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GEOLOGICAL SURVEY

Geology of Giant Forest - Lodgepole area, Sequoia National Park, California

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This report and map are preliminary and have not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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Introduction

This report and accompanying geologic map sheet briefly describe the geology of the Giant Forest and Lodgepole area in Sequoia National Park, California. The map and report are ancilliary to a detailed water resources study of Wolverton and Long Meadows. Our mapping, though more detailed, supports and reiterates most of the conclusions reached by Ross (1958) in his study of a larger area of Sequoia National Park, including the area covered by the present work. The map area covers parts of the Triple Divide Peak and Giant Forest 15 minute quadrangles, and includes 60 square miles.

The many important groves of Sequoia Gigantea (giant redwood trees) which occur within the mapped area attract a large number of park visitors each year. As a result much of the park development for camping, housing, and access is concentrated in this area. Consequently the general geology of this region should be of interest to the park visitors, ranger-naturalists, and land use planners; a less technical, more popular, report on the general geology of this important area is planned and will be based in large part on this report. Metamorphic rocks of controversial origin, and parts of two major sequences of granitic intrusions are highlights of the bedrock geology. The strongly "U"-shaped Tokopah Valley is a striking example of a canyon cut by glacial action. The Tahoe and Tioga moraines flanking the valley are perhaps the most easily accessible well-preserved late Pleistocene glacial deposits on the west side of the Sierra Nevada.

Metamorphic Rocks

Metamorphic rocks in the southwest corner of the map area occur as northwest-trending belts of 1) biotite-feldspar-quartz schist, 2) mafic (amphibolitic) schist, 3) foliated marble, 4) massive and foliated quartzite, and 5) calc-silicate schist. The probable original rock types from which these recrystallized rocks were derived are respectively 1) interlayered aluminous shale and thin quartz-rich sandstone beds, 2) mafic volcanics and associated mixed mafic volcanogenic and shaly sediments, 3) pure and slightly impure limestone, 4) medium to thick bedded quartz-rich sandstone with little to no interbedded shale, 5) calcareous siliceous shale. Contacts between units are sharp, with the exception of those between the mafic and micaceous quartzo-feldspathic schists. Excellent exposures of the contacts between metamorphic units can be visited in the vicinity of Admiration Point and Marble Falls. Foliation in schistose units and cleavage in massive units generally parallel contacts between units. Mineralogic data (Ross,1958) indicate a metamorphic grade of hornblende-hornfels facies or the equivalent andalusite-cordierite-muscovite subfacies of cordierite-amphibolite Abukuma-type regional metamorphism (Winkler, 1965).

Isoclinal folds a few meters in wave length, with moderately to strongly attenuated limbs and thickened hinges, are common in most metamorphic units. The fold hinges plunge steeply north through northwest and south through southeast. Excellent water-polished exposures of folds are present in the Marble and Middle Forks of the Kaweah River. Larger folds in quartzite and marble are present north-northeast of Admiration Point, and in marble and micaceous quartzo-feldspathic schist at Marble Falls. A very large fold in marble has been split by granodiorite and granite dikes on Deer Ridge.

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Small-scale interlayering of quartzite and micaceous quartzo-feldspathic schist (<5 cm thick) is characteristic of the micaceous schist units and is interpreted as relict sedimentary bedding. Limited intergradation between amphibolite and micaceous schist probably reflects mixed mafic volcanic and pelitic sediment sources.

The metamorphic rocks are intruded by the granodiorite of Giant Forest, as well as by older granodiorite and granite dikes that cannot be directly assigned to a major granitic intrusion. The older dikes are intruded by the dikes of the granodiorite of Giant Forest. Dikes of the granodiorite of Giant Forest are only moderately foliated, whereas the older dikes are highly foliated, locally schistose, and veined with quartz. This suggests that the older dikes pre-date the development of some foliation in the metamorphic rocks.

No fossils have been found in the metamorphic rocks. Lithologic similarity with fossiliferous rocks in the Boyden Cave and Mineral King Pendants is suggestive of a similar, late-Triassic and early-Jurassic age (Jones and Moore, 1973; Saleeby and others, 1978).

Mesozoic Granitic Rocks

Mesozoic granitic rocks of the Sierra Nevada Batholith underlie 95 percent of the map area. Fourteen discrete granitic intrusions, including parts of the 97-102 m.y. Sequoia intrusive sequence and the ~91 m.y. Mitchell Peak intrusive sequence (Chen and Moore, 1982), have been mapped. Relative ages of intrusions could generally be determined by contact relations. Nine of the 14 igneous plutons are granodiorites that contain minor to conspicuous hornblende, three are hornblende-free leucogranites, one is biotite granite and granodiorite, and one is mafic diorite. The granitoid rock classification used throughout is that of Streckeisen (1973).

Planar structures (foliations) defined by pancake-shaped mafic inclusions and oriented mafic mineral grains, have been mapped in all granitic units. Foliations generally parallel intrusive contacts and define flattening fabrics. The near absence of broken or deformed mafic mineral grains indicates that the foliation formed before complete solidification of the intrusive bodies.

