsided rapidly, forming deep-water basins within and east of the Inyo Mountains. In the Inyo Mountains and southern Last Chance Range to the northeast, thick sequences of shelf-derived calcareous turbidites (Keeler Canyon Formation) were deposited in basinal settings. These rocks are similar to the Mount Baldwin Marble in the Bloody Mountain block.

Subsidence of the southeastern carbonate shelf continued into early middle Wolfcampian time. In response

to local thrust faulting in the central part of the area, however, a southwest-trending, faulted submarine ridge was developed (Stone and Stevens, 1988). A pair of deep-water, marine basins evolved on either side of the submarine ridge, which persisted throughout the late Wolfcampian. The southeastern basin, which encompassed the southeasternmost Inyo Mountains, Darwin Hills, Argus and Panamint ranges, and central and southern Cottonwood Mountains (Fig. 36), was filled by a thick sequence of quartzose and calcareous sediment-gravity-flow deposits that are interpreted to have been derived from the east (Stone and Stevens, 1988). The northwestern basin included the southern Last Chance Range and most of the Inyo Mountains (Fig. 36) and was filled mainly by hemipelagic mudstone with a few limestone-clast-bearing debris-flow deposits. This sequence is similar to the sequence in the Permian rocks in the Bloody Mountain block.

Beginning in the latter part of the Early Permian (Leonardian) and ending by the Late Permian (Guadalupian), tectonic uplift of the Inyo Mountain region to and above sea level ended marine sedimentation. The basins were uplifted and exposed to subaerial erosion with as much as 1800 m of strata having been removed locally (Stone and Stevens, 1984). This resulted in the development of a regional angular unconformity, which separates Lower Permian from

Upper Permian and Triassic rocks. A brief period of tectonic stability was followed by slow subsidence in the Late Permian and rapid subsidence in the Early Triassic, leading to marine transgression and the renewal of offshore-marine deposition (Stone and Stevens, 1984). No rocks similar to this Late Permian to Early Triassic sequence are recognized in the Bloody Mountain block.

Position of the Bloody Mountain Block during the Late Paleozoic

Mesozoic granitic rocks intruded through continental basement have initial $\text{Sr}^{87}/\text{Sr}^{86}$ (S_{ri}) > 0.706 , whereas those intruded through oceanic basement have $S_{ri} < 0.706$ (Kistler and Peterman, 1973, 1978). The rocks of the Mount Morrison pendant lie within, but near the edge of, the region considered to be underlain by continental basement (Kistler and Peterman, 1973, 1978).

The present irregular configuration of the Paleozoic continental margin is due to the disruption and displacement of continental fragments by tectonic events throughout Phanerozoic time (Stone and Stevens, 1988; Walker, 1988). A model proposed by Stevens and others (submitted, 1991) includes: (1) 500-km of left-lateral displacement of a large part of the margin during a late Paleozoic truncation; (2) Mesozoic slivering of the margin by right-lateral faulting

with approximately 275 km total displacement; and (3) right-lateral faulting, oroclinal bending and crustal extension of the margin during the Cenozoic.

The eastern and central Sierra Nevada have been considered to be composed of several linear, northwest-southeast-trending blocks separated by major fault zones (Saleeby, 1986). These include the Mount Morrison block and the Snow Lake block (Fig. 37). The Bloody Mountain section of the Mount Morrison roof pendant is part of the Mount Morrison block. This block is defined by Stevens and others (submitted, 1991) as a composite of most of the High Sierra and Goddard terranes of Nokleberg (1983) and Silberling and others (1987). The Mount Morrison block (Fig. 37) is bounded on the west by intrabatholithic break 2 and on the east by intrabatholithic break 3 (Saleeby, 1986). The Laurel-Convict fault, which cuts the Mississippian rocks of the Bloody Mountain block, is considered to be part of intrabatholithic break 3 (Kistler and others, 1980), and intrabatholithic break 2 corresponds with the Mojave-Snow Lake fault of Lahren and Schweickert (1989). Part of the evidence for these intrabatholithic breaks are two major right-lateral offsets in the 0.706 Sri isopleth within the Sierra Nevada (Saleeby, 1986).

