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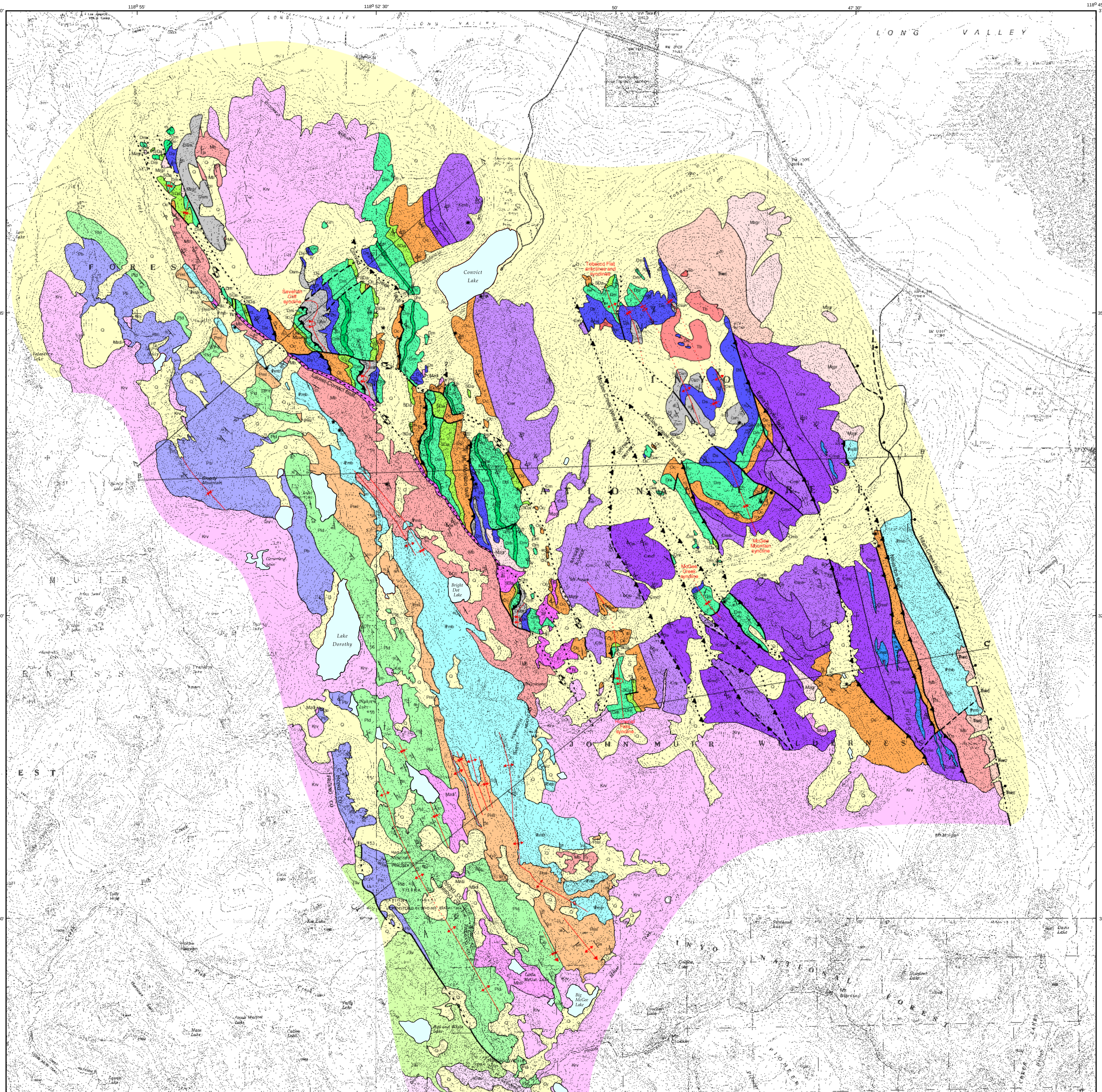

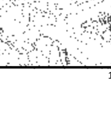

Scale 1:24 000
0.5 0 1 Mile
1000 0 1000 2000 3000 4000 5000 6000 7000 Feet
1 0.5 0 1 Kilometer

119°	118° 52' 30"	118° 45'	118° 37' 30"
Old Mammoth	Whitmore Hot Springs	Watterson Canyon	37° 45'
Bloody Mountain	Convict Lake	Toms Place	37° 37' 30"
Graveyard Peak	Mount Abbot	Mount Morgan	37° 30'
			37° 22' 30"

Index map showing location of this map (shaded) in relation to adjacent 7.5' quadrangles.

Topographic base from the following U.S. Geological Survey 7.5' quadrangle maps:

Convict Lake (1994)	contour interval 20 meters
Bloody Mountain (1990)	contour interval 20 meters
Mount Abbot (1982)	contour interval 40 feet
Graveyard Peak (1994)	contour interval 40 feet

Horizontal Datum: North American Datum of 1927 (NAD 27)

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Geologic Map of Paleozoic Rocks in the Mount Morrison Pendant, Eastern Sierra Nevada, California

By
David C. Greene and Calvin H. Stevens

2002

CORRELATION OF MAP UNITS

SURFICIAL DEPOSITS
- Q — QUATERNARY
- Tb — TERTIARY

INTRUSIVE ROCKS
- Kmo, Krv — CRETACEOUS
- TRwc, (Laurel-Convict felsite) — TRIASSIC
- Mzdi, Mzgr — MESOZOIC

METAVOLCANIC ROCKS
- JTRv — JURASSIC OR TRIASSIC

METASEDIMENTARY ROCKS
- Pb, Pld, Pml — PERMIAN
- l — PENNSYLVANIAN
- Mb — MISSISSIPPIAN
- Dsm, Ds — DEVONIAN
- Dmp, Dm — DEVONIAN
- SDa — DEVONIAN(?) AND SILURIAN
- Oc — ORDOVICIAN
- Єmc, Єmsl, Єmb — CAMBRIAN

DESCRIPTION OF MAP SYMBOLS

Contact - Approximately located.

Normal fault - Bar and ball on downthrown side. Dashed where uncertain, dotted where concealed.

Overturned thrust fault - Base of sawteeth on upper plate. Dashed where uncertain, dotted where concealed.

