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EVIDENCE OF UPPERMOST PROTEROZOIC TO LOWER CAMBRIAN MIOGEOCLINAL ROCKS AND THE MOJAVE-SNOW LAKE FAULT: SNOW LAKE PENDANT, CENTRAL SIERRA NEVADA, CALIFORNIA

Mary M. Lahren and Richard A. Schweickert

Department of Geological Sciences,
University of Nevada, Reno

James M. Mattinson

Department of Geological Sciences,
University of California, Santa Barbara

J. Douglas Walker

Department of Geology, University of Kansas

Abstract. Displaced uppermost Precambrian to Lower Cambrian miogeoclinal strata occur within Snow Lake pendant in the central Sierra Nevada. These rocks have been correlated with the Stirling Quartzite, the Wood Canyon Formation, the Zabriskie Quartzite, and the Carrara Formation in the western Mojave Desert and the San Bernardino Mountains (Lahren and Schweickert, 1989; Lahren, 1989). This correlation is based on new, updated, and previously reported data including (1) lithologic similarities, (2) overall stratigraphic sequence, (3) vertical sequence within individual formations, (4) approximate stratigraphic thicknesses, (5) *Skolithos* in the correct stratigraphic position, (6) depositional environments, and (7) petrographic character and provenance of quartz arenites. The correlation is strengthened by the fact that Snow Lake pendant and the western Mojave share many other close similarities including (1) initial $^{87}Sr/^{86}Sr$ ratios of associated granitic rocks > 0.706, (2) passive margin tectonic setting of Precambrian to Cambrian miogeoclinal rocks, (3) dikes of the Independence dike swarm, (4) possible Lower Triassic overlap sequence, the Fairview Valley Formation, (5) petrographically similar gabbroic complexes of the same age, (6) associated eugeoclinal rocks, and (7) identical(?) pre-Tertiary structural configuration. New U/Pb zircon geochronology unequivocally shows that dikes at Snow Lake pendant are coeval with the Independence dike swarm of the eastern Sierra and the western Mojave desert and that associated gabbroic complexes in both the Mojave and Snow Lake pendant are the same age. Correlation of Snow Lake pendant with the western Mojave requires about 400 km of dextral displacement of the rocks of Snow Lake pendant, together with associated rocks (Snow Lake block), from the western Mojave Desert along the Mojave-Snow Lake fault. Displacement most likely occurred after 150 Ma, the age of the Independence dike swarm, and before about 110 Ma, the age of major plutons within the Sierra Nevada batholith. This interpretation, if correct, holds major implications for allochthonous terranes west of Snow Lake pendant, which were probably attached to the Snow Lake block before its northward transport. In addition, a number of Paleozoic and Mesozoic tectonic features in western Nevada and eastern California may have been offset dextrally along the proposed Mojave-Snow Lake fault.

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INTRODUCTION

A major problem in deciphering the crustal evolution of the Sierran region has been the lack of direct links between Paleozoic and Mesozoic orogenic belts located on opposite sides of the Sierra Nevada mountains in Nevada and California. The Sierra Nevada batholith has obscured relations between the Antler and Sonoma orogenic belts in Nevada and eastern California and lower Paleozoic to Mesozoic accreted terranes of the western metamorphic belt in the western Sierra (Figure 1).

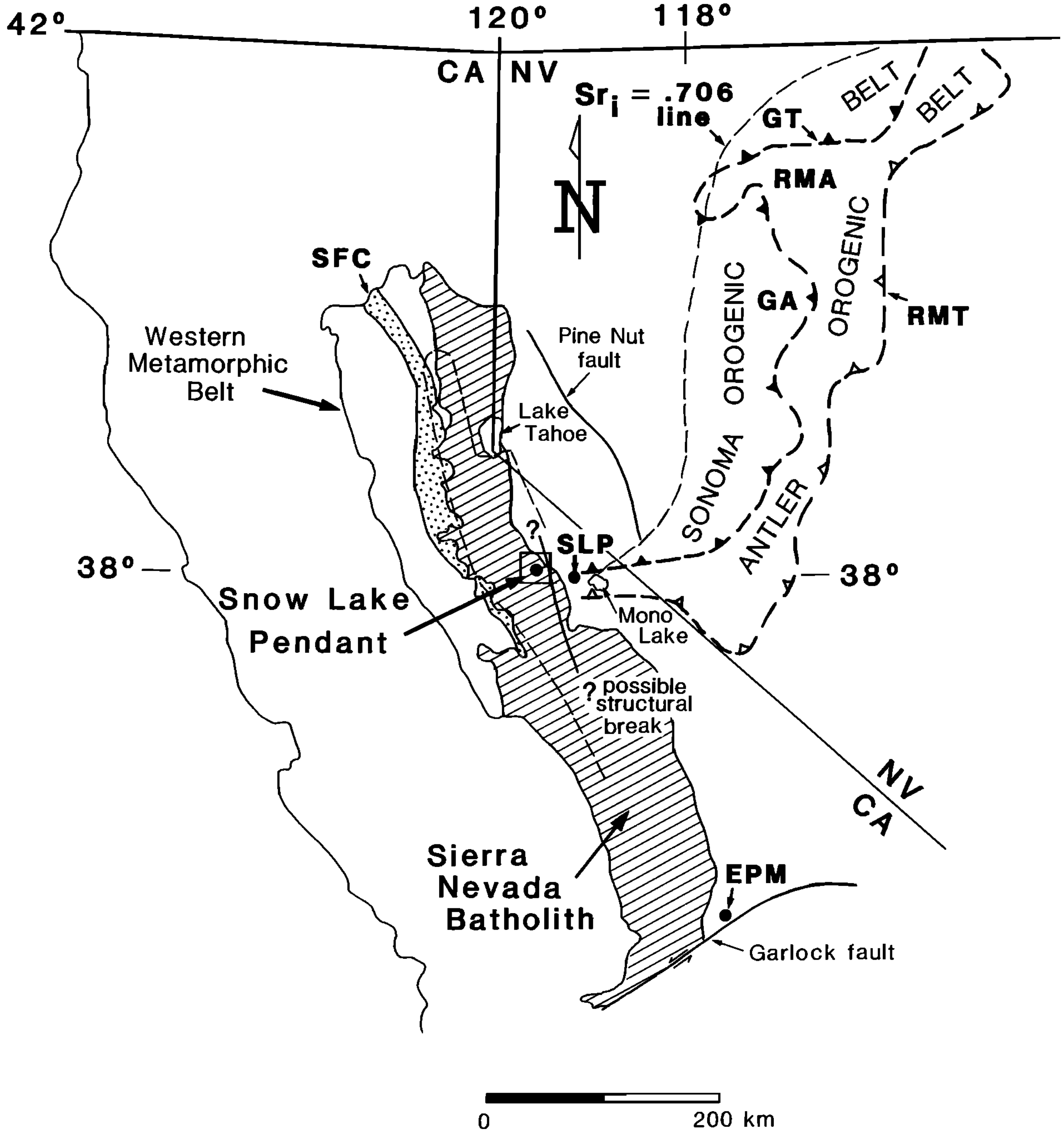


Fig. 1. Generalized tectonic map of parts of California and Nevada, showing the Sierra Nevada batholith, the western metamorphic belt, and the Antler and Sonoma orogenic belts. Note possible structural break between Snow Lake pendant and Saddlebag Lake pendant (SLP). Area of this study, Snow Lake pendant, is boxed. Abbreviations are EPM, El Paso Mountains; GA, Golconda allochthon; GT, Golconda thrust; RMA, Roberts Mountains allochthon; RMT, Roberts Mountains thrust; and SFC, Shoo Fly Complex (stippled). Initial $^{87}Sr/^{86}Sr = 0.706$ line after Kistler et al. [1981]. Pine Nut fault after Oldow [1983].

Numerous crustal boundaries, sutures, and strike-slip faults have been proposed to lie within the Sierra Nevada batholith to explain differences in lithology, structure, and isotopic signatures among rocks preserved east and west of, and within, the batholith [Kistler et al., 1980; DePaolo, 1981; Saleeby, 1981; Nokleberg, 1983; Saleeby et al., 1986; Bennett and DePaolo, 1987; Silberling et al., 1987; Ague and Brimhall, 1987, 1988a, b, 1990]. Despite the fact that many tectonic boundaries have been proposed, little direct evidence has been obtained about the timing, magnitude, location, or significance of such breaks.

Our recent studies in the central Sierra have provided new and direct evidence for the existence of tectonic breaks within the batholith, based on stratigraphy, provenance and depositional setting, structure, geochemistry, and U/Pb geochronology of rocks in Snow Lake pendant. In this pendant, we have identified stratigraphic units that appear to be related to Precambrian and Cambrian miogeoclinal rocks of the western Mojave Desert near Victorville, California [Lahren and Schweickert, 1988a, b, 1989; Lahren, 1989]. In addition, this work has shown that the deformational and intrusive histories of the two areas are very similar.

The correlation of Snow Lake pendant and related pendants with rocks of the western Mojave probably requires minimum transport of these rocks of about 400 km (revised from 500 km) [see Lahren and Schweickert, 1989] northward on the newly proposed dextral Mojave-Snow Lake fault during the Early Cretaceous [Lahren and Schweickert, 1988b; 1989; Lahren, 1989; Schweickert and Lahren, this issue; M.M. Lahren and R.A. Schweickert, unpublished data, 1989].

The objectives of this paper are to present a more complete, updated summary of the stratigraphy and structural relations of Snow Lake pendant and to present both new and previously published evidence for correlation with rocks of the western Mojave Desert. Important new U/Pb zircon geochronologic data that strongly support the correlation are also presented. In addition, we revise and review existing evidence for the magnitude of displacement, timing, and location of the Mojave-Snow Lake fault. More detailed descriptions of the stratigraphy, depositional environments, provenance, and structural history, together with geochronology and geochemistry are given by Lahren [1989] and Lahren and Schweickert (manuscript in preparation, 1990). This paper provides background data for and complements the companion paper in this issue, which presents a restoration of the Mojave-Snow Lake fault and implications for pre-Cretaceous paleogeography [Schweickert and Lahren, this issue].

Scope of Present Work

Detailed structural and stratigraphic analyses combined with geologic mapping at a scale of 1:5900 have been completed at Snow Lake pendant [see Lahren, 1989, Plate 1]; a simplified map is shown in Figure 2. In addition, Lahren and Schweickert examined in the field all known exposures of possibly correlative units in eastern California and western Nevada, including rocks in Death Valley, the White-Inyo Mountains, the western Mojave Desert, and rocks in many other Sierran roof pendants, including Piute Mountain, Glen Aulin, May Lake, Dinkey Creek, Boyden Cave, Mt. Morrison, Ritter Range, Pine Creek, Coyote Ridge, and Bishop Creek. Prior to this study, we examined the structure and stratigraphy of Saddlebag Lake pendant (Figure 1) [Schweickert and Lahren, 1987] and the Shoo Fly Complex in the western metamorphic belt (Figure 1) [Schweickert, 1981; Schweickert and Snyder, 1981; Schweickert et al., 1984a, b, 1988; Merguerian and Schweickert, 1987].

Walker has worked for many years in the western Mojave region and is now involved in the comparison of rocks of Snow Lake pendant with those of the western Mojave. Mattinson is presently performing geochronologic studies of rocks in the western Mojave and will be conducting isotopic comparisons between the western Mojave and Snow Lake pendant. For this study, Mattinson and Walker have completed U/Pb zircon geochronology on selected samples from Snow Lake pendant.

Regional Tectonic Setting

Snow Lake pendant is situated at the northern boundary of Yosemite National Park in the central Sierra Nevada (Figures 1 and 2). Rocks of Snow Lake pendant appear to be out-of-place, shallow-water, miogeoclinal rocks that were deposited as part of a passive margin sequence. These units differ from deep marine strata of eugeoclinal affinity at Saddlebag Lake pendant (Figure 1), which form the westernmost known exposures of the Antler and Sonoma orogenic belts. Similarly, rocks of the Shoo Fly Complex in the western metamorphic belt differ greatly from units at Snow Lake pendant (Figure 1). The rocks at Snow Lake are enclosed within the Cretaceous Sierra Nevada batholith, which separates Snow Lake pendant from Saddlebag Lake pendant and the western metamorphic belt.