Displacement of crustal fragments in the Sierra Nevada has important implications for interpretation of the

Figure 37. Generalized map showing the present location of the Snow Lake and Mount Morrison blocks of Stevens and others (submitted, 1991) and the positions of the Mount Morrison pendant (MMP) and Owens Lake (OL). IBB2= intrabatholithic break 2; IBB3= intrabatholithic break 3; heavy dotted line= 0.706 Sri isopleth (modified from Stevens and others, submitted 1991).

original paleogeographic position of the Bloody Mountain block of the Mount Morrison roof pendant. Stevens and others (submitted, 1991) interpreted the Mount Morrison block to have been offset northward during the Mesozoic on intrabatholithic break 3, primarily because of the offset of the 0.706 strontium isopleth. They stated that approximately 130 km of displacement involving faulting and rotation is needed to straighten out the 0.706 strontium isopleth north of the Mount Morrison block. Reconstruction based on this figure places the late Paleozoic Bloody Mountain block of the Mount Morrison roof pendant west of Owens Lake (Fig. 38). This position also brings together Upper Mississippian to Permian rocks in the Bloody Mountain block and the southwestern Inyo Mountains which have similar chronologic and lithologic characteristics (Fig. 33).

The Inyo Mountain rocks are interpreted to be part of Paleozoic North America, and more or less in place (Stevens, 1986). The chronologic, lithologic and isotopic data presented in this study have shown that the similarity between the Inyo Mountain rocks and those of the Bloody Mountain block are not just coincidental but indicate that this part of the Mount Morrison pendant represents a piece of the North American continent that probably originated near Owens Lake and was moved about 130 km northward during the Mesozoic.

Figure 38. Generalized map showing inferred original paleogeographic position of the Bloody Mountain block of the Mount Morrison pendant (MMP) after offset along intra-batholithic break 2 and 3 is removed. OL= Owens Lake (modified from Stevens and others, submitted 1991).

CONCLUSIONS

The upper Paleozoic rocks in the Bloody Mountain block of the Mount Morrison roof pendant show similarities to the Upper Mississippian-Lower Permian rocks of the southern Inyo Mountains, including comparable ages of lithologic change, and similarity of rock units deposited in similar environments. Reconstruction of the Paleozoic continental margin by restoration of the apparent displacement of the 0.706 Sri isopleth places the pendant rocks in the same general paleogeographic position as that based on chronologic and lithologic correlations. Therefore, it is concluded here that the Bloody Mountain block represents a displaced fragment of Paleozoic North America and that the original sediment was deposited in lower-slope and basinal environments along the late Paleozoic continental margin west of the southwestern Inyo Mountains.

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Walker, J.D., 1988, Permian and Triassic rocks of the Mojave desert and their implications for timing and mechanism of continental truncation: *Tectonics*, v. 7, p. 685-709.

APPENDIX A: MEASURED SECTIONS

Section 1

Includes the Mount Baldwin Marble and the upper Bright Dot Formation.

Location: Convict Lake 7.5-minute quadrangle, Mono County, California. Partial section measured along eastern slope of hill located west of Bright Dot Lake, approximately 75 m northwest of northern lake margin, from an elevation of 3213 m to an elevation of 3292 m. Location marked on Plate 1.

Unit

Thickness (m)

Top of section eroded

Mount Baldwin Marble (Pennsylvanian-Permian ?)

5	Marble, white to dark-grey; interbedded with medium-brown, nodular, chert beds and fossiliferous marble beds containing gastropods and pelmatozoan detritus.....	64
4	Marble, medium-grey, fossiliferous (gastropods and pelmatozoan detritus); bedding characterized by alternating medium- to dark-grey, fossiliferous and unfossiliferous layers; chert nodules locally abundant.....	35
3	Marble, as in 4; light-grey laminae increase	