Strike-slip fault - Arrows indicate relative motion. Dotted where concealed.

Landslide(?) block

Anticline - Upright, showing trace of axial surface, dotted where concealed.

Synformal (inverted) anticline - showing trace of axial surface, dotted where concealed.

Syncline - Upright, showing trace of axial surface, dotted where concealed.

Syncline- Overturned, showing trace of axial surface, dotted where concealed.

Strike and dip of beds
- 78 **Inclined**
- **Vertical**
- 52 **Overturned**

Fossil Locality

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Q **Surficial Deposits (Quaternary)**—Unconsolidated alluvium, colluvium, and glacial deposits; includes lacustrine and stream deposits in valleys, talus deposits on steep slopes, and glacial moraines at mouths of major valleys.

Tb **McGee Mountain basalt (Pliocene)**—Dark-red-weathering, very fine grained basalt with abundant scoria and volcanic bombs (Bailey, 1989). Whole rock K/Ar age of 2.6 +/- 0.1 Ma (Dalrymple, 1963).

INTRUSIVE ROCKS

Kmo **Mono Creek Granite (Cretaceous)**—Light-colored, medium-grained, porphyritic, biotite granite with alkali feldspar megacrysts (Bateman, 1992). U/Pb zircon age of 86 +/- 1 Ma (Tikoff et al., 1999).

Krv **Round Valley Peak Granodiorite (Cretaceous)**—Fine- to medium-grained, equigranular, hornblende-biotite granodiorite with locally abundant mafic enclaves, especially near pluton boundaries (Rinehart and Ross, 1964; Bateman, 1992). U/Pb zircon age of 89 Ma (Stern et al., 1981).

TRwc **Wheeler Crest Granodiorite (Triassic)**—Reddish-brown-weathering, gray, medium-grained, porphyritic granodiorite; typically with alkali feldspar megacrysts (Rinehart and Ross, 1964). U/Pb zircon age of 214 Ma (Stern et al., 1981)

Laurel-Convict felsite (Triassic)—Fine-grained, light-colored felsite porphyry with characteristic euhedral quartz and feldspar phenocrysts. U-Pb zircon age of 225 +/- 16 Ma (Greene and others, 1997b).

Mzgr **Granitic rocks, undifferentiated (Mesozoic)**—Includes albite granite of McGee Mountain (Cretaceous?) (Rinehart and Ross, 1964) and various small felsic intrusions of unknown affinity.

Mzdi **Diorite, undifferentiated (Mesozoic)**—Primarily medium- to dark-gray, fine- to medium-grained hornblende diorite. Includes large sill-like intrusion southeast of Constance Lake and various small intrusions. Age presumed Mesozoic; relations to other intrusive rocks uncertain.

METAVOLCANIC ROCKS

JTRv **Metavolcanic rocks, undifferentiated (Jurassic or Triassic)**—Andesitic to rhyolitic tuffs, flows, hypabyssal intrusives, and volcanic breccias. Generally metamorphosed to laminated biotite schist and hornfels, sericite schist, and hornblende hornfels (Lockwood and Lydon, 1975).

METASEDIMENTARY ROCKS

Unit descriptions abbreviated from Stevens and Greene (1999) and Rinehart and Ross (1964).

Pb **Bloody Mountain Formation (Permian)**—Primarily medium- to dark-gray, massive, calc-silicate and siliceous hornfels, weathering dark reddish-brown; with rare beds of turbiditic marble and conglomerate. Top of formation not exposed; incomplete section on Bloody Mountain about 1200 m thick. Conodonts indicate a Permian age.

Pld **Lake Dorothy Hornfels (Permian)**—Primarily thin-bedded, microgranular hornfels. Commonly contains alternating grayish and yellowish layers 2 to 4 cm thick, giving the rock a distinctly striped appearance. Unit is about 500 m thick, and is considered Permian in age because of stratigraphic position. Conformably overlain by the Bloody Mountain Formation.

Pml **Mildred Lake Hornfels (Lower Permian)**—Generally massive, pale orange- to reddish-orange-weathering, light- to dark-gray, fine-grained siliceous hornfels. Layers of white to greenish-gray calcsilicate hornfels are present locally. According to Rinehart and Ross (1964) the unit is 150–300 m thick. Age is considered Early Permian because unit conformably overlies earliest Permian rocks and underlies rocks containing Permian conodonts. Conformably overlain by Lake Dorothy Hornfels.

l **Mount Baldwin Marble (Pennsylvanian to Lower Permian)**—Medium- to dark-gray to bluish-gray, fine-grained to very coarse-grained, generally thick-bedded to massive marble locally containing abundant crinoid columnals. Black chert in nodules or nodular beds is locally abundant in the lower part of the formation. Formation is 150 to 190 m thick in type area on east wall of Laurel Creek canyon, but appears substantially thicker, possibly due to structural repetition, to the south on Mount Baldwin. Lithologically similar rocks exposed on the east side of Nevahbe Ridge, called Hilton Creek Marble and considered Cambrian by Rinehart and Ross (1964), are here included in the Mount Baldwin Marble although no fossils have been discovered in this area. Unit spans earliest Pennsylvanian to earliest Permian time on the basis of conodont collections from near the base and top of formation. Contact with overlying Mildred Lake Hornfels is conformable and gradational over approximately 1 m.

Mb **Bright Dot Formation (Mississippian)**—Lower part consists of 300–450 m of brown-weathering, dark-gray, microgranular, muscovite-rich, siliceous hornfels and metachert, locally with beds of fine-grained sandstone. Upper part consists of 150–300 m of well-layered siliceous and calcareous hornfels in layers 1 cm to 1 m thick (Rinehart and Ross, 1964). A reworked conodont fauna from the upper part of the formation has yielded ages as young as Late Mississippian (Willahan, 1991). The unit appears to conformably overlie Upper Devonian rocks and be conformably overlain by Lower Pennsylvanian rocks of the Mount Baldwin Marble, although the latter contact may be locally discordant (Wise, 1996).