GEOLOGY OF SNOW LAKE PENDANT

Snow Lake pendant exposes a thick sequence of quartzite, feldspathic quartzite, quartz-mica schist, marble, and calc-silicate schist, with an unconformably

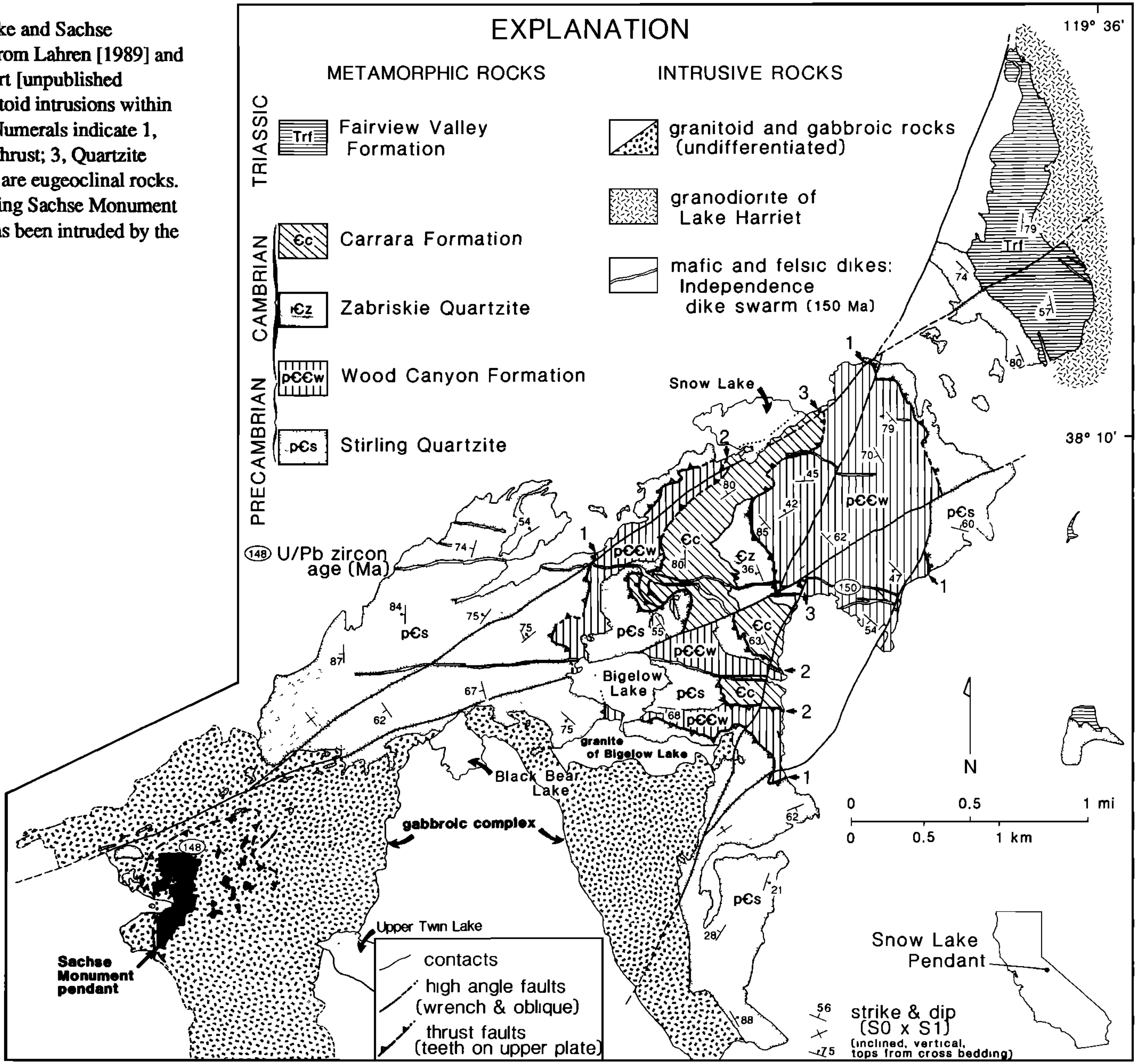


Fig. 2. Geologic map of Snow Lake and Sachse Monument pendants, generalized from Lahren [1989] and M.M. Lahren and R.A. Schweickert [unpublished mapping, 1989]. Most small granitoid intrusions within Snow Lake pendant are omitted. Numerals indicate 1, Bigelow Peak thrust; 2, Buckskin thrust; 3, Quartzite Peak thrust. Units shown in black are eugeoclinal rocks. The unnamed thrust fault surrounding Sachse Monument pendant is an inferred thrust that has been intruded by the gabbroic complex.

overlying sequence of fine-grained calc-silicate rocks (Figures 2 and 4). These rocks have been syntectonically metamorphosed at upper greenschist to lower amphibolite facies during several deformational events. Multiple contact metamorphic overprints of hornblende hornfels facies have been superimposed on the older regional metamorphic fabrics. However, primary sedimentary structures, such as cross bedding, are well preserved in the quartzites and in some of the quartz-mica schists (Figure 3). Abundant top directions have been determined at many localities from cross bedding, and these show remarkable consistency throughout the pendant [Lahren, 1989; M.M. Lahren and R.A. Schweickert, unpublished data, 1989].

The megascopic structure of the pendant consists of a domal structural window that exposes three upright thrust sheets in a duplex. The pendant is also cut by several northeast to east-northeast trending high-angle, oblique-slip faults of Tertiary age (Figure 2).

Rocks of Sachse Monument, a small pendant southwest of Snow Lake pendant (Figure 2), form a eugeoclinal suite that structurally overlies the miogeoclinal rocks of Snow Lake (M.M. Lahren and R.A. Schweickert, unpublished data, 1989).

All of the rocks of Snow Lake pendant were intruded by dikes of the Late Jurassic Independence dike swarm (Figure 2). In addition, the southern part of Snow Lake pendant, together with Sachse Monument pendant, is intruded by a metamorphosed Late Jurassic gabbroic complex and by the Late Jurassic granite of Bigelow Lake (Figure 2). Other parts of the pendant are intruded by Cretaceous plutons (C. Wahrhaftig, unpublished mapping of Tower Peak quadrangle, 1986), including the granodiorite of Lake Harriet (Figure 2).

Stratigraphy

General relations. The following section reviews stratigraphic data of Lahren and Schweickert [1989] and adds significant new details and structural relations of individual formations. The stratigraphic units of Snow Lake pendant have been correlated with the uppermost Proterozoic to Cambrian passive margin sequence (Death Valley facies) of western Nevada, eastern California, and

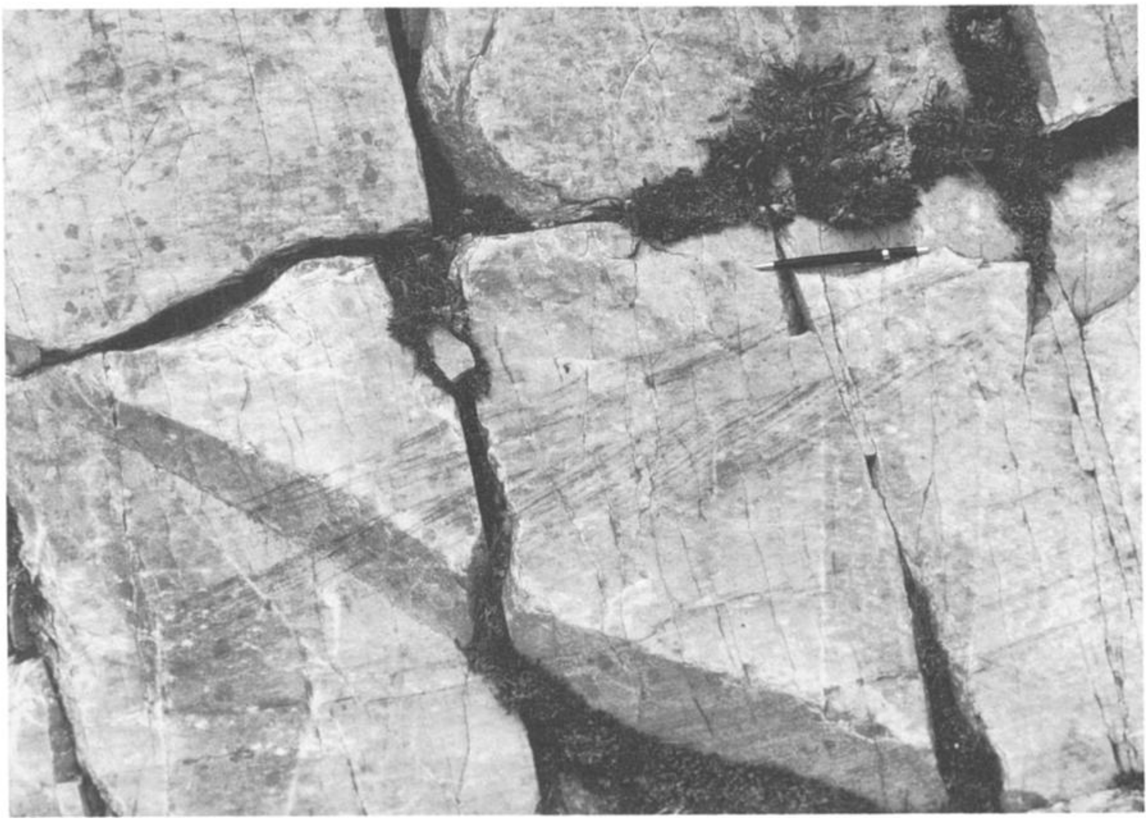


Fig. 3. Outcrop photograph of tabular cross bedding in the Zabriskie Quartzite at Snow Lake pendant. The cross bedding has tangentially based foresets and is upright.

the western Mojave Desert [Lahren and Schweickert, 1989; Lahren, 1989]. Therefore, in this paper, the units are provisionally named after correlative formations, as previously published: The Stirling Quartzite, Wood Canyon Formation, Zabriskie Quartzite, and Carrara Formation [Lahren and Schweickert, 1989]. The rationale for the correlation is presented in three separate sections following stratigraphic descriptions (see sections on basis for age and correlation of units, regional relations, and direct comparisons with the Mojave).

Thicknesses of units in the different thrust sheets at Snow Lake pendant are shown in Figure 4. Nomenclature for thrust sheets follows standard rules in that the thrust sheets are named after underlying thrust faults (Figure 2). Nearly all of these thicknesses and their internal structures have been revised from Lahren and Schweickert [1989] as a result of new and more detailed observations. All thicknesses are approximate stratigraphic thicknesses (as opposed to structural thicknesses), derived from structural thicknesses that have been adjusted on the basis of the geometry of map-scale folds.

Stirling Quartzite. The upper Precambrian Stirling Quartzite crops out nearly continuously around the periphery of the pendant in the Bigelow Peak thrust sheet and it also occurs in the Buckskin thrust sheet (Figures 2 and 4). In the Buckskin thrust sheet, the Stirling is conformably overlain by the Wood Canyon Formation, and in the northeast part of the pendant in the Bigelow Peak thrust sheet, it is unconformably overlain by a younger sequence (Fairview Valley Formation). Stirling Quartzite also crops out near Sachse Monument southwest of the main exposures of Snow Lake pendant (Figure 2). There, the Stirling lies structurally beneath the enigmatic rocks of Sachse Monument (see description below).

The most abundant unit in the Stirling consists of white, gray, buff, and pink weathering, cliff-forming, vitreous quartzite and micaceous, feldspathic quartzite. Subordinate interbeds of pebbly quartzite and very thin mica schist are present throughout the unit. Quartzite beds are thinly bedded to very thickly bedded, and preserved bedding is variably massive, parallel laminated, or cross bedded. Cross bedding is tabular with angular and tangentially based foresets (Figures 3 and 4). In addition, minor lenticular to continuous heterogeneous units of quartz-mica schist, calc-silicate schist, micaceous quartzite, and coarse-grained (dolomitic?) marble are locally interlayered with the quartzites (Figure 4). The minimum stratigraphic thickness of the Stirling Quartzite, estimated in the Bigelow Peak thrust sheet, is approximately 710 m (Figure 4).

Wood Canyon Formation. The Precambrian to Lower Cambrian Wood Canyon Formation conformably overlies the Stirling Quartzite in the Buckskin thrust sheet and also occurs in the lowest structural position within the pendant, where it is in thrust-fault contact with the overlying Lower Cambrian Zabriskie Quartzite in the Quartzite Peak thrust sheet (Figures 2 and 4). The Wood Canyon Formation is a heterogeneous unit composed of quartz-mica schist, quartzite, feldspathic quartzite, marble, dolomitic(?) marble, and calc-silicate schist (Figures 2 and 4). The 375-m thickness of the Wood Canyon, estimated in the lower plate of the Quartzite Peak thrust and in the Buckskin thrust sheet, is a minimum because unknown thicknesses are cut out at the top by the Quartzite Peak thrust and in the middle part of the formation by the Bigelow Peak thrust.

The lowest part of the Wood Canyon Formation, which is exposed in the Buckskin thrust sheet, consists of about 92 m of quartz-mica schist and feldspathic quartzite that conformably overlies the Stirling Quartzite (Figure 4). The lowest exposed unit beneath the Quartzite Peak thrust consists of 50 m of vitreous, parallel-laminated and cross-bedded quartzite and feldspathic quartzite with minor interbeds of quartz-mica schist (Figure 4).

The uppermost preserved part of the Wood Canyon Formation, beneath the Quartzite Peak thrust, is composed of quartz-mica schist with interbeds of fine-grained, micaceous, feldspathic quartzite that increase in abundance upward toward the Quartzite Peak thrust (Figure 4). The feldspathic quartzite is thinly bedded to medium bedded and shows both parallel laminations and small-scale, tabular and trough cross stratification. Minor vitreous quartzite and calcareous quartzite also occur in the upper part of the Wood Canyon. Abundant vertical burrows, *Skolithos*, occur within the schists and quartzites in the upper part of the Wood Canyon Formation (Figures 4 and 5). Horizontal burrows and bioturbated zones are also common in these units.

Two major marble beds also occur within the upper part of the Wood Canyon Formation, and smaller lenses of marble are present throughout the formation. These units consist of massive, coarse-grained, intensely deformed, and highly recrystallized marble, dolomitic(?) marble, and sandy marble. Calcareous quartzite is commonly interbedded with the marble together with subordinate amounts of calc-silicate schist. Calc-silicate schist occurs mainly in the upper part of the Wood Canyon Formation (Figure 4), but also is present throughout the formation, where it typically is interbedded with discontinuous marble lenses. These units consist of thinly bedded to medium bedded calc-silicate schist with interbeds of calcareous quartzite.