<u>Unit #</u>	<u>Thickness(m)</u>
in abundance up section, locally interbedded with light-brown, argillaceous marble beds < 1 m thick; chert nodules and masses, 1-8 cm in diameter with rare masses >15 cm in diameter, abundant.....	20
2 Marble, medium- to dark-grey, massive, unfossiliferous, pyritic, fine-grained; interbedded with light-brown, argillaceous marble beds > 1 m thick; chert beds and nodules less abundant than in 3.....	35
1 Marble, as in 2; interbedded with light-brown, argillaceous marble beds 4 cm to 1 m thick; chert locally abundant as irregular nodular beds and zones of nodules < 2 cm to > 15 cm across.....	35
Incomplete thickness of Mount Baldwin Marble.....	189 m
Conformable contact with Bright Dot Formation.	
Bright Dot Formation (Upper Mississippian ?)	
5 Calc-silicate hornfels, medium-grey, massive, without apparent bedding, fine-grained; intercalated with siliceous, dense, black hornfels characterized by black and white layering 0.5 to 5 cm thick; rip-up clasts locally abundant; bedding features not	

<u>Unit #</u>	<u>Thickness(m)</u>
seen on fresh surfaces.....	16
4 Porcelanite, cherty, white, very fine-grained...	16
3 Calc-silicate and siliceous hornfels, as in 5...	44
2 Chert-pebble conglomerate, matrix siliceous; clasts of chert, marble, hornfels, ranging from 2 mm to > 5 cm and rarely to 15 cm, sub-angular to subrounded.....	1
1 Siliceous hornfels, as in 5.....	9
Incomplete thickness of Bright Dot Formation.....	86 m
Unit 1 is underlain by the intensely folded part of the upper member of the Bright Dot Formation.	

Section 2

Includes the Lake Dorothy and Mildred Lake Hornfels.

Location: Bloody Mountain 7.5-minute quadrangle, Mono County, California. Section measured southwest of saddle between Laurel Mountain and Bloody Mountain. Measured along northeastern flank of Bloody Mountain, from an elevation of 3280 m to an elevation of 3550 m. Location marked on Plate 1.

Unit #Thickness (m)

Conformable contact with siliceous hornfels of the Bloody Mountain Formation.

Lake Dorothy Hornfels (Permian)

14	Marble, sandy, medium-grey with convolute laminations and soft-sediment folds locally abundant; interbedded with coarse-grained, light- to medium-grey marble.....	7
13	Calc-silicate hornfels, dense, greenish-black resistant beds; interbedded with light-brown to light-grey, preferentially weathered, calcareous beds showing a "pock-marked" appearance.....	64
12	Marble, as in 14.....	24
11	Calc-silicate hornfels, dense; interbedded	

<u>Unit #</u>	<u>Thickness (m)</u>
yellow-grey and greenish-black layers 2 to 4 cm thick.....	24
10 Calc-silicate hornfels, as in 13.....	19
9 Conglomerate, matrix siliceous; clasts of fossiliferous, unfossiliferous, and sandy marble (as in 14), chert, and siliceous hornfels, subrounded to angular, unsorted; matrix-supported.....	5
8 Marble, as in 14.....	24
7 Calc-silicate hornfels, as in 11.....	71
6 Calc-silicate hornfels, as in 13.....	24
5 Calc-silicate hornfels, as in 11.....	47
4 Calc-silicate hornfels, as in 13.....	59
3 Calc-silicate hornfels, as in 11.....	24
2 Hornfels, siliceous, dense, black, massive.....	47
1 Covered interval.....	12
Thickness of Lake Dorothy Hornfels.....	451 m
Conformable contact with Mildred Lake Hornfels.	
Mildred Lake Hornfels (Permian)	
2 Hornfels, siliceous, light to medium grey, massive, fine grained; interbedded with white to greenish-grey, massive calc- silicate hornfels layers < 4 m thick.....	118

1 Covered interval.....	71
Thickness of Mildred Lake Hornfels.....	189 m
Conformable contact with Mount Baldwin Marble.	

Section 3

Location: Bloody Mountain 7.5-minute quadrangle, Mono County, California. Section (incomplete) measured along the major northeastern ridge of Bloody Mountain, beginning at the top of Section 2, from an elevation of 3550 m to the summit elevation of 3826 m. Location marked on Plate 1.