Sevehah Group—Consists of:

Ds **Squares Tunnel Formation (Upper Devonian)**—Black chert and argillite with light-gray, phosphatic lenses and nodules; generally with an upper member, the McGee Mountain Member, containing beds of calcareous sandstone and/or conglomerate resembling the Mount Morrison Sandstone. Incomplete measured thickness of 334 m on McGee Mountain includes lower member and incomplete upper member. Conodonts from McGee Mountain Member, and conodonts and radiolaria from correlative rocks in the Inyo Mountains (Stevens, et al., 1996) indicate a Late Devonian age. Contact with overlying Bright Dot Formation interpreted as conformable because northwest of Laurel Mountain rocks typical of McGee Mountain member and overlying Bright Dot Formation are interbedded, and in Bishop Creek and Log Cabin Mine pendants (south of and north of map area, respectively), Squares Tunnel Formation is concordantly overlain by the Bright Dot Formation.

Dsm **McGee Mountain Member**—Calcareous quartz sandstone, and conglomerate with black chert and argillite clasts in a calcareous sandstone matrix. Here consists of 2 units separated by black argillite (mapped as Ds). In most other pendants this member is overlain by black argillite (Stevens and Greene, 1999).

Dm **Mount Morrison Sandstone (Middle Devonian)**—Thick-bedded to massive, fine- to coarse-grained, light- to medium-gray, calcareous, quartz sandstone, prominently exposed in light-colored cliff faces on Mount Morrison, Sevehah Cliff and McGee Mountain. Sparse black chert and argillite clasts, generally 0.5 to 2 cm in diameter, are suspended in the sandstone. Rare dish structures and small- to medium-scale cross-bedding are present locally. Contrary to a thickness of 177 m cited by Stevens and Greene (1999), unit is about 377 m thick in type section northwest of Convict Lake, and includes finer grained rocks near the center of the formation as originally proposed by Rinehart and Ross (1964). A conglomeratic facies exposed on McGee Mountain contains clasts of medium-gray limestone, black chert, brown-weathering argillite, and light brown or light-gray sandstone and calcareous siltstone up to 1 m in diameter. Matrix consists of coarse-grained calcareous quartz sandstone. Conglomerate is interbedded with medium- to coarse-grained calcareous sandstone containing matrix-supported lithoclasts of black chert and argillite in a section with a total thickness of 575 m. Rare conodonts and small tabulate corals indicate a Middle Devonian age. The Mount Morrison Sandstone is conformably overlain by the Squares Tunnel Formation.

Dmp **Prow member**—Consists of medium-gray, thin-bedded, fine-grained calcareous sandstone, silty sandstone and silty limestone. Forms a distinctive gray band about 60 m thick within the Mount Morrison Sandstone.

SDa **Aspen Meadow Formation (Lower Devonian to Silurian)**— Distinctive unit of orange-weathering, light-colored, thinly-banded, very fine-grained siliceous and calc-silicate hornfels, consisting mostly of interbedded very light-gray and light-green hornfels in bands mostly 1 to 5 cm thick. Formation is 79 m thick on ridge north of Convict Lake. Age is inferred from ages of enclosing rocks. Conformably overlain by Mount Morrison Sandstone except in McGee Mountain area, where formation is missing due to submarine channel erosion. Upper contact is placed at base of lowest calcareous sandstone in Mount Morrison Sandstone.

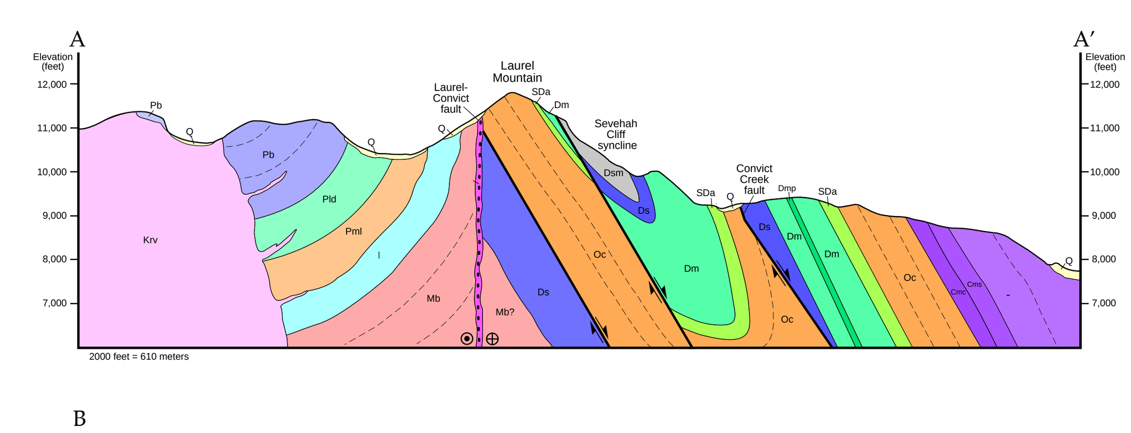
Oc **Convict Lake Formation (Ordovician)**—Primarily rusty-weathering, dark-gray, fine-grained argillite and siliceous hornfels with some very dark-gray slate. Resistant ribs of medium- to coarse-grained, medium- to light-gray-weathering, noncalcareous quartzite are generally present. Formation is 336 m thick in its type section on the ridge north of Convict Lake. All known graptolite localities in map area are in this unit. Graptolite zones 6 through 15 (Early to Late Ordovician) have been recognized. Conformably overlain by Aspen Meadow Formation except on McGee Mountain, where it is unconformably overlain by Mount Morrison Sandstone. Upper contact is placed below lowest sequence of light-colored, thin-bedded, calc-silicate beds of overlying Aspen Meadow Formation.