The vertical sequence in the Wood Canyon Formation can be subdivided into three distinctive units: A lower unit that is dominantly quartz-mica schist (exposed in the Buckskin thrust sheet), a middle unit that is mainly

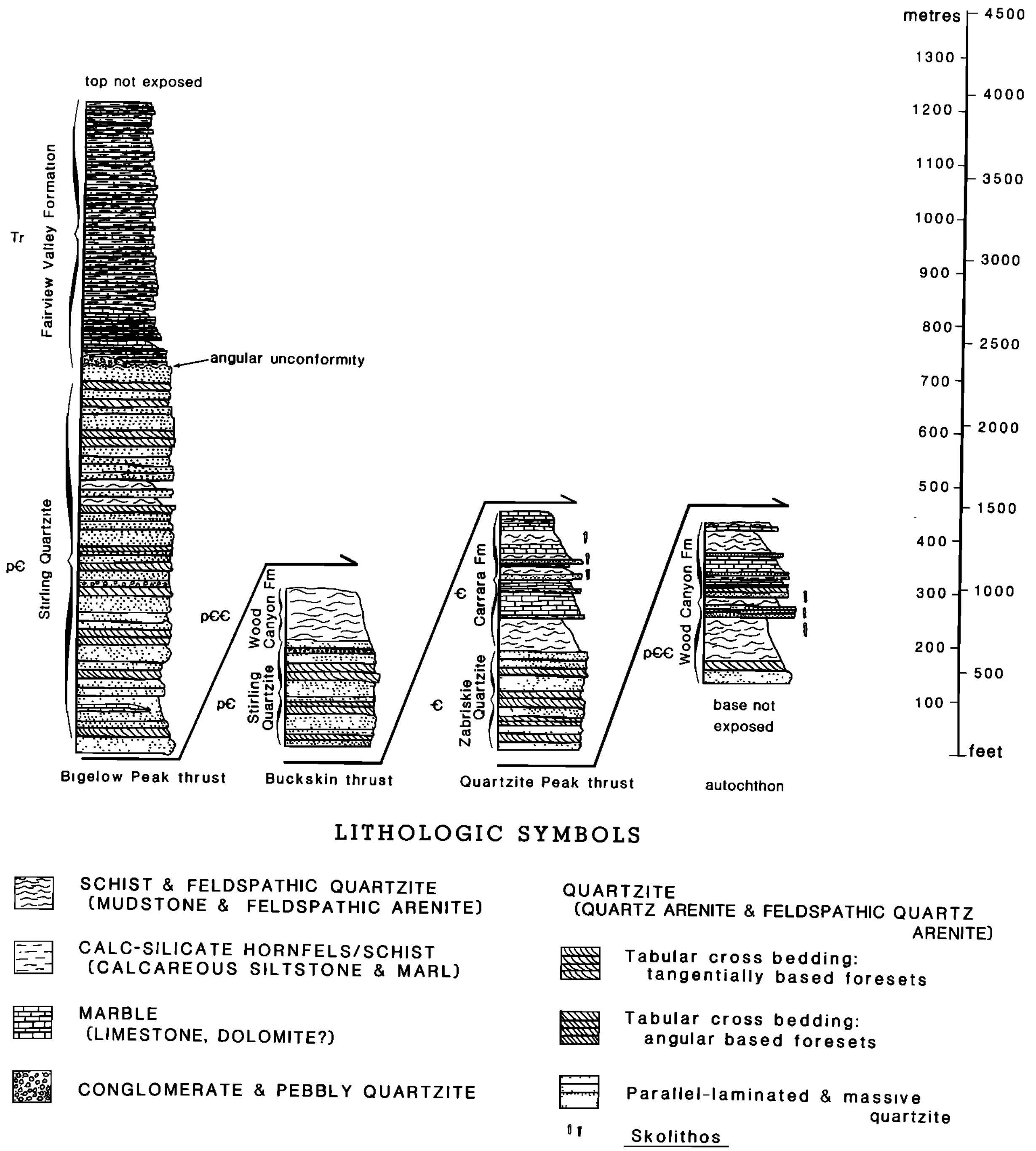


Fig. 4. Approximate stratigraphic thicknesses of units in the various thrust sheets at Snow Lake pendant. Stratigraphic thicknesses have been estimated by taking into account the geometry of map-scale folds and adjusting structural thicknesses accordingly. From Lahren [1989].

quartzite and feldspathic quartzite, and an upper unit consisting mainly of quartz-mica schist and feldspathic quartzite. The upper part of the upper unit contains significant amounts of marble (dolomitic?) and calc-silicate schist overlain by more quartz-mica schist and feldspathic quartzite. Both the middle and upper units are exposed beneath the Quartzite Peak thrust in the central part of the pendant (Figure 4).

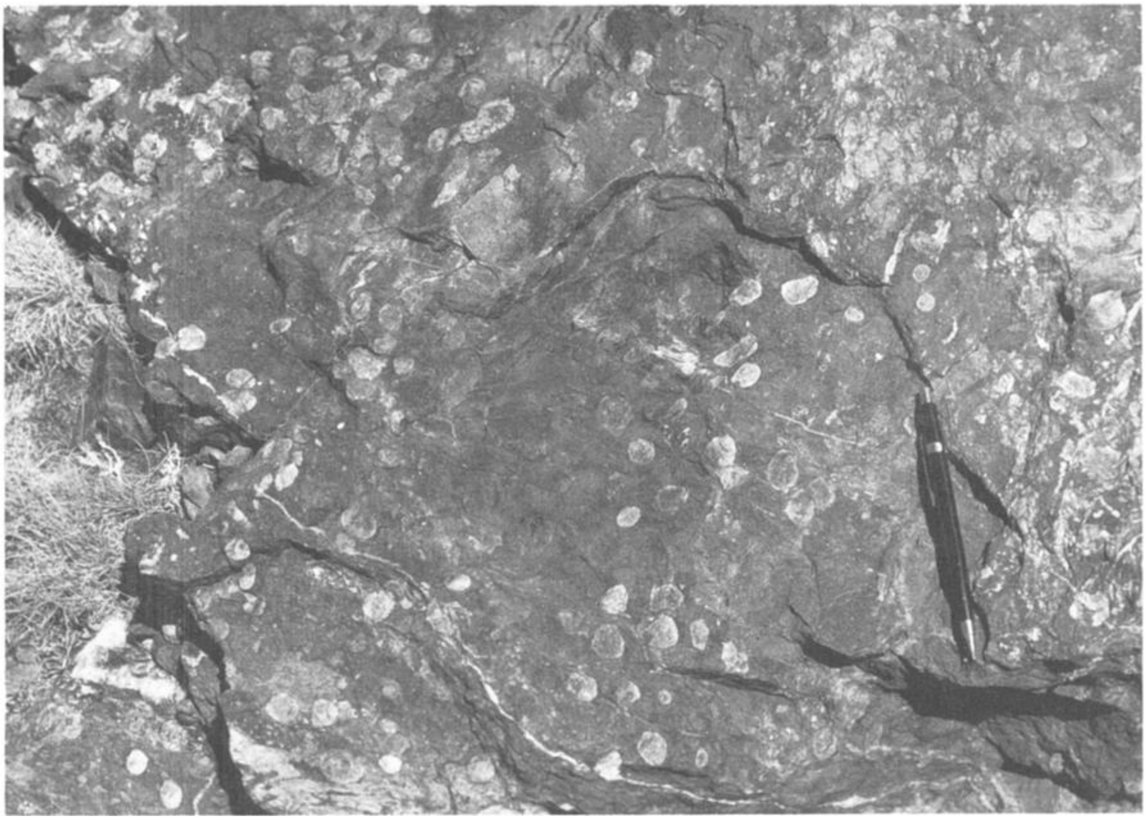


Fig. 5. Outcrop of metamorphosed siltstone in the Wood Canyon Formation that contains well-preserved *Skolithos*, which are composed of quartz arenite.

Zabriskie Quartzite. The Lower Cambrian Zabriskie Quartzite, which is in thrust-fault contact with the underlying Wood Canyon Formation, is a homogeneous, cliff-forming unit that consists of over 180 m of gray, pinkish-gray, and white, vitreous, massive, parallel-laminated, and cross-stratified quartzite (Figure 4). An unknown thickness of quartzite is cut out along the Quartzite Peak thrust, which places Zabriskie on Wood Canyon in a younger on older structural configuration. The younger on older relationship is probably a result of the Quartzite Peak thrust cutting previously folded strata [Lahren, 1989]. The Zabriskie is conformably overlain by the Lower to Middle Cambrian Carrara Formation.

The Zabriskie Quartzite ranges from thinly to very thickly bedded, and cross bedding is tabular with tangentially and angular based foresets. The majority of the quartzite is very clean and is composed of approximately 98% monocrystalline quartz with minor muscovite and zircon. Local millimeter- to centimeter-scale partings of micaceous schist occur between the quartzite beds. The upper part of the Zabriskie is generally thinner bedded and shows an increase in the number and thickness of schist interbeds towards the overlying Carrara Formation. The formation is consistently upright with one mappable internal imbrication in the lower part of the formation, near the Quartzite Peak thrust.

Carrara Formation. The Lower to Middle Cambrian Carrara Formation, which conformably overlies the Zabriskie Quartzite, is a heterogeneous unit of quartz-mica schist and micaceous, feldspathic quartzite, marble, calc-silicate schist, and subordinate quartzite, with an approximate thickness of 260 m (Figures 2 and 4). An unknown thickness at the top of the formation is cut out by the overlying Buckskin thrust, which places Stirling Quartzite on Carrara.

In the Carrara Formation, quartz-mica schist is interbedded with finely laminated, thinly bedded, micaceous, feldspathic quartzite throughout the section. *Skolithos* occur within micaceous quartzite in the upper part of the section (Figure 4). Marble beds consist of coarse-grained, highly deformed, and recrystallized marble (dolomitic?). Locally, thinly bedded, calcareous quartzite is interbedded with the marble. Calc-silicate schists are thinly banded with interbeds of calcareous quartzite. Locally, calcareous quartzite makes up the majority of individual calc-silicate schist units. Quartzite within the Carrara is composed of massive, medium to thickly bedded, white, vitreous quartzite to feldspathic quartzite. These units thicken and thin locally and grade both upward and downward into quartz-mica schist or micaceous, feldspathic quartzite.

The Carrara Formation has a distinctive vertical sequence that includes three clastic-carbonate cycles (Figure 4). The lowest cycle consists of a thick lower unit of quartz-mica schist and feldspathic quartzite overlain by marble and calc-silicate. It is overlain by two thinner cycles of clastic and carbonate rocks.

Fairview Valley Formation. Rocks correlated wth the Lower Triassic Fairview Valley Formation unconformably overlie the Stirling Quartzite in the Bigelow Peak thrust sheet in the northeast part of the pendant (Figures 2 and 4). The Fairview Valley Formation has a preserved stratigraphic thickness of about 500 m (adjusted for folds) and consists of calc-silicate hornfels, marble, and metaconglomerate (Figure 4). The unconformity is defined by a discontinuous basal metaconglomerate, containing quartzite and marble clasts in a sandy to silty, calcareous(?) matrix. Clasts range in size from pebbles to boulders. A local small-angle discordance exists between bedding in the Stirling Quartzite and that in calc-silicate hornfels of the Fairview Valley Formation. The upper part of the Fairview Valley is intruded by the granodiorite of Lake Harriet (Figure 2).

Calc-silicate hornfels is the predominant lithology in the Fairview Valley Formation. It consists of metamorphosed, rhythmically layered, rusty orange- and green-weathering, calcareous, fine-grained sandstone, siltstone, mudstone, and silty limestone that are thinly laminated to thinly bedded; massive, thickly bedded mudstone-siltstone is also present. Small-scale cross lamination is rare, and one partial Bouma sequence with silt- to sand-sized graded bedding was identified. Clastic dikes containing clasts of augite monzonite and siltstone in a siltstone matrix locally cut the section.

Two major marble units occur in the lower part of the Fairview Valley Formation (Figure 4). The marble is very coarse grained and strongly foliated. Minor lenticular interbeds of marble and sandy marble occur throughout the section. Marble also occurs in two small remnants east of the main pendant (Figure 2).

Possible Eugeoclinal Rocks of Sachse Monument Pendant

Sachse Monument pendant, located 0.5 km southwest of Snow Lake pendant (Figure 2), exposes rocks related to Snow Lake pendant, namely Stirling Quartzite, together with eugeoclinal rocks that are lithologically and structurally dissimilar to the rocks of Snow Lake pendant. The eugeoclinal rocks consist of metamorphosed siltstone/sandstone, bedded metachert, marble, marble clast conglomerate, and minor quartzite (M.M. Lahren and R.A. Schweickert, unpublished data, 1989).

These rocks lie structurally above the Stirling Quartzite along what is interpreted to be a thrust fault that has been intruded by a Jurassic gabbroic complex described below (M.M. Lahren and R.A. Schweickert, unpublished data, 1989). The eugeoclinal rocks are still under study; their age and affinity are presently unknown.

Protoliths, Environments of Deposition, and Provenance

Stirling Quartzite, Wood Canyon Formation, Zabriskie Quartzite, Carrara Formation. These units originally consisted of quartz arenite to feldspathic arenite, feldspathic siltstone and silty mudstone, limestone or dolomite, and marl or calcareous siltstone. The protoliths, the presence of *Skolithos*, extensive bioturbation, widespread tabular cross bedding, the compositional maturity of the quartzites, and the presence of pebbly quartzite are all consistent with deposition in a shallow marine depositional environment, probably on the continental shelf [Walker, 1984; Lahren, 1989].

These units have strong cratonal provenance ties as indicated by both lithology and detrital zircon data. As reported previously [Lahren and Schweickert, 1989; Lahren, 1989], detrital zircon from the Zabriskie Quartzite yielded an average $^{207}Pb/^{206}Pb$ age of approximately 1.6 Ga, indicating a mid-Proterozoic cratonal source terrane for these rocks.

Fairview Valley Formation. The Fairview Valley Formation originally consisted of a basal conglomerate overlain by limestone and a fairly monotonous sequence of calcareous, fine-grained sandstone, siltstone, mudstone, and silty limestone. The abundance of fine parallel laminations and rare cross lamination suggest that the Fairview Valley Formation was deposited from suspension in a quiet, low-energy environment, below storm wave base in either a shallow marine (lagoonal?) or lacustrine environment (Lahren, 1989; M.M. Lahren and R.A. Schweickert, unpublished data, 1989).

Clasts of monzonite within the Fairview Valley suggest that the source area included an actively uplifting and eroding plutonic basement terrane that contributed monzonitic clasts to the basinal or shallow marine environment of deposition.

Basis for age and correlation of units

Precambrian to Cambrian units. Although no age-diagnostic fossils have been found, we have correlated the older rocks in Snow Lake pendant with Precambrian to Middle Cambrian units of the Death Valley facies in eastern California [Lahren and Schweickert, 1988b,1989; Lahren, 1989]. The correlation is based on (1) lithologic similarities, (2) bedding style, (3) stratigraphic sequence, (4) approximate stratigraphic thicknesses, (5) the presence of *Skolithos* in the correct stratigraphic position, (6) the extreme compositional maturity of the Zabriskie Quartzite, (7) shallow marine environments of deposition, (8) similarity of provenance, and (9) the complete lack of volcanic rocks within the section.

The two most distinctive units at Snow Lake are the Stirling Quartzite and the Zabriskie Quartzite. The only marine quartzites of any age in the central Cordillera of similar thickness and compositional maturity comparable to the quartzites at Snow Lake pendant are in the upper Precambrian to Lower Cambrian passive margin rocks (Death Valley facies) of eastern California and southwestern Nevada. In addition, the rocks at Snow Lake pendant clearly have cratonal provenance ties as discussed above.