Unit #
(m)

Thickness

Top of section eroded

Bloody Mountain Formation (Permian?) (incomplete)

14	Hornfels, siliceous, light-grey, massive, fine-grained; medium- to dark-grey, unfossiliferous, fine-grained marble lenses < 0.6 m wide occurring randomly throughout the unit; minor chert-pebble conglomerate beds, matrix siliceous; with subangular to subrounded clasts of chert ranging from 1 to 8 mm.....	173
13	Interval intruded by Round Valley Peak granodiorite.	
12	Hornfels, siliceous, dense, black; crude bedding features observable on weathered surfaces.....	140
11	Hornfels, siliceous, dense, dark-grey to black, weathers a distinctive greenish-black; locally abundant conglomerate beds with chert clasts <2 cm, poorly sorted, subangular to subrounded;	

<u>Unit #</u> <u>(m)</u>	<u>Thickness</u>
matrix siliceous; 1.5-m-thick, coarse-grained, crinoidal marble bed at approximately the middle of this unit.....	94
10 Hornfels, siliceous, dense, black.....	18
9 Conglomerate, as in 11; interbedded between marble beds.....	3
8 Hornfels, as in 10; marble lenses as in 14, locally abundant.....	14
7 Marble, medium-grey, thinly-bedded, unfossiliferous.....	14
6 Conglomerate, with clasts of chert, hornfels, and fine-grained, fossiliferous and unfossiliferous marble, unsorted, ranging from pebble to boulder in size; matrix calcareous.....	70
5 Hornfels, as in 12; interbedded with marble, as in 7; a 1-m-thick chert-pebble conglomerate associated with the marble beds, with subangular to subrounded clasts of chert ranging from 1 to 8 mm; matrix siliceous.....	23
4 Hornfels, as in 12; crude bedding as in 12 not observed; abundant marble lenses, as in 14.....	268
3 Hornfels, as in 14.....	107

<u>Unit #</u>	<u>Thickness</u>
(m) 2 Hornfels, as in 12; crude bedding as in 12 not observed.....	189
1 Hornfels, as in 12.....	94
Incomplete thickness of Bloody Mountain Formation....	1207 m
Conformable contact with interbedded marble and sandy marble at the top of the Lake Dorothy Hornfels.	

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PLATE 1

**GEOLOGIC MAP OF A PORTION OF THE BLOCK
MOUNT MORRISON ROOF PENDANT, MONO**

**D.E. WILLAHAN
1987-88**

SCALE 1:24000

CONTOUR INTERVAL 20 METERS

PLATE 1

ION OF THE BLOODY MOUNTAIN BLOCK, PENDANT, MONO COUNTY, CALIFORNIA

D.E. WILLAHAN
1987-88

SCALE 1:24000

ITOUR INTERVAL 20 METERS

EXPLANATION

QUATERNARY	{	Ql	TALUS AND SLOPE WASH
		Qal	VALLEY FILL
CRETACEOUS	{	Kfd Kfm	FELSIC DIKES AND MASSES
		Krv	ROUND VALLEY PEAK GRANODIORITE
PERMIAN(?)	{	Pbm	BLOODY MOUNTAIN FORMATION
		Pld	LAKE DOROTHY HORNFELS
		Pml	MILDRED LAKE HORNFELS
PENNSYLVANIAN- IN PERMIAN(?)	{	Ppmb	MOUNT BALDWIN MARBLE

CRETACEOUS	{	Krv	ROUND VALLEY PEAK GRANODIORITE
PERMIAN(?)	{	Pbm	BLOODY MOUNTAIN FORMATION
		Pld	LAKE DOROTHY HORNFELS
		Pml	MILDRED LAKE HORNFELS
PENNSYLVANIAN- PERMIAN(?)	{	P Pmb	MOUNT BALDWIN MARBLE
MISSISSIPPIAN	{	Mbd	BRIGHT DOT FORMATION

CONTACT

DASHED WHERE APPROXIMATELY LOCATED

FAULT

DOTTED WHERE CONCEALED

ANTICLINE

DASHED WHERE APPROXIMATELY LOCATED

FAULT

DOTTED WHERE CONCEALED

ANTICLINE

DASHED WHERE APPROXIMATELY LOCATED

SYNCLINE

DASHED WHERE APPROXIMATELY LOCATED

STRIKE AND DIP OF BEDS

LINE OF MEASURED SECTION

NE

B'

FOSSIL LOCALITY

NE

SW

NE

A'

B

B'