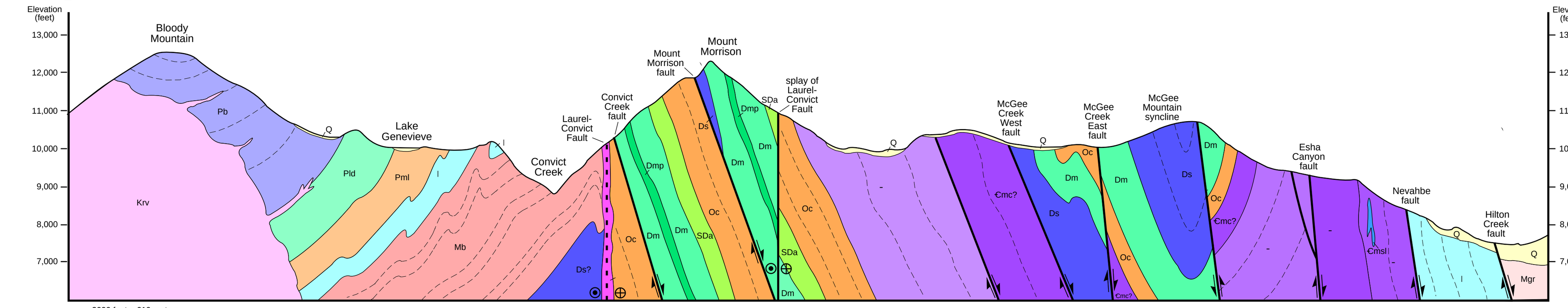
Mount Aggie Formation (Lower Ordovician? and Cambrian)—Characterized by very dark-gray, laminated to thin-bedded, siliceous argillite interbedded with variable amounts of thin-bedded, medium-gray, fine-grained limestone, and brown-weathering, very dark-gray argillite. Type section northwest of Convict Lake can be divided into three informal members: Buzztail Spring member, Salty Peterson member, and Coyote Ridge member. Distinctions between members are not clear-cut in all areas, and member designations should be considered tentative, especially in highly deformed areas south of McGee Creek. Base of section not exposed, but thickness is greater than 1500 m (Rinehart and Ross, 1964). Conodonts collected from Salty Peterson member indicate an age near Cambro-Ordovician boundary.

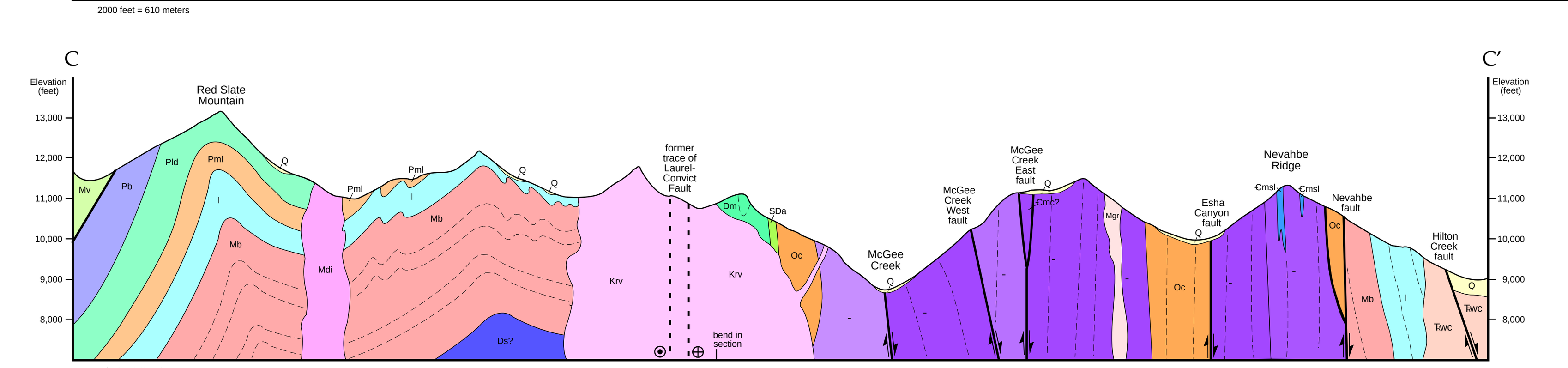
Coyote Ridge member—Characterized by alternating 0.5–1-cm-thick beds of black and orange or black and white chert and siliceous argillite. On ridge northwest of Convict Lake unit is 94 m thick, but appears much thicker (500+ m) in McGee Creek area. Conformably overlain by Convict Lake Formation.

Єmsl **Salty Peterson member**—Characterized by light-gray limestone layers and tectonically disrupted lenses in a matrix of dark-gray, thin-bedded argillite. On ridge northwest of Convict Lake member is less than 100 m thick, but thickness is much greater (500+ m) on Nevahbe Ridge, where prominent lenses of grey limestone within dark-brown-weathering argillite are locally mapped as Єmsl. Conformably overlain by Coyote Ridge member, with upper contact placed above highest limestone that is more than 1.5 m thick.

Buzztail Spring member—Characterized by 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. Limestone locally composes as much as 30% of rock. Base of formation not exposed, but unit is greater than 600 m thick (Wise, 1996). Conformably overlain by Salty Peterson member, with upper contact placed below the lowest limestone unit that has a minimum thickness of 4 m.







DISCUSSION

INTRODUCTION

The Mount Morrison pendant consists of middle(?) Cambrian to middle(?) Permian metasedimentary rocks that are structurally overlain by Triassic and Jurassic metavolcanic rocks. These rocks have been intruded and partially engulfed by Mesozoic granitic plutons and are now preserved as an isolated remnant of older rocks within the predominantly Cretaceous Sierra Nevada batholith. Such isolated remnants of country rock have historically been referred to as roof pendants, although many actually occur as screens between individual plutons and are more accurately described as wall-rock septa.

The Mount Morrison pendant is located southeast of the town of Mammoth Lakes in the central eastern Sierra Nevada of California. Pendant rocks form part of the Sierran range front along the southwest edge of Long Valley caldera, and are prominently visible from U.S. Highway 395. Paleozoic rocks in the pendant are exposed over an area of about 100 km^2.

Most of the pendant is designated as Wilderness Area, with access only via hiking trails. There are trail heads at Convict Lake and McGee Creek, and a rough dirt road up Laurel Creek canyon that provides access to Laurel Lakes and the northwest part of the pendant. A very poor dirt road also extends from Tobacco Flat to the plateau north of McGee Mountain. The terrain is generally rugged, with steep, glaciated mountain sides rising to peaks mostly over 3,000 m (10,000 feet) in elevation. The highest point in the pendant is Red Slate Mountain with an elevation of just over 4,000 m (13,120+ ft).