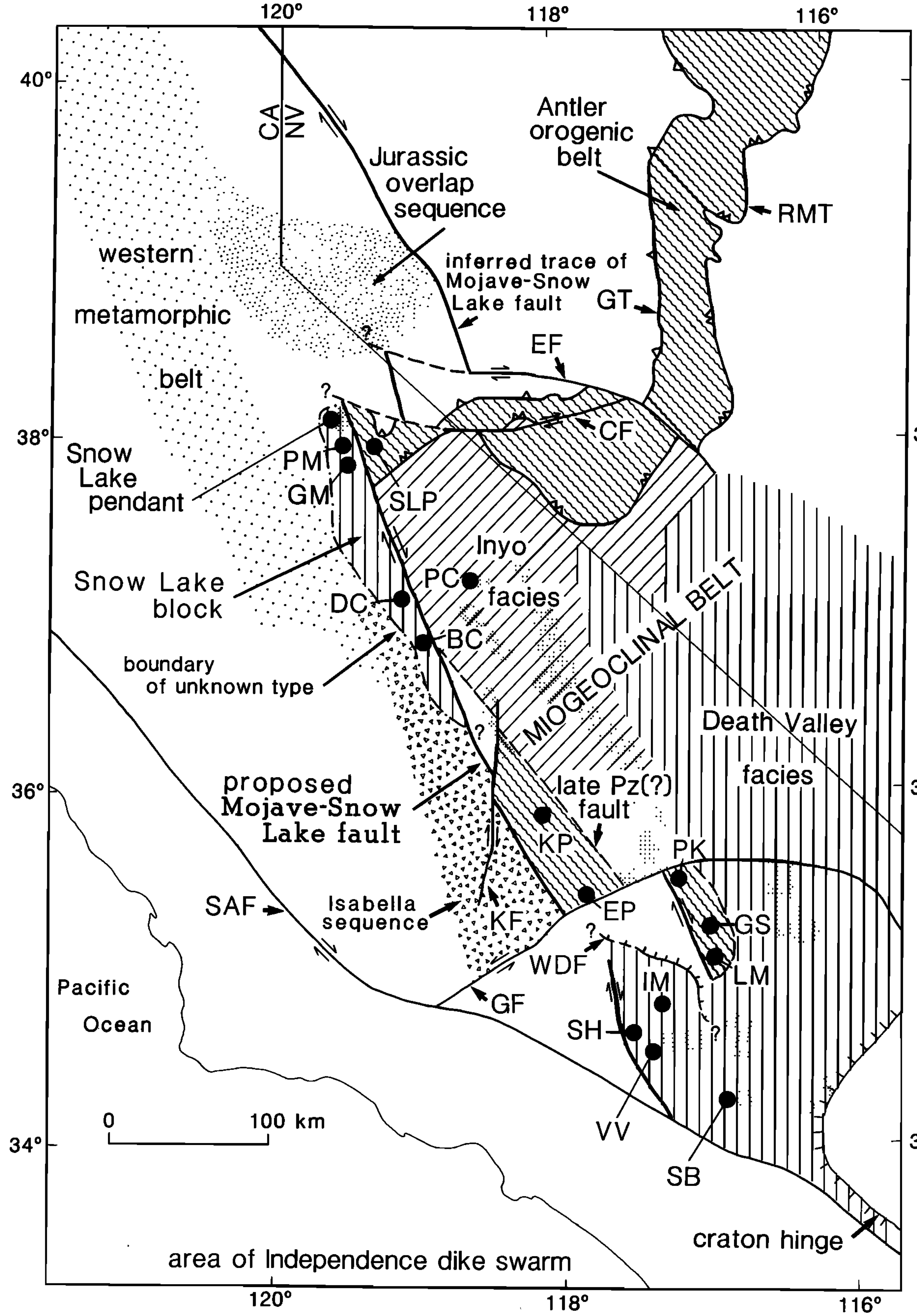
Furthermore, vertical sequences in the Wood Canyon and Carrara formations are similar to those reported elsewhere in the Wood Canyon and Carrara [Stewart, 1970; Palmer and Halley, 1979]. For example, both the middle unit of the Wood Canyon at Snow Lake pendant and the middle member of the Wood Canyon Formation in the Death Valley region are composed mainly of quartz arenite and feldspathic arenite [Stewart, 1970]. In both areas, the upper part of the Wood Canyon Formation is composed of siltstone and feldspathic arenite, with distinctive marker beds of limestone/dolomite (marble) [Stewart, 1970; Lahren, 1989]. The Carrara Formation in both areas is composed of several clastic-carbonate cycles [Palmer and Halley, 1979], although the uppermost, thick carbonate unit of the Carrara does not occur at Snow Lake pendant; we infer that it has been cut out by the Buckskin thrust [Lahren, 1989]. Furthermore, the trace fossil, *Skolithos*, occurs in the same stratigraphic position within the Wood Canyon and Carrara Formations at Snow Lake pendant as it does in rocks of the Death Valley facies [Stewart, 1970; Palmer and Halley, 1979; Lahren, 1989].

Additional Correlations

On the basis of broad lithologic similarities, we suggest that the rocks of Snow Lake pendant also correlate with metasedimentary rocks in several other Sierran pendants including Piute Mountain (C. Wahrhaftig, unpublished data; R.A. Schweickert and M.M. Lahren, unpublished data, 1987), Glen Aulin, May Lake [Rose, 1957], Tuolumne Peak [Walker, 1980], Dinkey Creek [Kistler and Bateman, 1966; Merritt, 1985], Patterson Mountain [Krauskopf, 1953], and the western part of Boyden Cave [Girty, 1985] (Figure 6). We believe these pendants, together with Snow Lake pendant, form a large crustal block that we have called the Snow Lake block.

The internal stratigraphy of these pendants is for the most part unknown, precluding comparison of detailed stratigraphic columns. Nevertheless, all these pendants contain substantial amounts of clean quartzite and interlayered schist, marble and calc-silicate schist and also lack interlayered metavolcanic rocks. Owing, in part, to lithologic analogs and to the lack of associated or interstratified volcanic rocks, such units most closely resemble uppermost Proterozoic to Middle Cambrian miogeoclinal strata of eastern California. Boyden Cave pendant contains younger metasedimentary and metavolcanic rocks that either unconformably overlie or are in tectonic contact with the quartzite-rich rocks [Girty, 1985]; the latter rocks are not included in the Snow Lake block (Figure 6). Previously, Kistler and Bateman

Fig. 6. Interpretive tectonic sketch map of western Nevada and eastern California showing the Snow Lake block, a displaced crustal slice of Precambrian and Cambrian rocks, and the proposed dextral Mojave-Snow Lake fault. Fault abbreviations are CF, Coaldale fault; EF, Excelsior fault; GF, Garlock fault; GT, Golconda thrust; KF, Kern Canyon fault; RMT, Roberts Mountains thrust; SAF, San Andreas fault; and WDF, Waterman Hills detachment fault [Glazner et al., 1989]. The late Paleozoic fault is inferred to have displaced rocks of the Antler orogenic belt in a sinistral sense [Stone and Stevens, 1988; Walker, 1988]. Other abbreviations are BC, Boyden Cave pendant; DC, Dinkey Creek pendant; EP, El Paso Mountains; GM, Glen Aulin-May Lake pendants; GS, Goldstone; IM, Iron Mountain; KP, Kern Plateau; LM, Lane Mountain; PC, Pine Creek; PK, Pilot Knob Valley; PM, Piute Mountain pendant; SB, San Bernardino Mountains; SH, Shadow Mountains; SLP, Saddlebag Lake pendant; and VV, Victorville. The area of Independence dike swarm is taken from Moore and Hopson [1961], Smith [1962], Chen and Moore [1979], James [1987, 1989], and Karish et al. [1987]. Shadow Mountains are included in miogeoclinal belt, following Brown [1983] and Martin and Walker [1990]. Figure modified from Lahren and Schweickert [1989] and Lahren [1989].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Jurassic overlap sequence
Antler orogenic belt
RMT
western metamorphic belt
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GT
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boundary of unknown type
MIOGEOCLINAL BELT
Death Valley facies
proposed Mojave-Snow Lake fault
late Pz(?) fault
KP
PK
Isabella sequence
KF
EP
GS
SAF
WDF
LM
IM
GF
Pacific Ocean
SH
VV
SB
0
100 km
craton hinge
area of Independence dike swarm

[1966] and Girty [1985] inferred that the metasedimentary rocks of Dinkey Creek pendant and the western part of Boyden Cave pendant, respectively, are miogeoclinal strata of Paleozoic age.

Lower Triassic overlap sequence. The Lower Triassic Fairview Valley Formation in the western Mojave Desert at Black Mountain and Quartzite Mountain is a distinctive overlap sequence which is, in part, lithologically almost identical to the unit at Snow Lake. Although no fossils have been found at Snow Lake, the correlation is based upon lithologic similarity and on the fact that this sequence, in both areas, unconformably overlies unfossiliferous miogeoclinal rocks of the Death Valley facies [Stewart and Poole, 1975; Miller, 1978; 1981a, b; Lahren and Schweickert, 1988b, 1989; Lahren 1989]. (see section below on comparison with the western Mojave).

INTRUSIVE ROCKS

Independence Dike Swarm

Dikes that we correlate with the Independence dike swarm intrude the metamorphic rocks of Snow Lake pendant (Figure 2) [Lahren and Schweickert, 1989; Lahren, 1989; M.M. Lahren and R.A. Schweickert, manuscript in preparation, 1990]. The dikes vary in width from 0.5 to 8 m and consist of porphyritic microgranite (rhyolite) to microdiorite (basalt) that are petrographically and texturally similar to dikes of the Independence dike swarm in eastern California, the Mojave Desert, and the eastern Transverse Ranges [Chen and Moore, 1979, 1982; Karish et al., 1987; James, 1989]. In addition, major element chemistry of the dikes in Snow Lake pendant is similar to chemistry of dikes of the Independence dike swarm of eastern California [Chen and Moore, 1979, 1982; Lahren, 1989; M.M. Lahren and R.A. Schweickert, unpublished data, 1989] and of the western Mojave [Karish et al., 1987]. In all three areas, the dikes range from calc-alkalic to alkalic [Irvine and Baragar, 1971].

Although the dikes at Snow Lake pendant have a trend similar to that of the 160-Ma Sonora dike swarm near latitude 38° in the western metamorphic belt [Schweickert et al., 1988], they are petrographically and texturally dissimilar. The Sonora dike swarm is characterized by dikes of porphyritic andesite, lamprophyre, and aphanitic basalt [Merguerian, 1985, 1986].

U/Pb zircon results. The Independence dike swarm has been dated by U/Pb techniques at approximately 148 Ma by Chen and Moore [1979, 1982] and James [1989]. We have analyzed three size fractions of nonmagnetic zircon from one of the felsic dikes (sample SL-1016) in Snow Lake pendant (Figure 2). Each zircon fraction was subjected to a four-step dissolution procedure.

Detailed results of our analyses will be presented elsewhere, but, briefly, the first two steps removed slightly more discordant and common Pb-rich zircon. The final two dissolution steps sampled less discordant, "cleaner" zircon. A summary of the combined results from the final two steps is presented in Table 1 (sample SL-1016). All three fractions yielded near-concordant ages in the range of 144-150 Ma. The dikes show a well-developed hornfelsic texture, evidently the result of strong reheating by surrounding Cretaceous plutons. Thus, the zircons have undoubtedly lost some Pb since their original crystallization, and we regard the Pb/U ages as minimum ages for original igneous crystallization. The Pb losses have been minor, however, as indicated by near-concordance of the Pb/U and Pb/Pb ages from individual fractions and by the limited spread in ages among the three fractions. The rather low U concentrations may have been an important factor here.

An early dissolution step for the finest zircon fraction showed clear evidence of slight inheritance of older zircon; such inheritance is common in samples of the Independence dike swarm [Chen and Moore, 1982; James, 1989]. Most of this inherited zircon was apparently removed in the early dissolution steps, but we suspect that the slightly higher Pb/Pb age for the final dissolution steps for this fraction (Table 1) still reflects a slight inheritance. We therefore place more weight on the two coarser fractions.

The very tight clustering of data precludes a conventional concordia interpretation. However, considering the slight discordance, at least some of which is probably due to Pb loss during emplacement and cooling of Cretaceous plutons, as opposed to more recent Pb loss associated with uplift, we believe that the $^{207}Pb/^{206}Pb$ ages of the two coarser fractions are very close to (but still slightly younger than) the crystallization age of the dike. Our best estimate of crystallization age of the Snow Lake dikes, accounting for uncertainties in the data, as well as interpretation, is 150 ± 2-3 Ma, leaving absolutely no doubt that these dikes are coeval with the Independence dike swarm. A Late Jurassic age for the dikes is also supported by the fact that the dikes appear to be related to the Jurassic gabbroic complex (described below).

Gabbroic Complex

This complex, located south and west of Bigelow Lake, separates the metasedimentary rocks of Snow Lake pendant from those at Sachse Monument (Figure 2) and intrudes the former thrust contact between the two

TABLE 1. Analytic Data From Snow Lake Area

				Measured Ratios			Radiogenic Ratios			Ages (Ma)		
Fraction	Sample Weight mg	U ppm	^{206}Pb* ppm	^{206}Pb/ ^{204}Pb	^{207}Pb/ ^{206}Pb	^{208}Pb/ ^{206}Pb	^{206}Pb*/ ^{238}U	^{207}Pb*/ ^{235}U	^{207}Pb*/ ^{206}Pb*	^{206}Pb*/ ^{238}U	^{207}Pb*/ ^{235}U	^{207}Pb*/ † ^{206}Pb*
SL 1016‡												
>52 µm	5.30	122.2	2.394	6289	0.05146	0.2279	0.02278	0.1543	0.04912	145.2	145.7	153.4 (4)
50-70 µm	5.10	111.0	2.160	4464	0.05232	0.2250	0.02264	0.1530	0.04902	144.3	144.6	148.9 (4)
70-105 µm	5.80	93.67	1.828	4505	0.05231	0.2146	0.02271	0.1536	0.04904	144.8	145.1	149.9 (4)
SM-100§												
nm(-1) >240	6.56	62.75	1.190	5588	0.05159	0.2008	0.02207	0.1491	0.04900	140.7	141.1	148.1 (2)
nm(0) <240	2.16	272.2	5.132	2448	0.05498	0.2026	0.02195	0.1484	0.04902	140.0	140.5	149.0 (3)
nm(0) >240	3.87	214.3	4.002	2136	0.05585	0.2189	0.02174	0.1469	0.04902	138.6	139.2	149.0 (4)
nm(1) >240	3.67	130.9	2.402	2054	0.05609	0.2345	0.02135	0.1442	0.04899	136.2	136.8	147.4 (4)

Decay constants used were ^{238}U=0.15513x10^{-9} yr^{-1} and ^{235}U=0.98485x10^{-9} yr^{-1} [Steiger and Jäger, 1977]. Common lead corrections were made using values determined from Stacey and Kramers [1975] for 148 Ma. Values used are ^{206}Pb/^{204}Pb=18.477, ^{207}Pb/^{204}Pb=15.618, and ^{208}Pb/^{204}Pb=38.360.