ANTICLINE

DASHED WHERE APPROXIMATELY LOCATED

SYNCLINE

DASHED WHERE APPROXIMATELY LOCATED

STRIKE AND DIP OF BEDS

LINE OF MEASURED SECTION

NE

B'

FOSSIL LOCALITY

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MEAS

LITHOLOG

SEE PLATE

20 m
10
0
VERTICAL SCALE 1 cm=10 m

FORMATION	UNIT #	THICKNESS (m)
	5	64

TOP OF INCOMPLETE SECTION

FORMATION	UNIT #	THICKNESS (m)
LAKE DOROTHY HORNFELS	4	59
	3	24
	2	47

PLATE 2

MEASURED SECTIONS 1 AND 2

LOCATIONS ON PLATE 1

LITHOLOGIC SYMBOLS SHOW INFERRED PARENT ROCK

SEE PLATE 3 FOR EXPLANATION OF LITHOLOGIC SYMBOLS

SEE APPENDIX A FOR DESCRIPTION

FORMATION	UNIT #	THICKNESS (m)
LAKE DOROTHY HORNFELS	4	59
	3	24
	2	47

LD90

FORMATION	UNIT #	THICKNESS (m)
	14	7
	13	64
	12	24

ATE 1

NFERRED PARENT ROCK

OF LITHOLOGIC SYMBOLS

DESCRIPTION

FORMATION	UNIT #	THICKNESS (m)
	14	7
	13	64
	12	24
	11	24

TOP OF LAKE DOROTHY
HORNFELS
LD93
(BASE OF SECTION 3; SEE PLATE 3)

MOUNT BALDWIN MARBLE	5	64
	4	35
	3	20		MB58
	2	35
	1	35
BRIGHT DOT FM	5	16		BD56
	4	16		BD55
	3	44
	2	1
	1	9		BD49

BASE OF
INCOMPLETE SECTION

LAKE DOR	2	47
	1	12
MILDRED LAKE HORNFEELS	2	118
	1	71

ON

LD89

LAKE DOROTHY HORNFELS

12

24

11

24

10

19

9

5

8

24

7

71

6

24

5

47

LD92

LD91

BASE OF MILDRED
LAKE HORNFELS

MILDRED LAKE HORNFELS	2	118
	1	71

SECTION # 1

MILDRED LAKE HORNFELS	2	118	
	1	71	

BASE OF MILDRED
LAKE HORNFELS

LAKE DOROTHY HORNFELS	9	5	
	8	24	
	7	71	
	6	24	
	5	47	

SECTION # 2

SECTION # 2

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MEASU

L

LITHOLOGIC SY

SEE

FORMATION	UNIT #	THICKNESS (m)
	4	268

FORMATION	UNIT #	THICKNESS (m)
	14	173
	13	?

PLATE 3

MEASURED SECTION 3

LOCATION ON PLATE 1

LITHOLOGIC SYMBOLS SHOW INFERRED PARENT ROCK

SEE APPENDIX A FOR DESCRIPTION

ION 3

1

RED PARENT ROCK
DESCRIPTION

COMPLETE
ON

EXPLANATION

SILICEOUS HORNFELS

SILICEOUS CALC-HORNFELS

MARBLE

BLOODY MOUNTAIN FORMATION

BM78

BM36

BM76

BM37
BM75a
BM75b
BM75c

BM75

MARB

FOSSIL

SILTY

CHERT

PORCE

CONGLO

COVER

GRANO

MB26

SAMPLE

MARBLE

FOSSILIFEROUS MARBLE

SILTY MARBLE

CHERT NODULES, LENSES, & BEDS

PORCELANITE

CONGLOMERATE

COVERED INTERVAL

GRANODIORITIC INTRUSION

MB26

SAMPLE LOCALITY

SECTION # 3

PLEISTOCENE MOUNTAIN FORMATION

FOSSILIFEROUS

SILTY MARBLE

CHERT NODULES

PORCELANITE

CONGLOMERATE

COVERED INTERBEDDED

GRANODIORITE

MB26

SAMPLE LOCALITY

FOSSILIFEROUS MARBLE

SILTY MARBLE

CHERT NODULES, LENSES, & BEDS

PORCELANITE

CONGLOMERATE

COVERED INTERVAL

GRANODIORITIC INTRUSION

M826

SAMPLE LOCALITY