Previous work in the Mount Morrison pendant includes the original geologic map of the Mount Morrison quadrangle at a scale of 1:62,500 by Rinehart and Ross (1964), and studies of portions of the pendant by Morgan and Rankin (1972), Willahan (1991), and Bergeron (1992). Metamorphic reactions in the Mount Morrison Sandstone have been examined by Lackey and Valley (1999) and Ferry et al. (2001). Wise (1996) completed a detailed study of the area around Mount Morrison, including a geologic map of the Convict Lake 7.5' quadrangle. Published geologic maps of adjacent areas (all at a scale of 1:62,500) include Devils Postpile (Huber and Rinehart, 1965), Mount Abbot (Lockwood and Lydon, 1975), Casa Diablo (Rinehart and Ross, 1957) and Long Valley Caldera (Bailey, 1989). Russell and Nokleberg (1977) described and interpreted structures in the pendant. Greene et al. (1997b) described the Laurel-Convict fault, and Stevens and Greene (1999; 2000) discussed the stratigraphy, structure and regional tectonic significance of the Mount Morrison pendant in detail.

For this study we remapped all the Paleozoic rocks in the Mount Morrison pendant, utilizing a combination of field work and interpretation of color air photographs. We based our work on the initial mapping of Rinehart and Ross (1964), and incorporate some orientation data and unit boundaries from their work and that of Willahan (1991) and Wise (1996). Geologic mapping was compiled on a topographic base map constructed from a mosaic of the Convict Lake 7.5' quadrangle plus portions of the adjacent Bloody Mountain, Graveyard Peak and Mount Abbot quadrangles. The Convict Lake and Bloody Mountain quadrangles utilize a contour interval of 20 meters, whereas the Graveyard Peak and Mount Abbot quadrangles have a contour interval of 40 feet. Contour lines and spot elevations in the northern part of the map area are therefore in meters, whereas south of the 37° 30' latitude line these data are in feet.

Age		Autochthonous and Parautochonous Rocks: White-Inyo Mtns.	Morrison block	W-C Nevada	Rocks of Roberts Mountains Allochthon: Sierra Nevada	W-C Nevada
TR		Union Wash Fm			Candelaria Fm	Candelaria Fm
Pm		Congl. Mesa Fm			Diablo Fm	Diablo Fm
Pm		Lone Pine Formation	Bloody Mountain Fm Lake Dorothy Hornfels Mildred Lake Hornfels			
IP		Keeler Canyon Fm	Mt Baldwin Marble			
M		Rest Spring Shale	Bright Dot Fm			
M		Kearsarge Fm				
D		Squares Tunnel Fm	Squares Tunnel Fm			
D		Vaughn Gulch Ls	Mt. Morrison Ss		Interleaved Ordovician through Devonian rocks	Interleaved Ordovician through Devonian rocks
S		Ely Springs Dol	Aspen Mdw Fm			
O		Johnson Spring Fm Barrel Spring Fm Badger Flat Ls Al Rose Fm	Convict Lake Fm	Palmetto Fm		
				?	?	?
Є	L	Tamarack Cyn Dol Lead Gulch Fm	Mt. Aggie Fm	Emigrant Fm		
Є	M	Bonanza King Dol Monola Fm				
Є	E	Mule Spring Ls	?	Mule Spring Ls		
Є	E	Saline Valley Fm Harkless Fm		Harkless Fm		
Є	E	Poleta Fm		Poleta Fm		
PЄ		Campito Fm		Campito Fm		

Figure 1. Correlation of units in the Morrison block with those in west-central Nevada and the White-Inyo Mountains (from Stevens and Greene, 1999).

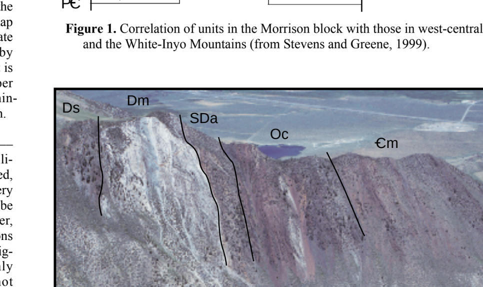


Figure 2. View of ridge northwest of Convict Lake, looking north from summit of Mount Morrison. Ridge exposes a relatively complete Lower Paleozoic stratigraphic section, including the Mount Aggie Formation (Єm), Convict Lake Formation (Oc), Aspen Meadow Formation (SDa), Mount Morrison Sandstone (Dm) and lower part of the Squares Tunnel Formation (Ds). Beds are overturned and dip steeply to the east.

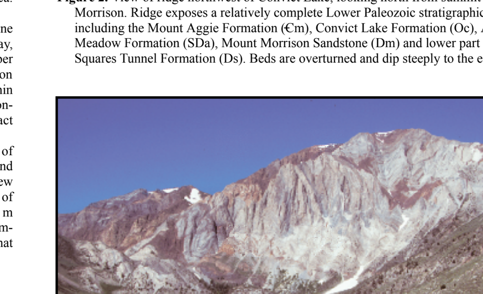


Figure 3. View of Sevehah Cliff from Convict Lake, showing complex folding and faulting of Lower Paleozoic metasedimentary rocks.

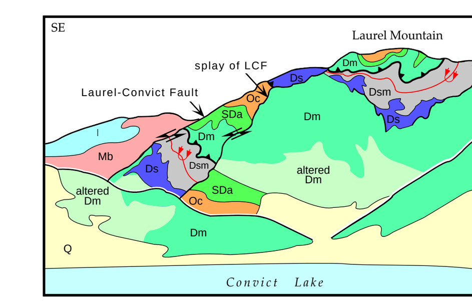


Figure 4. Interpretive sketch of Sevehah Cliff from Convict Lake, showing units and structures in the cliff face.

STRATIGRAPHY

In the Mount Morrison pendant locally highly deformed, predominantly Cambrian through Devonian metasedimentary rocks are juxtaposed against less deformed Mississippian through Permian metasedimentary rocks across the Laurel-Convict fault. The lower Paleozoic (Cambrian through Devonian) rocks are generally north striking and overturned, dipping steeply to the east. The section is imbricated by north-striking faults interpreted to be overturned thrust faults and contains steeply plunging, map-scale folds. In contrast, there is little or no significant faulting in the upper Paleozoic (Mississippian through Permian) section, which instead displays outcrop- and map-scale open folds with horizontal, northwest-trending hinge lines.

In general, we interpret the lower Paleozoic section to consist of complex structural repetitions of a relatively simple stratigraphy, in contrast to Rinehart and Ross (1964), who interpreted the section as consisting of a relatively simple homoclinal sequence with a complex stratigraphy. Consequently, in place of the 21 lower Paleozoic map units of Rinehart and Ross (1964), we utilize a stratigraphic nomenclature consisting of 5 formations and 5 informal members, as described above and discussed in detail in Stevens and Greene (1999). We utilize, with minor revisions, the upper Paleozoic stratigraphy defined by Rinehart and Ross (1964).