* Radiogenic component.

† Numbers in parentheses are analytical errors on age (in m.y., 2-sigma).

‡All fractions nonmagnetic at 1° side tilt on Frantz separator. Sample analysed at the University of California, Santa Barbara. Chemistry for both lead and uranium by HCl anion exchange. Isotopic analyses were determined on the UCSB MAT 261 multicollector intruments. Laboratory blank is less than 0.03 ng. Uncertainties on the ^{207}Pb*/^{206}Pb* ages are quoted at the 2-sigma level, using the treatment of Mattinson [1987].

§nm(#) = nonmagnetic on Frantz separator at angle of side tilt # degrees. >240 = size in standard mesh. Sample analyzed at the University of Kansas. Elemental separation was done with a HBr anion column chemistry for lead and HCl column chemistry for uranium. Isotopic analyses were determined on a VG Sector multicollector thermal ionization mass spectrometer. Laboratory blank is 0.15 ng or less total lead and 0.2 ng uranium. Errors on data were computed using data reduction program PBDAT of Ludwig [1983].

pendants. It consists of a composite suite of gabbro, fine-grained diorite, megacrystic hornblende gabbro, and hornblendite. Some of the hornblende gabbro and hornblendite contain 3-4 cm-long poikilitic hornblende crystals. Locally, garnet-bearing granitic dikes cut the complex. The gabbroic complex shares comingling textures with the granite of Bigelow Lake.

U/Pb zircon results. We have analyzed several fractions of zircon from a sample of hornblende diorite (SM-100) near Sachse Monument (Figure 2). Analytical data are given in Table 1 (sample SM-100). The zircon systematics are identical to those of the sample of the Independence dike (SL-1016) except SM-100 showed a somewhat higher degree of lead loss. Tight clustering of data for this rock also precludes a conventional concordia interpretation. The average of the $^{207}Pb/^{206}Pb$ ages, 148.4 ± 1.5 Ma, is interpreted to represent the crystallization age of this rock.

Both igneous suites, the gabbroic complex together with the granite of Bigelow Lake (discussed below), and the mafic to felsic dikes of the Independence dike swarm, have the same compositional range, similar structural relations, and identical U/Pb zircon ages and thus are most likely comagmatic. This supports the idea that this gabbroic complex may represent plutonic roots of the Independence dike swarm. A similar interpretation for dikes of the Independence dike swarm and gabbro bodies in the Mojave Desert was presented by Walker et al. [1990a, b].

Granite of Bigelow Lake

The granite of Bigelow Lake is a small, deformed pluton located south of Bigelow Lake (Figure 2). It is important because it places timing constraints on structural elements within the pendant and shows mutually intrusive relations with the gabbroic complex. The granite of Bigelow Lake has a seriate, hypidiomorphic-granular texture and is composed of subequal amounts of quartz and perthitic orthoclase, plus microcline with lesser amounts of plagioclase and minor biotite and hornblende.

Preliminary U/Pb zircon ages from this pluton are both internally and externally discordant, possibly suggesting a combination of lead loss and inheritance. The U/Pb zircon data suggest an age of about 150 Ma [Lahren, 1989; M.M. Lahren and R.A. Schweickert, unpublished data, 1989], although this is not a unique interpretation. Zircons from a less deformed part of the pluton are now being analyzed to obtain a more reliable age. Nonetheless, a 150-Ma age of crystallization for the granite of Bigelow Lake is supported by the new U/Pb zircon age on diorite from the comagmatic gabbroic complex (described above, Table 1).

STRUCTURAL GEOLOGY

Detailed descriptions of structure and possible regional correlations of deformational events are discussed by Lahren [1989] and Lahren and Schweickert (manuscript in preparation, 1990). Only a brief structural overview is included here. The structural history of Snow Lake pendant is separable into four penetrative deformational events and at least two nonpenetrative deformational events. The units correlated with the Lower Triassic Fairview Valley Formation were involved in all deformation except for the first, D_1.

The oldest deformational event, D_1, resulted in the development of asymmetric, isoclinal folds and the pervasive development of a composite fabric consisting of bedding (S_0) and S_1 compositional layering in the Stirling Quartzite, Wood Canyon Formation, Zabriskie Quartzite, and Carrara Formation. The asymmetric nature of folding during this event did not result in major stratigraphic inversion. D_1 deformation was most likely associated with a cryptic episode of thrust displacement, because large structural relief is suggested by the deposition of the Lower Triassic Fairview Valley Formation unconformably on the Precambrian Stirling Quartzite. The vergence of D_1 structures varies widely because of reorientation by later deformational events. D_1 probably was pre-Early Triassic, based on the inferred Early Triassic age of the Fairview Valley Formation, and post-Middle Cambrian, the age of the Carrara Formation.

D_2 deformation affected all of the metasedimentary rocks in Snow Lake and Sachse Monument pendants. The D_2 deformational event resulted in the development of the megascopic, northeast-vergent duplex structure [Lahren, 1989]. This event involved both synchronous and progressive development of northeast-vergent D_2 thrusts (Figures 2 and 7) and F_2 folds and associated foliations. Folding outlasted movement of the exposed thrusts and deformed the entire duplex structure. D_2 deformation occurred after the Early Triassic and prior to 150 Ma. Subsequent to D_2 deformation and thrust imbrication of all rocks in Snow Lake and Sachse Monument pendants, the gabbroic complex, the granite of Bigelow Lake, and dikes of the Independence dike swarm were emplaced as a comagmatic suite.

D_2 folds and thrusts, the gabbroic complex, the granite of Bigelow Lake, and the Independence dikes are deformed by northwest trending F_3 folds and S_3 foliations, and by east-west trending F_4 folds. The superposition of these two distinct younger fold generations is responsible for much of the domal outline of the Snow Lake structural window. D_3 and D_4 deformation occurred between intrusion of the Independence dike swarm and the granodiorite of Lake Harriet, therefore between 148 and about 115-120 Ma (preliminary U/Pb zircon age of granodiorite of Lake Harriet - J.M. Mattinson, unpublished data, 1990).

REGIONAL RELATIONS

Contrasts Between Snow Lake Pendant and Rocks in Surrounding Areas

The metamorphic rocks at Snow Lake pendant are dissimilar in lithology, environment of deposition, structure, and tectonic setting from the Shoo Fly Complex to the west, rocks of the Saddlebag Lake pendant to the east, and Upper Triassic to Lower Jurassic quartzites of the "Kings sequence" to the south.

Shoo Fly Complex. The lower Paleozoic Shoo Fly Complex, an extensive unit within the western Sierra metamorphic belt, is a polyphase-deformed assemblage of quartzite, quartzofeldspathic gneiss, garnet schist, calc-silicate rock, marble, chert, and rare amphibolite. These rocks are associated with Paleozoic orthogneisses of granitic, syenitic, and gabbroic composition. The metasedimentary rocks within the Shoo Fly Complex underwent seven phases of superimposed deformation, with the earliest phase of deformation predating the intrusion of the Paleozoic orthogneisses [Merguerian, 1985; Merguerian and Schweickert, 1987]. Distinctive dikes of the 160-Ma Sonora dike swarm intruded the Shoo Fly Complex. In the northern Sierra, the Shoo Fly Complex consists mainly of eugeoclinal rocks, including melange, feldspathic sandstones, volcanic rocks, and chert [Schweickert et al., 1984b]. Rocks of Snow Lake and Sachse Monument pendants are lithologically dissimilar to, and structurally simpler than, rocks of the Shoo Fly Complex.

Saddlebag Lake pendant. Saddlebag Lake pendant, 25 km east of Snow Lake pendant (Figure 1), exposes a different sequence of eugeoclinal rocks that represent continuations of the Sonoma and Antler orogenic belts from west-central Nevada [Schweickert and Lahren, 1987]. Lower Paleozoic rocks of the Antler orogenic belt consist of phosphatic chert, shale, siltstone, and argillite with minor lenses of quartzite, calcarenite, and basalt. Upper Paleozoic rocks of the Sonoma orogenic belt include metagabbro and ultramafic rocks, basaltic pillow lava, pillow breccia and chert-argillite breccia of the Golconda allochthon. The oldest rocks in Saddlebag Lake pendant have experienced only three phases of deformation [Schweickert and Lahren, 1987].

Saddlebag Lake pendant also contains extensive exposures of Triassic to Jurassic metavolcanic and metasedimentary rocks that are part of the early Mesozoic continental-margin magmatic arc. A presumed continuation of these metavolcanic rocks lies to the east of Snow Lake pendant, although the relationship between these rocks and Snow Lake pendant is unknown as the granodiorite of Lake Harriet separates the two areas. It is noteworthy that Saddlebag Lake pendant lacks dikes of the Independence dike swarm (R.A. Schweickert and M.M. Lahren, unpublished data, 1989).

Sierran Upper Triassic to Lower Jurassic quartzites ("Kings sequence"). As originally defined by Bateman and Clark [1974], the "Kings sequence" included presumed Upper Triassic to Lower Jurassic metasedimentary and metavolcanic rocks exposed in a series of roof pendants that occur discontinuously from south of Yosemite Valley to the Mineral King pendant, a distance of approximately 150 km. The southern pendants, such as Mineral King pendant, contain metasedimentary rocks together with interstratified volcanic and metasedimentary rocks, and Late Triassic to Early Jurassic fauna [Bateman and Clark, 1974; Saleeby et al., 1978]. However, the northern pendants contain sequences of metasedimentary rocks that include thick cross-bedded quartzites, schists, marbles, and calc-silicate rocks that were originally thought to be early Paleozoic in age [Kistler and Bateman, 1966; Girty, 1985].

As noted above (see section on basis for age and correlation of units), we consider the northern pendants of the so-called "Kings sequence" [Bateman and Clark, 1974] such as Boyden Cave, Patterson Mountain, and Dinkey Creek pendants, to consist of Precambrian to Cambrian strata of the Snow Lake block (Figure 6) [Lahren and Schweickert, 1989; Lahren, 1989]. Late Triassic to Early Jurassic ammonites found at Boyden Cave [Jones and Moore, 1973; Saleeby et al., 1978] appear to have been collected from the matrix and blocks within a chaotic melange unit that separates the older, shallow-water units from younger, deep-water, metasedimentary and interstratified metavolcanic and metasedimentary rocks [Girty, 1985; unpublished data, 1988].

We propose that the southern roof pendants of the "Kings sequence," which contain a Late Triassic to Early Jurassic fauna, partly consist of a distinctly younger sequence of rocks than those exposed in the northern pendants (Figure 6). These southern pendants are characterized by metavolcanic rocks and immature metasedimentary rocks and apparently do not contain quartzites of comparable thickness or tectonic setting as those in the northern pendants [Saleeby et al., 1978; Busby-Spera, 1984]. The lower Kaweah River, Yokohl Valley, Tule River, Kern Canyon, Isabella, and Tehachapi pendants may also belong in part to this younger sequence of Upper Triassic to Lower Jurassic rocks [Saleeby et al., 1978; Busby-Spera, 1984]. We refer to the rocks of these pendants informally as the "Isabella sequence" (Figure 6).

Summary. Rocks of Snow Lake pendant, together with possibly correlative pendants to the south (Snow Lake block), are miogeoclinal rocks of a passive margin sequence and are sandwiched between deep marine metasedimentary rocks of the Antler and Sonoma orogenic belts to the east and the Shoo Fly Complex to the west.

In addition, the absence of interstratified volcanic rocks and the predominance of thick, clean quartzites within the sequence at Snow Lake pendant strongly argue against an origin within the Mesozoic continental-margin magmatic arc environment represented by Upper Triassic to Lower Jurassic rocks of eastern California. This does not preclude the possibility that Mesozoic volcanic rocks could have once overlain the miogeoclinal rocks in Snow Lake pendant and other pendants within the Snow Lake block. In fact, Mesozoic metavolcanic rocks crop out east of Snow Lake pendant; their structural and/or stratigraphic relation to Snow Lake pendant is now under study.

Alternative Source Areas and the Western Mojave

From the preceding discussion, it is readily apparent that the rocks of Snow Lake pendant are out of place and unrelated to rocks to the east and west. It is unlikely that the metasedimentary rocks of Snow Lake pendant were derived from areas 100 to 200 km to the southeast either, because quartzite-poor Precambrian and lower Paleozoic rocks of the Inyo facies separate Snow Lake from rocks of the Death Valley facies in eastern California (Figure 6) [Stewart, 1970]. Still farther to the south, where rocks of the Death Valley and Inyo facies are not exposed, allochthonous eugeoclinal rocks of southeastern Sierra pendants on the Kern Plateau [Dunne et al., 1988] and the El Paso Mountains [Carr et al., 1981, 1982; Carr and Christiansen, 1984] lie between the Snow Lake block and rocks of the Death Valley and Inyo facies to the east (Figure 6).

A search for possible source areas for the rocks of Snow Lake pendant leads to the southwestern Mojave Desert (Figure 6). The western Mojave Desert is the only region in the southwestern Cordillera where rocks of the Death Valley facies approach the post-Triassic continental margin [Stewart and Poole, 1975; Miller, 1981a, b], thus making the western Mojave a viable source region for stratigraphic units of Snow Lake pendant and correlative pendants to the south (Figure 6).

DIRECT COMPARISON WITH THE WESTERN MOJAVE

The western Mojave shares six other important similarities with Snow Lake pendant that reinforce our correlation of the Proterozoic and Lower Cambrian rocks. These similarities include (1) the presence of a possible Lower Triassic overlap sequence (Fairview Valley Formation), containing distinctive monzonite clasts, (2) the presence of dikes of the Independence dike swarm, (3) inferred Precambrian basement based on similar initial $^{87}Sr/^{86}Sr$ ratios on intrusive rocks, (4) Late Jurassic gabbroic complexes, (5) possible eugeoclinal rocks, and (6) similar pre-Miocene structural configuration.

We stress that several of these features at Snow Lake pendant, including the monzonite clasts in the Fairview Valley Formation, the 150-Ma Independence dike swarm, the 148-Ma gabbroic complex, possible eugeoclinal rocks, and the structural configuration of eugeoclinal rocks, were not documented at the time Lahren and Schweickert [1988b,1989] made the initial correlation with the western Mojave. Instead, these features were predicted to exist based upon the correlation, and subsequent detailed studies at Snow Lake have now revealed their presence.

Fairview Valley Formation

The Lower Triassic Fairview Valley Formation of the western Mojave Desert at Black Mountain and Quartzite Mountain near Victorville (Figure 6) unconformably overlies the folded and metamorphosed miogeoclinal strata, as does the unit we have designated Fairview Valley Formation in Snow Lake pendant (described above) (Figure 2). In both areas, a polymict basal conglomerate is overlain by a thick section of distinctive rusty orange-weathering calcareous sandstone, siltstone and mudstone, siltstone, and silty limestone. In addition, the Fairview Valley Formation at Snow Lake contains monzonite clasts that are a distinctive feature of the formation in the Mojave [Miller, 1978, 1981a, b; Walker, 1985; Lahren, 1989; M.M. Lahren and R.A. Schweickert, unpublished data, 1989]. No plutonic rocks petrographically similar to the monzonite clasts at Snow Lake pendant have been identified anywhere near Snow Lake pendant within the Sierra Nevada batholith.

The Fairview Valley Formation at Snow Lake most closely resembles the section at Black Mountain, 20 km east of Quartzite Mountain, although an upper thick limestone cobble conglomerate which occurs at Black Mountain is not present in Snow Lake pendant. This may be because the top of the section at Snow Lake has been cut out by the granodiorite of Lake Harriet (Figure 2); the preserved stratigraphic thickness at Snow Lake is only about 500 m, as compared to a structural thickness of 1,150 m at Black Mountain [Miller, 1981a, b].

Depositional environments of parts of the Fairview Valley Formation have been interpreted as either shallow marine or lacustrine in both the Mojave Desert and Snow

Lake pendant [Miller, 1978, 1981a, b; Lahren, 1989]. We infer that the upper part of the Fairview Valley Formation, which was interpreted to have been deposited in an alluvial fan environment [Miller, 1978], is not present at Snow Lake pendant. In addition, preliminary U/Pb data [J.M. Mattinson, et al., unpublished data, 1990] shows that dikes of the Independence dike swarm also cut the Fairview Valley Formation at Black Mountain. We are unaware of any other stratigraphic units in the Sierra or eastern California that share this same combination of attributes.

Independence Dike Swarm

The dike swarm at Snow Lake pendant (described above) was originally correlated with the Independence dike swarm in the western Mojave and eastern California on the basis of petrographic and chemical similarities [Lahren, 1989; Lahren and Schweickert, 1989]. Our new U/Pb zircon age of 150 Ma has confirmed this correlation (see above).

In the eastern Sierra, the Independence dike swarm extends northward from the Garlock fault to the vicinity of Pine Creek pendant. The swarm does not intrude Jurassic and older rocks that occur north of the Pine Creek area [Chen and Moore, 1979, 1982], in the Mount Morrison and Ritter Range pendants [Rinehart and Ross, 1964; Huber and Rinehart, 1965; Kistler, 1966; Fiske and Tobisch, 1978; Bateman et al., 1983], or in Saddlebag Lake pendant (R.A. Schweickert and M.M. Lahren, unpublished data, 1989) (Figure 6). In fact, dikes of the Independence dike swarm are absent in rocks of appropriate age over a distance of 100 km, making it unlikely that the dikes in Snow Lake pendant represent a simple northwesterly continuation of the Independence dike swarm of eastern California. The western Mojave Desert and the San Bernardino Mountains are the only areas where rocks of the Death Valley facies and the Fairview Valley Formation are cut by dikes of the Independence dike swarm (Figure 6) [Miller, 1981a, b; Karish et al., 1987; Cameron, 1982; James, 1987, 1989].

Initial $^{87}Sr/^{86}Sr$ Ratios

Snow Lake pendant, correlative pendants to the south, and the western Mojave-San Bernardino Mountain areas are located where initial $^{87}Sr/^{86}Sr$ ratios of granitic rocks are greater than 0.706 [Kistler and Peterman, 1973, 1978; Kistler et al., 1981]. The initial $^{87}Sr/^{86}Sr = 0.706$ line has been commonly interpreted to approximate the edge of Precambrian continental crust and the outer edge of Precambrian to Paleozoic miogeoclinal sedimentation [Kistler and Peterman, 1973, 1978; Kistler et al., 1981]. These data suggest that granitic rocks in both areas were intruded into Precambrian basement overlain by Precambrian and Cambrian miogeoclinal sediments. Specific values of the initial $^{87}Sr/^{86}Sr$ ratios in the two areas probably reflect differences in the types, ages, and amount of contamination of individual plutons in different areas. The key point is that both areas can be presumed on the basis of independent isotopic data to be underlain by Precambrian continental crust or by sedimentary rocks derived from Precambrian crust.

Gabbroic Complexes

Recent work of Miller and Sutter [1981], Glazner et al. [1989], and Smith [1989] has focussed new attention on several distinctive gabbroic complexes at Iron Mountain, Lane Mountain, Goldstone, and the Shadow Mountains in the western Mojave Desert (Figure 6). These complexes include characteristic poikilitic hornblende gabbros, which are associated with minor amounts of granite, and are locally intruded by dikes of muscovite-garnet granite at Iron and Lane Mountains. The gabbro near Goldstone has yielded a 148-Ma hornblende $^{40}Ar/^{39}Ar$ cooling age [Miller and Sutter, 1981].

Significantly, the gabbroic complex along the southern edge of Snow Lake pendant (see above) (Figure 2) is petrographically similar to the gabbroic complexes in the western Mojave and contains dikes of muscovite-garnet granite. In addition, the granite of Bigelow Lake is similar to deformed granites associated with gabbroic complexes in the Mojave. New geochronologic data, presented here, confirms that the Snow Lake gabbroic complex is the same age as the reported age of the gabbro at Goldstone. Additional geochemical studies are underway to test this correlation. Clearly, gabbroic rocks are not unique to either area, but the association of 148-Ma gabbroic complexes with many other distinctive features in both areas (discussed herein) probably argues for a unique match.

Eugeoclinal Rocks and Pre-Miocene Structural Configuration

Eugeoclinal rocks of Sachse Monument pendant structurally overlie the miogeoclinal rocks of Snow Lake pendant, and the fault is intruded by the Late Jurassic gabbroic complex as shown in Figure 7 (M.M. Lahren and R.A. Schweickert, unpublished data, 1989), and therefore appear to occupy a structural position analogous to that of eugeoclinal rocks in the pre-Tertiary western Mojave.

Glazner et al. [1989] have argued that restoration of 40 km of slip on the Waterman Hills detachment fault places the eugeoclinal rocks of the western Mojave structurally above and possibly west of the miogeoclinal rocks. In

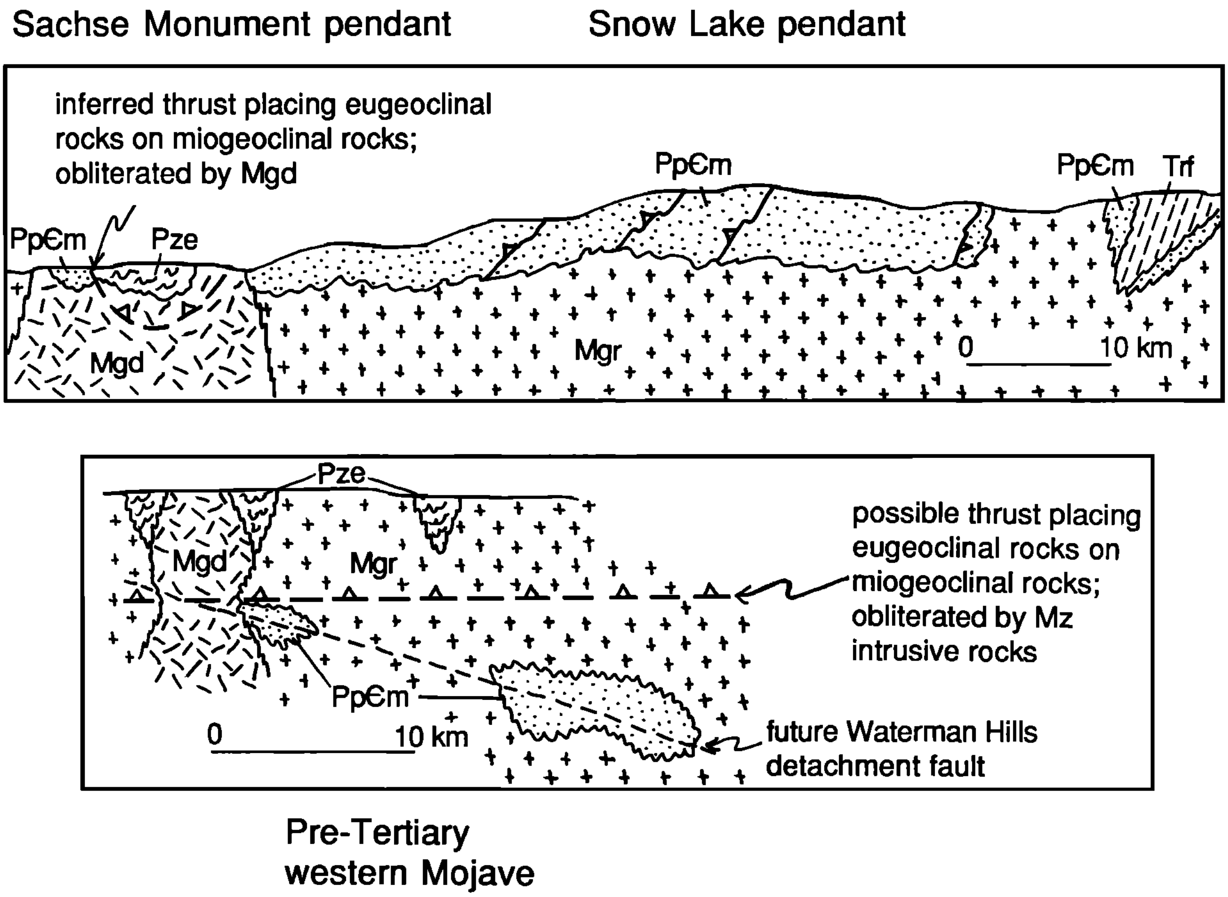

Fig. 7. Comparison of present-day structural configuration of Snow Lake pendant with inferred pre-Tertiary structure of part of the western Mojave Desert area. (Top) Schematic SW-NE cross section of Snow Lake and Sachse Monument pendants. (Bottom) Schematic, restored E-W section of area near Waterman Hills, after removal of 40 km of normal slip on Waterman Hills detachment fault after Glazner et al. [1989]. Abbreviations are Pze, eugeoclinal Paleozoic and Paleozoic(?) rocks; PpЄm, miogeoclinal Proterozoic and Paleozoic rocks; Trf, Triassic(?) Fairview Valley Formation; Mgd, Jurassic gabbroic complexes; and Mgr, Mesozoic granitic rocks.

their restoration, Figure 7 (bottom), a Late Jurassic gabbroic complex obliterates the presumed thrust between the eugeoclinal and miogeoclinal/cratonal rocks [Glazner et al., 1989]. We think it is highly significant that Snow Lake and Sachse Monument pendants preserve the same structural configuration as that in the western Mojave which existed prior to movement on the Waterman Hills detachment (e.g., pre-middle Miocene) (Figure 7).

Discussion of Structural History

The structural histories of Snow Lake pendant and the western Mojave do not appear to be as similar as previously suggested by Lahren and Schweickert [1989], although if one accepts the presence of Fairview Valley Formation at Snow Lake pendant, the early structural histories of Snow Lake pendant and the miogeoclinal rocks near Victorville seem to be broadly similar. The uppermost Proterozoic to Middle Cambrian strata at Snow Lake pendant were involved in isoclinal folding and possibly a cryptic thrusting event prior to the deposition of the Fairview Valley Formation, constraining this first deformational event as pre-Early Triassic. Younger deformational events, involving all of the rocks within Snow Lake pendant, occurred between Triassic and Late Jurassic or Early Cretaceous times.

In the Mojave region, the Precambrian and Cambrian miogeoclinal rocks at Quartzite Mountain and in the Black Mountain/Sidewinder Mountain area were also isoclinally folded prior to deposition of the Fairview Valley Formation [Miller, 1981a, b]; and as at Snow Lake pendant, the original orientation of F_1 folds is uncertain

[Miller, 1981a, b]. In the western Mojave, the Fairview Valley Formation was subsequently deformed, although it is not clear how these younger events correlate with structures in the older miogeoclinal strata [Miller, 1981a, b].

A detailed comparison of the structural histories of the western Mojave and Snow Lake pendant is not possible at present because the structural history is not yet known in detail in the Mojave, and structural relations in that area appear highly variable [Miller, 1981a, b]. In any case, we suspect that some of the younger deformational events may not be correlative because they could have occurred during or after translation of the Snow Lake block from the Mojave region.