DEPOSITIONAL ENVIRONMENTS

Metasedimentary rocks in the Mount Morrison pendant are transitional between mostly shallow-water rocks exposed to the southeast in the White-Inyo Range that were deposited in a continental shelf (miogeoclinal) environment, and coeval, deep-water siliceous and argillaceous (eugeoclinal) rocks of the Antler belt exposed to the north and northeast in west central Nevada and in the Saddlebag Lake, Northern Ritter Range and Log Cabin Mine pendants (Greene et al., 1997a). In general, the Mount Morrison pendant seems to have occupied a position at the base of the continental slope, where fine-grained, siliceous, deep-water sediments were interbedded with coarse-grained sand and fine-grained carbonate derived from the continental shelf. Sedimentary rocks in the pendant have been metamorphosed to hornblende hornfels facies (Rinehart and Ross, 1964), but this alteration has not obscured the original character of the rock, and sedimentary features are commonly preserved.

The Mount Aggie and Convict Lake Formations both consist predominantly of dark-colored, fine-grained, thin-bedded siliceous and argillaceous rocks lacking a fauna other than conodonts and graptolites. These units were probably deposited in quiet, moderately deep water on the continental rise, far from a sediment source. Quartzite layers in the Convict Lake Formation are locally channelform, and probably represent channel fill on a deep-water, sand-poor submarine fan.

The Aspen Meadow Formation is typically laminated to very thin bedded, very fine grained, and undisturbed by burrowing infauna. Deposition is interpreted to have been in relatively deep, quiet water far from shore, during a period with little argillaceous input.

The Mount Morrison Sandstone consists of well-sorted, thick-bedded, calcareous sandstone, with sedimentary structures including ripple laminations, dish structures, and floating clasts of black chert and argillite. The unit is about 400 m thick in the Mount Morrison pendant, but thins rapidly to the north and south. It is interpreted as representing a deep-water, submarine fan system on the basis of these features and its close association with deep-water, black chert and argillite of the Squares Tunnel Formation. The conglomerate facies on McGee Mountain probably represents the back fill of a major submarine channel that fed the fan system.

In the Squares Tunnel Formation the presence of black, radiolaria-bearing chert and argillite suggests deposition in relatively deep water. The calcareous sandstones and conglomerates are similar to those in the Mount Morrison Sandstone and are similarly interpreted as deep-water, submarine-fan deposits.

The depositional environment of the Bright Dot Formation is obscure, but it probably represents a shallowing-upward sequence transitional between underlying deep-water rocks of the Squares Tunnel Formation and overlying carbonate rocks of the Mount Baldwin Marble interpreted as shallow-water deposits.

The Mount Baldwin Marble consists of thick-bedded, pure limestone and contains a variety of shallow-water fossils, suggesting deposition in a shallow-water, carbonate-bank environment.

The Mildred Lake, Lake Dorothy, and Bloody Mountain formations consist primarily of fine-grained siliceous hornfels, with rare interbeds of coarse-grained debris-flow deposits containing shallow-water fossils. These rocks suggest a depositional environment at or near the base of a submarine slope.

REGIONAL CORRELATIONS

Cambrian through Pennsylvanian formations defined in the Mount Morrison pendant can be identified in other pendants in the eastern Sierra Nevada, including the Bishop Creek and Pine Creek pendants to the south, and the Deadman Pass, Gull Lake, and eastern parts of the Northern Ritter Range and Log Cabin Mine pendants to the north. This group of pendants apparently is separated from all other exposures of Paleozoic rocks by faults, defining a discrete structural block referred to as the Morrison block (Stevens and Greene, 1999). The Permian Mildred Lake, Lake Dorothy and Bloody Mountain formations have not been recognized outside the Mount Morrison pendant. Correlations made by Stevens and Greene (1999) are summarized on Figure 1, and discussed below.

Middle(?) Cambrian through Ordovician rocks in the pendant compare most closely with rocks exposed in west-central Nevada. In both areas rocks of this age are represented by deep-water, continental-margin sequences that contrast significantly with the coeval, dominantly platform deposits in the White-Inyo Range to the southeast. The fine-grained, thin bedded Mount Aggie Formation, especially the interbedded black chert and limestone of the Buzztail Springs member, resembles the similar-aged Emigrant Formation in west-central Nevada. The deep-water Convict Lake Formation is lithologically similar to the Palmetto Formation in west-central Nevada. Influxes of pure quartz sand into the Convict Lake Formation probably represent the distal edge of the middle Ordovician Eureka Quartzite.

Paleozoic sedimentary rocks younger than Ordovician are not preserved in west-central Nevada, but sediments correlative with units in the Mount Morrison pendant continued to be deposited on the continental shelf to the southeast. The deep-water Aspen Meadow Formation is coeval with the upper Ely Springs Dolomite and Vaughn Gulch Limestone in the Inyo Mountains, and appears to have formed during a period of high carbonate productivity. The Mount Morrison Sandstone, which in the Mount Morrison pendant represents 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, where it is probably correlative with the thin, quartz-rich Lippincott Member of the Lost Burro Formation. The Squares Tunnel Formation is present in both the Mount Morrison pendant and the western Inyo Mountains, whereas the Lost Burro Formation was deposited concurrently on the carbonate platform in the eastern Inyo Mountains.

The predominantly clastic Bright Dot Formation is approximately equivalent in age to clastic rocks of the Kearsarge Formation and Rest Spring Shale in the western Inyo Mountains. The Mount Baldwin Marble, a carbonate platform accumulation, is coeval with the Keeler Canyon Formation, a thick sequence of limestone turbidites in the Inyo Mountains. The source of the Keeler Canyon turbidites, however, was probably not the Mount Baldwin platform but instead the Bird Spring platform to the east, because the Keeler Canyon Formation contains siliciclastic material not present in the Mount Baldwin Marble. The general age and lithology of the Permian Mildred Lake, Lake Dorothy and Bloody Mountain formations suggest correlation with the Lower Permian Lone Pine Formation in the southern Inyo Mountains.