Summary

Correlation of units at Snow Lake pendant with rocks of the western Mojave (Figure 6) is supported by numerous lines of evidence reported previously, including (1) lithologic similarities, (2) stratigraphic sequence, (3) approximate stratigraphic thicknesses, (4) *Skolithos* in the correct stratigraphic position, (5) environments of deposition, (6) provenance of the older rocks and petrographic character of quartz arenites (7) Precambrian continental crust inferred from initial $^{87}Sr/^{86}Sr$ ratios of granitic rocks, 8) passive margin tectonic setting, 9) probable Fairview Valley Formation, and (10) possible Independence dike swarm.

Recent work suggests important new similarities including (1) clasts of pre-Jurassic monzonitic plutonic rocks within the Fairview Valley Formation, (2) 150-Ma U/Pb zircon ages on dikes of the Independence dike swarm at Snow Lake pendant, (3) distinctive gabbroic rocks at Snow Lake pendant identical in age (148-150 Ma) and lithology to those in the western Mojave Desert, (4) eugeoclinal rocks located southwest of Snow Lake pendant that may be correlative with similar rocks in the western Mojave Desert, and (5) the preserved pre-Miocene structural configuration of the western Mojave desert. While none of these similarities alone is a compelling reason for correlation, the large number of unique features in common between the two areas provides strong support of our hypothesis.

MOJAVE-SNOW LAKE FAULT

The correlations discussed in this paper seemingly require that Snow Lake pendant and the Snow Lake block were translated northward from the western Mojave region. Presumably this translation occurred along a cryptic pre-batholithic or intrabatholithic strike-slip fault. Lahren and Schweickert [1989] and Lahren [1989] referred to this proposed fault as the Mojave-Snow Lake fault.

Magnitude of Displacement

Lahren and Schweickert [1989] originally inferred that the Mojave-Snow Lake fault displaced the rocks at Snow Lake pendant as much as 450-500 km northward from the vicinity of Victorville or the San Bernardino Mountains (Figure 6). However, restoration of the Waterman Hills detachment fault in the Mojave Desert moves the miogeoclinal rocks and the Independence dike swarm from their present locations near Victorville northeast towards Lane Mountain and Goldstone [Glazner et al., 1989]. With this restoration, displacement on the Mojave-Snow Lake fault is decreased to approximately 400 km, using areas west of Victorville-Iron Mountain-Shadow Mountains-Lane Mountain as the likely areas of origin [Lahren, 1989].

Timing

The exact timing of movement on the Mojave-Snow Lake fault is not yet tightly constrained. Displacement probably occurred after 150 Ma, the age of the Independence dike swarm [Chen and Moore, 1979, 1982; this paper], and prior to 110 Ma, the age of major Cretaceous plutons within the central part of Sierran batholith [Stern et al., 1981; Chen and Moore, 1982]. Movement on the fault may not have been continuous and could have occurred in more than one stage. However, using the above estimates of timing and magnitude, the average displacement rate may have been about 1.1 cm/yr, which is comparable to rates of displacement of modern intraarc strike-slip faults [Jarrard, 1986b].

Location

The fault originally must have lain to the west of eugeoclinal rocks of the Antler and Sonoma orogenic belts in Saddlebag Lake pendant [Schweickert and Lahren, 1987] and west of eugeoclinal rocks in the Kern Plateau area [Dunne et al., 1988], the El Paso Mountains [Carr et al., 1982; Carr and Christiansen, 1984], and the Mojave Desert at Pilot Knob Valley, Goldstone, and Lane Mountain [Carr et al., 1981] (Figure 6). The fault would also have lain west of miogeoclinal rocks at Victorville [Stewart and Poole, 1975; Miller, 1981a, b], in the Shadow Mountains [Brown, 1983; Martin and Walker, 1990], and in the San Bernardino Mountains [Cameron, 1982].

The location of the Mojave-Snow Lake fault to the north of Snow Lake is uncertain. The fault may have continued directly north of Snow Lake through the Lake Tahoe region. However, this seems unlikely because the Lower Jurassic Sailor Canyon Formation in the northern Sierra and related rocks of western Nevada probably formed a continuous overlap sequence in those regions [Lahren and Schweickert, 1989] (Figure 6). Until evidence of a major fault in the northern Sierra region is found, we maintain the earlier interpretation [Lahren and Schweickert, 1989; Lahren, 1989] that the northward continuation of the Mojave-Snow Lake fault has been offset right-laterally on the Coaldale and Excelsior faults [Stewart, 1985]. A combined offset of about 110 km on the Coaldale and Excelsior faults moves the trace of the Mojave-Snow Lake fault to the approximate position of the Pine Nut fault (Figure 6) [Oldow, 1983; 1984, Oldow et al., 1984], although the Mojave-Snow Lake fault and the Pine Nut fault need not have been the same structure. In any case, Tertiary extension and possible oroclinal bending in western Nevada probably would have dismembered and reoriented the Mojave-Snow Lake fault. The location and geometry of the Mojave-Snow Lake fault are discussed in more detail by Lahren [1989] and Schweickert and Lahren [this issue].

Tectonic Significance

The Mojave-Snow Lake fault probably originated as a trench-linked, strike-slip fault that developed parallel to the continental margin in response to right-oblique subduction during the Early Cretaceous in an area that was thermally weakened by Mesozoic magmatic activity. We note that relative plate motions during this time are highly equivocal and that right-oblique displacement cannot be precluded (Engebretson et al., 1985; Debiche et al., 1987). Such right-oblique subduction could have resulted in the dextral translation of a tectonic sliver of North American crust (Snow Lake block) along the Mojave-Snow Lake fault, which was located along the axis of the Mesozoic continental-margin magmatic arc. The Snow Lake block (Figure 6) represents a sliver of continental crust similar in size to the Salinian block in coastal California, with an estimate of displacement comparable in magnitude to the post-Middle Miocene displacement on the San Andreas fault. Subsequent to or during the last stages of displacement of the Snow Lake block, the late Early to Late Cretaceous Sierra Nevada batholith was emplaced along or near the trace of this intrabatholithic fault (cf. Figures 1 and 6). A modern analog of the Mojave-Snow Lake fault would be the Semangko fault, which follows the axis of the Sumatran magmatic arc in southeast Asia, decoupling a sliver of crust from the Asian plate [Fitch, 1972; Beck, 1986]. According to Jarrard [1986a], strike-slip faulting (related to oblique convergence) along magmatic arcs is facilitated by high geothermal gradients, thin lithosphere, and thick crust.

CONCLUSIONS

Many lines of evidence from the central Sierra Nevada suggest that the metasedimentary rocks of Snow Lake pendant are correlative with miogeoclinal rocks of the Death Valley facies and their overlap sequence, the Fairview Valley Formation, in the western Mojave Desert. This correlation leads to the hypothesis that Snow Lake pendant and correlative pendants to the south (Piute Mountain, Glen Aulin, May Lake, Patterson Mountain, Dinkey Creek, and the western part of Boyden Cave) are part of a slice of continental crust, the Snow Lake block, that has been translated approximately 400 km northward along the dextral Mojave-Snow Lake fault. Available evidence indicates that translation of the Snow Lake block took place during the Early Cretaceous. Subsequent to or during the last stages of movement on the Mojave-Snow Lake fault, the composite Cretaceous Sierra Nevada batholith was intruded along the general trend of the fault.

This hypothesis has major implications for tectonic and paleogeographic reconstructions of the western metamorphic belt of the Sierra Nevada and allochthonous terranes to the west, because Early Cretaceous displacement requires that all of these terranes were attached to the Snow Lake block before transport. If our interpretations are correct, rethinking of many existing tectonic and paleogeographic syntheses is in order. For example, certain orogenic belts and terranes in western Nevada and eastern California may have counterparts that have been displaced as much as 400 km northward. Restoration of slip on the Mojave-Snow Lake fault and discussion of tectonic and paleogeographic implications are presented by Schweickert and Lahren [this issue].

The model presented in this paper is speculative, but several predictions based upon it have been confirmed, as reported herein. Several additional studies are in progress to test further and refine the correlations we have proposed here. We hope that our findings will encourage others to undertake new studies to explore these interpretations or to develop alternatives.

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REFERENCES

Ague, J.J., and G.H. Brimhall, Granites of the batholiths of California: Products of local assimilation and regional-scale crustal contamination, *Geology, 15,* 63-66, 1987.

Ague, J.J., and G.H. Brimhall, Regional variations in bulk chemistry, mineralogy, and the compositions of mafic and accessory minerals in the batholiths of California, *Geol. Soc. Am. Bull., 100,* 891-911,1988a.

Ague, J.J., and G.H. Brimhall, Magmatic arc asymmetry and distribution of anomalous plutonic belts in the batholiths of California: Effects of assimilation, crustal thickness, and depth of crystallization, *Geol. Soc. Am. Bull., 100,* 912-927, 1988b.

Bateman, P.C., and L.D. Clark, Stratigraphic and structural setting of the Sierra Nevada batholith, California, *Pac. Geol., 8,* 79-89, 1974.

Bateman, P.C., R.W. Kistler, D.L. Peck, and A. Busacca, Geologic map of the Tuolumne Meadows quadrangle, Yosemite National Park, California, *U.S. Geol. Surv. Geol. Quad. Map, GQ-1570,* 1983.

Beck, M.E., Jr., Model for late Mesozoic-early Tertiary tectonics of coastal California and western Mexico and speculations on the origin of the San Andreas fault, *Tectonics, 5,* 49-64, 1986.

Bennett, V.C., and D.J. DePaolo, Proterozoic crustal history of the western United States as determined by neodymium isotopic mapping, *Geol. Soc. Am. Bull., 99,* 674-685, 1987.

Brown, H.J., Possible Cambrian miogeoclinal strata in the Shadow Mountains, western Mojave Desert, California, *Geol. Soc. Am. Abstr. Programs, 15,* 413, 1983.

Busby-Spera, C.J., The lower Mesozoic continental margin and marine intra-arc sedimentation at Mineral King, California, in *Tectonics and Sedimentation Along the California Margin,* vol. 38, edited by J.K. Crouch and S.B. Bachman, pp. 135-156, Pacific Section, Society of Economic Paleontologists and Mineralogists, Los Angles, Calif., 1984.

Carr, M.D., and R.L. Christiansen, Pre-Cenozoic geology of the El Paso Mountains, southwestern Great Basin, California--A Summary, in *Western Geological Excursions,* vol. 4, edited by J. Lintz, Jr., pp. 84-93, Geological Society of America, Reno, Nev., 1984.

Carr, M.D., F.G. Poole, A.G. Harris, and R.L. Christiansen, Western facies Paleozoic rocks in the Mojave Desert, California, *U.S. Geol. Surv. Open File Rep., 81-503,* 15-17, 1981.

Carr, M.D., F.G. Poole, and R.L. Christiansen, Geologic framework of Paleozoic eugeoclinal and transitional assemblage rocks in north central Mojave Desert, southern California, *Geol. Soc. Am. Abstr. Programs, 14,* 154, 1982.

Cameron, C.S., Stratigraphy and significance of the upper Precambrian Big Bear Group, in *Geology of Selected Areas in the San Bernardino Mountains, Western Mojave Desert, and Southern Great Basin, California,* edited by J.B. Cooper, pp. 5-20, Geological Society of America, Anaheim, Calif., 1982.

Chen, J.H., and J.G. Moore, Late Jurassic Independence dike swarm in eastern California, *Geology, 7,* 129-133, 1979.

Chen, J.H., and J.G. Moore, Uranium-lead isotopic ages from the Sierra Nevada batholith, California, *J. Geophys. Res., 87,* 4761-4784, 1982.

Debiche, M.G., A. Cox, and D. Engebretson, The motion of allochthonous terranes across the North Pacific basin, *Spec. Pap. Geol. Soc. Am. 207,* 49 p., 1987.

DePaolo, D.J., A neodymium and strontium isotopic study of the Mesozoic calc-alkaline granitic batholiths of the Sierra Nevada and Peninsular Ranges, California, *J. Geophys. Res., 86,* 10470-10488, 1981.

Dunne, G.C., C.A. Suczek, B.E. Dybel, M. Godwin, J.C. Kofoed, J.C. Lindquist, and B. Swanson, Newly recognized Paleozoic eugeoclinal strata in the southern Sierra Nevada, California, *Geol. Soc. Am. Abstr. Programs, 20,* A149, 1988.

Engebretson, D.C., A. Cox, and R.G. Gordon, Relative motions between oceanic and continental plates in the Pacific basin, *Spec. Pap. Geol. Soc. Am. 206,* 59 p., 1985.

Fiske, R.S., and O.T. Tobisch, Paleogeographic significance of volcanic rocks of the Ritter Range pendant, central Sierra Nevada, California, in *Mesozoic Paleogeography of the Western United States, Pac. Coast Paleogeogr. Symp.,* vol. 2, edited by D.G Howell and K.A. McKougall, pp. 209-221, Pacific Section, Society of Economic Paleontologists and Mineralogists, Los Angeles, Calif., 1978.

Fitch, T.J., Plate convergence, transcurrent faults, and internal deformation adjacent to Southeast Asia and the western Pacific, *J. Geophys. Res.*, *77*, 4432-4461, 1972.

Girty, G.H., Shallow marine deposits in Boyden Cave roof pendant, westcentral Sierra Nevada, *Calif. Geol.*, *38*, 51-55, 1985.

Glazner, A.F., J.M. Bartley, and J.D. Walker, Magnitude and significance of Miocene crustal extension in the central Mojave Desert, California, *Geology*, *17*, 50-53, 1989.

Huber, N.K., and C.K. Rinehart, Geologic map of the Devils Postpile quadrangle, California, *U.S. Geol. Surv. Geol. Quad. Map*, *GQ-437*, 1965.

Irving, T.N., and W.R.A. Baragar, A guide to the chemical classification of the common volcanic rocks, *Canadian Journal Earth Sciences*, *8*, 523-548, 1971.

James, E.W., Extension of the Independence dike swarm to the western Mojave Desert and eastern Transverse Ranges of California, *Geol. Soc. Am. Abstr. Programs*, *19*, 715, 1987.

James, E.W., Southern extension of the Independence dike swarm of eastern California, *Geology*, *17*, 587-590, 1989.

Jarrard, R.D., Relations among subduction parameters, *Rev. Geophys.*, *24*, 217-284, 1986a.