STRUCTURAL GEOLOGY

The Mount Morrison pendant is divided into two major structural domains by the northwest-trending Laurel-Convict fault. East of the fault the lower Paleozoic section is generally overturned, dipping steeply to the east. The section is imbricated by major bedding-parallel faults, and deformed by kilometer-scale, tight, vertically-plunging folds. Steeply east-dipping faults are interpreted as overturned thrust faults, because the enclosing stratigraphy is generally overturned, the faults repeat the stratigraphic section, and the faults are associated with tight folds in which the western limbs are thinned or faulted (e.g., Sevehah Cliff syncline). These folds thus are probably footwall synclines.

West of the Laurel-Convict fault the upper Paleozoic section is generally west-dipping, and characterized by open to tight folds with horizontal hinge lines. No significant faulting has been observed in this section.

Major Folds

Sevehah Cliff syncline. This large faulted fold is exposed west of Convict Lake in Sevehah Cliff (cross section A–A'). It trends slightly west of north, is overturned to the west, and is cored by highly deformed beds of the Squares Tunnel Formation. To the south this fold is displaced by splays of the Laurel-Convict fault, and farther south it is cut off by the major trace of the Laurel-Convict fault.

Horsetail Falls syncline. This structure, named for a waterfall in the vicinity, is exposed in upper McGee Creek. It is overturned to the west and plunges steeply to the south. At the south end, where it is cored by the Mount Morrison Sandstone, it trends northward, but to the north it bends to the northwest. The syncline is bounded on the west by a splay of the Laurel-Convict fault.

McGee Creek syncline. This small syncline is exposed along the south bank of McGee Creek and is bounded by the McGee Creek West fault on the west. It plunges very steeply to the north and is cored by the Squares Tunnel Formation.

McGee Mountain syncline. This spectacular structure underlies McGee Mountain. It is northwest-striking, upright, and plunges almost vertically, opening to the northwest. This syncline is bounded by McGee Creek East fault on the west, and the Esha Canyon fault on the east.

Tobacco Flat anticlines and synclines. These folds, exposed in the mountain side southwest of Tobacco Flat, are very steeply plunging and are bounded on the west by the McGee Creek fault.

Major Faults

Convict Creek fault. The Convict Creek fault is an overturned thrust fault that emplaces the Convict Lake Formation on the west against the Mount Morrison Sandstone (cross section B–B'). This fault is cut by both the Laurel-Convict fault and its prominent eastern splay. The fault trace is offset on the Laurel-Convict splay from the east side of Convict Creek to the cliffs on the west face of Mount Morrison, where it is prominently displayed but inaccessible. Along the east side of Convict Creek, quartzites in the Convict Lake Formation near the fault have been separated into large isolated blocks surrounded by argillite. Wise (1996) measured the fault plane in this area as striking N-S and dipping 70° E.

Mount Morrison fault. This is an overturned thrust fault that emplaces the Convict Lake Formation on the west against the Mount Morrison Sandstone and Squares Tunnel Formation on the east. The fault strikes approximately north-south and dips steeply to the east. The fault cuts down-section to the north, and displacement apparently dies out in the Convict Lake Formation. South of Mount Morrison the fault trace is cut off by the Laurel-Convict fault; to the north the fault trace is offset about 500 meters northwest by the Laurel-Convict splay.

McGee Creek fault. We consider the McGee Creek fault to consist of two main strands, the McGee Creek West fault and the McGee Creek East fault, that probably merge into one to the north. Wise (1996) observed rare kinematic indicators of mostly left-lateral shear along the fault zone. However, we interpret both structures as primarily thrust faults, possibly reactivated with left-lateral displacement synchronous with the Laurel Convict fault. The McGee Creek West fault places the Mount Aggie Formation on the southwest against the Mount Morrison Sandstone and other units on the northeast (cross section B–B'). This fault also juxtaposes the sandstone and conglomerate facies of the Mount Morrison Sandstone, suggesting that it may be one of the most important faults in the pendant. Along the McGee Creek East fault, the Mount Morrison Sandstone on the west is emplaced against the Mount Aggie and Convict Lake Formations. The McGee Mountain syncline and folds involving the Mount Aggie and Convict Lake Formation south of McGee Creek lie east of this fault.

Esha Canyon fault. We interpret the Esha Canyon fault as a thrust fault that places the McGee Mountain syncline against Mount Aggie Formation north of McGee Creek. South of McGee Creek it separates Mount Aggie and Convict Lake formations on the west from highly deformed Mount Aggie Formation farther east.

Nevahbe fault. The Nevahbe fault places Convict Lake and Mount Aggie formations on the west against highly altered Bright Dot Formation and Mount Baldwin Marble on the east (cross section C–C'). We interpret this fault to be an east-vergent thrust fault placing the entire lower Paleozoic section structurally above the Pennsylvanian Mount Baldwin Marble. This represents the largest stratigraphic separation of any fault in the Mount Morrison pendant. The Mount Aggie Formation in the upper plate of this thrust is intensely deformed, and discontinuous beds and large lenses of marble surrounded by argillite are clearly visible from U.S. Highway 395 several kilometers to the northeast.

Laurel-Convict fault. This prominent, northwest-striking, very steeply-dipping fault and its associated splays have been studied in detail by Greene et al. (1997b). The fault zone is well exposed in the cliffs on both sides of Convict Creek, and north of Bright Dot Lake. It cuts bedding in the upper Paleozoic rocks at a low angle, and cuts obliquely across folds and faults in the lower Paleozoic rocks.

Displacement criteria including curvature and offset of bedding in the fault zone, rare mesoscopic ductile shear indicators, and restoration of offset lower Paleozoic stratigraphy and structures across splay faults, all indicate moderate, left-lateral strike-slip displacement. South of Laurel Mountain the trace of the Sevehah Cliff syncline and associated thrust fault are offset 500 m to the east by a splay of the Laurel-Convict fault. Farther to the southeast, in the cirque south of Mount Morrison, a similar repetition of units suggests that a block containing these same structures has been offset a further 4.5 km in a left-lateral sense.