Jarrard, R.D., Terrane motion by strike-slip faulting of forearc slivers, *Geology*, *14*, 780-783, 1986b.

Jones, D.L., and J.G. Moore, Lower Jurassic ammonite from the south central Sierra Nevada, California, *J. Res. U.S. Geol. Surv.*, *1*, 453-458, 1973.

Karish, C.R., E.L. Miller, and J.F. Sutter, Mesozoic tectonic and magmatic history of the central Mojave, in Mesozoic Rocks of Southern Arizona and Adjacent Areas, edited by W.R. Dickinson and M.A. Klute, pp. 15-32, *Ariz. Geol. Soc. Dig.*, *18*, 15-32, 1987.

Kistler, R.W., Geologic map of the Mono Craters quadrangle, Mono and Tuolumne Counties, California, *U.S. Geol. Surv. Geol. Quad. Map*, *GQ-462*, 1966.

Kistler, R.W., and P.C. Bateman, Stratigraphy and structure of the Dinkey Creek roof pendant in the central Sierra Nevada, California, *U.S. Geol. Surv. Prof. Pap.*, *524-B*, 14 pp., 1966.

Kistler, R.W., and Z.E. Peterman, Variations in Sr, Rb, K, Na, and initial ^{87}Sr/^{86}Sr in Mesozoic granitic rocks and intruded wall rocks in central California, *Geol. Soc. Am. Bull.*, *84*, 3489-3512, 1973.

Kistler, R.W., and Z.E. Peterman, Reconstruction of crustal blocks of California on the basis of initial strontium isotopic compositions of Mesozoic granitic rocks, *U. S. Geol. Surv. Prof. Pap*, *1071*, 17 pp., 1978.

Kistler, R.W., A.C. Robinson, and R.J. Fleck, Mesozoic right-lateral fault in eastern California, *Geol. Soc. Am. Abstr. Programs*, *12*, 115, 1980.

Kistler, R.W., E.D. Ghent, and J.R. O'Neil, Petrogenesis of garnet two-mica granites in the Ruby Mountains, Nevada, *J. Geophys. Res.*, *86*, 10591-10606, 1981.

Krauskopf, K.B., Tungsten deposits of Madera, Fresno, and Tulare Counties, California, *Spec.Rep. Calif. Div. Mines Geol.*, *35*, 83 pp., 1953.

Lahren, M.M., Tectonic studies of the Sierra Nevada: Structure and stratigraphy of miogeoclinal rocks in Snow Lake pendant, Yosemite-Emigrant wilderness; and TIMS analysis of the Northern Sierra terrane, Ph.D. dissertation, 260 pp., Univ. of Nev., Reno, 1989.

Lahren, M.M., and R. A. Schweickert, Possible Proterozoic to Lower Cambrian miogeoclinal rocks in Snow Lake pendant (SNLP), northern Yosemite National Park, Sierra Nevada, California, *Geol. Soc. Am. Abstr. Programs*, *20*, 174, 1988a.

Lahren, M.M., and R.A. Schweickert, Snow Lake pendant (SNLP), Yosemite-Emigrant Wilderness, Sierra Nevada, California: Evidence for major Early Cretaceous dextral translation of a continental crustal sliver, *Geol. Soc. Am. Abstr. Programs*, *20*, A272, 1988b.

Lahren, M.M., and R.A. Schweickert, Proterozoic and Lower Cambrian miogeoclinal rocks of Snow Lake pendant, Yosemite-Emigrant Wilderness, Sierra Nevada, California: Evidence for major Early Cretaceous dextral translation, *Geology*, *17*, 156-160, 1989.

Ludwig, K.R., Plotting and regression programs for isotope geochemists, for use with HP 86/87 microcomputers, *U.S. Geol. Surv. Open File Rep.*, *83-849*, 102 pp., 1983.

Martin, M. W., and J.D. Walker, New stratigraphic relationships from the Shadow Mountains, western Mojave desert: Implications for late Paleozoic paleogeography, *Geol. Soc. Am. Abstr. Programs*, *22*, 64, 1990.

Mattinson, J.M., U-Pb ages of zircons: A basic examination of error propagation, *Chem. Geol.*, *66*, 151-162, 1987.

Merguerian, C., Stratigraphy, structural geology, and tectonic implications of the Shoo Fly Complex and the Calaveras-Shoo Fly thrust, central Sierra Nevada, California, Ph.D. dissertation, 255 pp., Columbia Univ., New York, N.Y., 1985.

Merguerian, C., Geology of the Sonora dike swarm, Sierra Nevada foothills, California, *Geol. Soc. Am. Abstr. Programs*, *18*, 157, 1986.

Merguerian, C., and R.A. Schweickert, Paleozoic gneissic granitoids in the Shoo Fly Complex, central Sierra Nevada, California, *Geol. Soc. Am. Bull.*, *99*, 699-717, 1987.

Merritt, N.J., The Dinkey Creek pendant; central Sierra

Nevada California: A pre-Nevadan (?) deep crustal shear zone, *Geol. Soc. Am. Abstr. Programs, 17*, 369, 1985.

Miller, E.L., The Fairview Valley Formation: A Mesozoic intraorogenic deposit in the southwestern Mojave Desert, in *Mesozoic Paleogeography of the Western United States, Pac. Coast Paleogeogr. Symp.*, vol. 2, edited by D.G. Howell and K.A. McDougall, pp. 283-289, Pacific Section, Society of Economic Paleontologists and Mineralogists, Los Angeles, Calif., 1978.

Miller, E.L., Geology of the Victorville region, California: Summary, *Geol. Soc. Am. Bull.*, Part 1 *92*, 160-163, 1981a.

Miller, E.L., Geology of the Victorville region, California, *Geol. Soc. Am. Bull.*, Part II, *92*, 554-608, 1981b.

Miller, E.L., and J.F. Sutter, ^{40}Ar/^{39}Ar age spectra for biotite and hornblende from plutonic rocks in the Victorville region, California, *Geol. Soc. Am. Bull.*, Part I, *92*, 164-169, 1981.

Moore, J.G., and C.A. Hopson, The Independence dike swarm in eastern California, *Am. J. Sci., 259*, 241-259, 1961.

Nokleberg, W.J., Wallrocks of the central Sierra Nevada batholith, California: A collage of accreted tectono-stratigraphic terranes, *U.S. Geol. Surv. Prof. Pap., 1255*, 28 pp., 1983.

Oldow, J.S., Tectonic Implications of a late Mesozoic fold and thrust belt in northwestern Nevada, *Geology, 11*, 542-546, 1983.

Oldow, J.S., Evolution of a late Mesozoic back-arc fold and thrust belt, northwestern Great Basin, U.S.A., *Tectonophysics, 102*, 245-274, 1984.

Oldow, J.S., H.B. Avé Lallemant, and W.J. Schmidt, Kinematics of plate convergence deduced from Mesozoic structures in the western Cordillera, *Tectonics*, *3*, 201-227, 1984.

Palmer, A.R., and R.B. Halley, Physical stratigraphy and trilobite biostratigraphy of the Carrara Formation (Lower and Middle Cambrian) in the southern Great Basin, *U.S. Geol. Surv. Prof. Pap., 1047*, 131 pp., 1979.

Rinehart, C.D. and D.C. Ross, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California, *U.S. Geol. Surv. Prof. Pap., 385*, 106 pp., 1964.

Rose, R., Geology of the May Lake area, Yosemite National Park, Ph.D. dissertation, 215 pp., Univ. of Calif., Berkeley, 1957.

Saleeby, J.B., Ocean floor accretion and volcanoplutonic arc evolution of the Mesozoic Sierra Nevada, in *The Geotectonic Development of California*, edited by W.G. Ernst, pp. 132-182, Prentice-Hall, Englewood Cliffs, N.J., 1981.

Saleeby, J.B., S.E. Goodin, W.D. Sharp, C.J. Busby, Early Mesozoic paleotectonic-paleogeographic reconstruction of the southern Sierra Nevada region, in *Mesozoic Paleogeography of the Western United States, Pac. Coast Paleogeogr. Symp.*, vol. 2, edited by D.G. Howell and K.A. McDougall, pp. 311-336, Pacific Section, Society of Economic Paleontologists and Mineralogists, Los Angeles, Calif., 1978.

Saleeby, J. B., R.C. Speed, M.C. Blake, R.W. Allmendinger, P.B. Gans, R.W. Kistler, D.C. Ross, D.A. Stauber, M.L. Zoback, A. Griscom, D.S. McCulloch, A.H. Lachenbruch, R.B. Smith, and D.P. Hill, Centennial continent/ocean transect #10, C-2 central California offshore to Colorado Plateau, *Centennial Continent/Ocean Transect Ser.*, 10, 63 pp., Geological Society of America, Boulder, Colo., 1986.

Schweickert, R.A., Tectonic evolution of the Sierra Nevada Range, in *The Geotectonic Development of California*, edited by W.G. Ernst, pp. 87-131, Prentice-Hall, Englewood Cliffs, N.J., 1981.

Schweickert, R.A., and M.M. Lahren, Continuation of Antler and Sonoma orogenic belts to the eastern Sierra Nevada, California, and Late Triassic thrusting in a compressional arc, *Geology, 15*, 270-273, 1987.

Schweickert, R.A., and M.M. Lahren, Speculative reconstruction of the Mojave-Snow Lake fault: Implications for Paleozoic and Mesozoic orogenesis in the western United States, *Tectonics*, this issue.

Schweickert, R.A., and W.S. Snyder, Paleozoic plate tectonics of the Sierra Nevada and adjacent regions, in *The Geotectonic Development of California*, edited by W.G. Ernst, pp. 182-201, Prentice-Hall, Englewood Cliffs, N.J., 1981.

Schweickert, R.A., N.L. Bogen, G.H. Girty, R.E. Hanson, and C. Merguerian, Timing and structural expression of the Nevadan orogeny, Sierra Nevada, California, *Geol. Soc. Am. Bull., 95*, 967-979, 1984a.

Schweickert, R. A., D.S. Harwood, G.H. Girty, and R.E. Hanson, Tectonic development of the northern Sierra Terrane: An accreted late Paleozoic island arc and its basement, in *Western Geological Excursions*, vol. 4, edited by J. Lintz, Jr., pp. 1-65, Geological Society of America, Reno, Nev., 1984b.

Schweickert, R.A., C. Merguerian, and N.L. Bogen, Deformational and metamorphic history of Paleozoic and Mesozoic basement terranes in the western Sierra Nevada metamorphic belt, in *Metamorphism and Crustal Evolution of the Western United States*, edited by W.G. Ernst, pp. 789-822, Prentice-Hall, Englewood Cliffs, N.J., 1988.

Silberling, N.J., D.L. Jones, M.C. Blake, Jr., and D.G. Howell, Lithotectonic terrane map, western conterminous United States, *U.S. Geol. Surv. Misc. Field Stud. Map, MF-1874-C*, 1987.

Smith, D.K., Arcuate gabbroic intrusions of the Shadow Mountains, San Bernardino County, California, *Geol. Soc. Am. Abstr. Programs, 21*, 145, 1989.

Smith, G.I., Large lateral displacement on Garlock fault, California, as measured from offset dike swarm, *Bull. Am. Assoc. Pet. Geol., 46*, 85-104, 1962.

Stacey, J.S., and J.D. Kramers, Approximation of terrestrial lead isotope evolution by a two stage model, *Earth Planet. Sci. Lett., 26*, 207-221, 1975.

Steiger, R.H., and E. Jäger, Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology, *Earth Planet. Sci. Lett., 36*, 369-371, 1977.

Stern, T.W., P.C. Bateman, B.A. Morgan, M.F. Newell, and D.L. Peck, Isotopic U-Pb ages of zircon from the granitoids of the central Sierra Nevada, California, *U.S. Geol. Surv. Prof. Pap., 1185*, 17 pp., 1981.

Stewart, J.H., Upper Precambrian and Lower Cambrian strata in the southern Great Basin, California and Nevada, *U.S. Geol. Surv. Prof. Pap., 620*, 206 pp., 1970.

Stewart, J.H., East-trending dextral faults in the western Great Basin: An explanation for anomalous trends of pre-Cenozoic strata and Cenozoic faults,*Tectonics, 4*, 547-564, 1985.

Stewart, J.H., and F.G. Poole, Extension of the Cordilleran miogeosynclinal belt to the San Andreas fault, southern California, *Geol. Soc. Am. Bull., 86*, 205-211, 1975.

Stone, P., and C.H. Stevens, Pennsylvanian and Early Permian paleogeography of east-central California: Implications for the shape of the continental margin and the timing of continental truncation, *Geology, 16*, 330-333, 1988.

Walker, J.D., Permo-Triassic paleogeography and tectonics of the southwestern United States, Ph.D. dissertation, 224 pp., Mass. Inst. of Technol., Cambridge, 1985.

Walker, J.D., Permian and Triassic rocks of the Mojave Desert and their implications for timing and mechanisms of continental truncation, *Tectonics, 7*, 685-709, 1988.

Walker, J.D., M.W. Martin, J.M. Bartley, and A.F. Glazner, Middle to Late Jurassic deformation belt through the Mojave Desert, California, *Geol. Soc. Am. Abstr. Programs, 22*, 91, 1990a.

Walker, J.D., J.M. Bartley, M.W. Martin, and D.S. Coleman, Timing and kinematics of deformation in the Cronese Hills, California, and implications for Mesozoic structure of the southwestern Cordillera, *Geology, 18*, 554-557, 1990b.

Walker, M.G., Petrogenesis of the Tuolumne Peak pendant and its border igneous intrusives, central Sierra Nevada, Calif., M.S. thesis, 86 pp., Humboldt State Univ., Arcata, California, 1980.

Walker, R.G., Shelf and shallow marine sands, in *Facies Models, Geoscience Canada Reprint Ser.*, vol. 1, edited by R.G. Walker, pp. 141-170, Toronto Canada, 1984.

M.M. Lahren and R.A. Schweickert, Department of Geological Sciences, Mackay School of Mines, Mail Stop 168, University of Nevada, Reno, NV 89557-0138.

J.M. Mattinson, Department of Geological Sciences, University of California, Santa Barbara, CA 93106

J.D. Walker, Department of Geology, University of Kansas, Lawrence, KS 66045

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