The main trace of the Laurel-Convict fault has been intruded by the undeformed Laurel-Convict felsite, dated at 225 +/- 16 Ma (Greene et al., 1997b). Upper Paleozoic rocks west of the fault appear to represent relatively continuous deposition from Mississippian through middle(?) Permian time. Displacement on the Laurel-Convict fault occurred after deposition of the middle(?) Permian Bloody Mountain Formation and before intrusion of the felsite in Late Triassic time.

Hilton Creek fault. This east-side down normal fault is well exposed at the base of Nevahbe Ridge, where it forms part of the Sierra Nevada range-front fault system. The fault forms a prominent scarp about 15 m high where it crosses Tioga-age glacial moraines at the entrance to McGee Creek canyon, indicating substantial Holocene-age displacement.

Discussion

The structural contrast across the Laurel-Convict Fault has been interpreted to indicate a minimum of two phases of contractional deformation, an early (Early Mississippian?) phase that affected only the lower Paleozoic section, and a later (post-middle Permian?) phase that resulted in folding of the upper Paleozoic section (e.g. Russell and Nokleberg, 1977; Nokleberg and Kistler, 1980; Wise, 1996).

Our work (Stevens and Greene, 1999, 2000) indicates, however, that the Devonian Squares Tunnel Formation is conformably overlain by the Mississippian Bright Dot Formation, which is in turn conformably overlain by the entire Pennsylvanian and Permian section. East of Laurel Creek at the northwest end of the Mount Morrison pendant, calcareous sandstone of the McGee Mountain member of the Squares Tunnel Formation appears to be interbedded with fine-grained sandstone and argillite of the Bright Dot Formation. Although alternate interpretations of these exposures are possible, stratigraphic relations in other pendants add considerable weight to this interpretation. In the Log Cabin Mine pendant (50 km to the north) and especially in the Bishop Creek pendant (45 km to the south), brown-weathering, micaceous sandstone characteristic of the Bright Dot Formation directly overlies Squares Tunnel Formation with parallel bedding orientations and in apparent conformity.

These stratigraphic relations suggest that there was no significant orogenic activity between the deposition of the Devonian and Mississippian rocks, and imply that all deformation was Early Permian or later. In addition, the entire lower Paleozoic section has been thrust over rocks on Nevahbe Ridge that we identify as Bright Dot Formation and Mount Baldwin Marble, indicating that major thrust imbrication occured in or after late Paleozoic time. The Laurel Convict fault cuts structures in both the lower and upper Paleozoic sections, and is sealed by the undeformed 225 +/- 16 Ma Laurel-Convict felsite. The orogenic activity that produced imbrication of the lower Paleozoic section and folding of the upper Paleozoic section is therefore constrained to the period between late Early Permian and Late Triassic time. We have referred to this period as the Morrison orogeny (Stevens and Greene, 2000). If the Laurel-Convict fault is a strike-slip fault as interpreted here, it probably formed in its present near-vertical orientation and has not been subsequently tilted. Westward tilting and overturning of the lower Paleozoic section in the pendant must therefore also have occurred during the Morrison orogeny.

THE VIEW FROM CONVICT LAKE

Most of the stratigraphic units and many of the important structures in the Mount Morrison pendant are visible in spectacular cliff exposures around Convict Lake. A relatively complete and undisturbed lower Paleozoic stratigraphic section is present in the ridge on the northwest side of Convict Lake, and can be viewed from the trail around the lake (Figure 2). Type sections for the Mount Aggie, Convict Lake, and Mount Morrison formations are located on the crest of this ridge (Rinehart and Ross, 1964; Stevens and Greene, 1999).

The view southwest across Convict Lake to Sevehah Cliff and Laurel Mountain is one of the most spectacular and colorful exposures in the Sierra Nevada, especially in the morning with the rising sun lighting up the face (Figures 3 and 4). This view provides an excellent sense of the character of the Paleozoic sedimentary rocks that existed across this region prior to intrusion of the Cretaceous granitic rocks that now form much of the high country in Yosemite and the central Sierra Nevada.

Prominent in the center of the view are steep, light gray cliffs formed by calcareous quartz sandstone of the Mount Morrison Sandstone. Bedding in this and all units in Sevehah Cliff is overturned and dips very steeply northeast, almost parallel to the slope of the cliff, accentuating the apparent structural complexity. Below the gray sandstone is a chalk-white zone in which calcite and quartz in the sandstone have been altered by metamorphic fluids to the mineral wollastonite. The irregular boundary between these two zones is thus an alteration front, and both the chalk-white zone and the gray cliffs above are part of the Mount Morrison Sandstone. Visible near the base of the cliff on the left are orange striped layers of the Aspen Meadow Formation, and below that dark-rusty-brown layers of the Convict Lake Formation. Above the gray Mount Morrison Sandstone in Sevehah Cliff is a prominent, irregular, rusty-brown layer that we interpret to be black chert and argillite of the Squares Tunnel Formation that directly overlies the Mount Morrison Sandstone. Above this layer a highly disturbed zone of gray, calcareous sandstone is interpreted as the McGee Mountain member of the Squares Tunnel Formation, folded into a tight, northeast-dipping, overturned syncline (see cross-section A-A'). Above this unit near the top of Laurel Mountain is a thin band of orange-weathering Aspen Meadow Formation, and the top of Laurel Mountain consists of rusty-brown-weathering rocks of the Convict Lake Formation.

At the base of Sevehah Cliff, the Convict Creek thrust fault (not visible) separates Laurel Mountain from the closer gray and chalk-white ridge, which consists of a structural repetition of the same wollastonite-altered Mount Morrison Sandstone visible in Sevehah Cliff.

The left skyline of Sevehah Cliff consists of a block that has been offset about 500 m in a left-lateral sense (i.e., to the viewers left) on a splay of the Laurel-Convict Lake (hidden in a gully on the face). Thus, the irregular, dark-rusty-brown layer near the base of this block is interpreted as Squares Tunnel Formation, and matches with the layer in the middle of the main cliff face. Above this are gray layered rocks of the McGee Mountain member, orange-weathering striped rocks of the Aspen Meadow Formation, rusty-brown-weathering rocks of the Convict Lake Formation, and (repeated by a thrust fault) Squares Tunnel Formation.

Beyond this block on the far left skyline, brown layered rocks of the Mississippian Bright Dot Formation and dark-gray rocks of the Pennsylvanian Mount Baldwin Marble are visible across the main strand of the Laurel-Convict fault.

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