Small stoped blocks are locally present in several plutons. Stoping apparently played only a minor role in the emplacement of the plutons as indicated by the small size and scarcity of stoped blocks . Stoped blocks are more common to the east and northeast of the map area in the granodiorite of Mitchell Peak. Foliation within these blocks parallels that in the inclosing granodiorite, and becomes more strongly developed with decreasing block size. These blocks are pieces of earlier members of the Mitchell Peak intrusive series. Although brittle enough to be broken from the walls and incorporated into the granodiorite, the blocks later became plastic enough to be flattened and to develop an internal foliation.

Small-scale faults with strike and oblique slip cut many of the granitic units. A few millimeters of recrystallized cataclasite is found along the faults formed through brittle deformation and as much as 4 cm of mylonite is found along those faults formed through ductile deformation. The brittle faults are local members of the regional micro-fault sets documented by Lockwood and Moore (1979). No major faults are present in the map area.

Old Granite and Granodiorite (KJgd). Strongly foliated and(or) quartz-veined dikes of granite and granodiorite intrude the metamorphic rocks of the Marble Fork pendant. Some of these granitic rocks are included within the large dike of the granodiorite of Giant Forest in the metamorphic pendant. The foliation in these granitic rocks, and the parallelism of the foliated granitic dikes with the other structural elements in the pendant, suggest that intrusion of these dikes predates some of the deformation in the pendant. None of the granitic units in the map area are logical sources for these dikes.

Granite of Lodgepole (KJlp). The granite of Lodgepole consists of coarse-grained equigranular-to-seriate biotite granite. The volume percent of dark minerals ranges from 2 to 7; mafic inclusion content is low, ranging from a trace per m^2 up to 4 per m^2 (rare). The granite of Lodgepole has been dated at >115 m.y. (U-Pb; Chen and Moore, 1982); it is older than all the units in contact with it.

The granite of Lodgepole has been split by the granodiorite of Castle Creek, and several isolated Lodgepole blocks lie within both the granodiorite of Castle Creek and the granodiorite of Giant Forest. The Lodgepole forms a gently dipping roof over the granodiorites of Castle Creek and Emerald Lake.

Mafic inclusions within the granite of Lodgepole are highly variable in size, ranging up to 1.5 m. The large mafic inclusions commonly contain plagioclase, K-feldspar, and rare quartz phenocrysts or porphyritic zones. A few large mafic inclusions have been found that contain K-feldspar phenocrysts identical in size and color to those within the surrounding granite. Other mafic inclusions from the same areas contain granite and granodiorite xenoliths with mafic reaction rims. Apparently, some mafic inclusions within the granite of Lodgepole Campground are recrystallized fragments of dismembered coeval mafic dikes that had entrained xenoliths and crystals before or during their incorporation into the Lodgepole granite. Two mafic dikes cut the Lodgepole granite above Pear Lake, to the east of the map area.

Red iron stain is locally present in the heavily jointed parts of the granite. A dike from the granodiorite of Emerald Lake terminates against a joint in the granite, indicating that some joints formed very early, before the intrusion of the granodiorite. Many joints in the granite are filled with quartz.

Granodiorite South of Crescent Lake (Kcr). The granodiorite south of Crescent Lake forms a small, body elongate north-south on the east side of Mount Silliman. The granodiorite is younger than the granite of Lodgepole and older than all other units with which it is in contact.

The granodiorite south of Crescent Lake is characterized by small (~ 2cm) and abundant K-feldspar and plagioclase phenocrysts crowded in a fine-to-medium grained interstitial groundmass. The volume percent of dark minerals ranges from 12 to 16; mafic inclusion content is high at 5 to 8 per m^2. This rock is similar in texture to some parts of the granodiorite of Clover Creek, but is designated as a separate unit because of its position east of the granite of Lodgepole and its unknown age relation with the Sequoia intrusive sequence.

Granodiorite of Giant Forest (Kgf). The granodiorite of Giant Forest is the most extensive unit in the map area. It has been dated at 97-102my (U-Pb; Chen and Moore, 1982), and is intrusive into metamorphic rocks on its southwest border and into the granite of Lodgepole along its northeast border. The granodiorite of Giant Forest is intruded by the granodiorite of Big Meadows, the granodiorite of Clover Creek, and the granite of Weaver Lake which, with the granodiorite of Giant Forest, comprise the concentrically zoned Sequoia intrusive sequence (Ross, 1958; Tracey, 1968; Chen and Moore, 1982). The granodiorite of Castle Creek intrudes the granodiorite of Giant Forest outside of the map area.

The granodiorite of Giant Forest is a medium-grained hypidiomorphic-granular hornblende biotite granodiorite intrusion with porphyritic granodiorite and granite margins. Mafic inclusions are numerous and variable in size and composition. Ross (1958) and Tracey (1968) demonstrate a considerable range in the modal composition of the granodiorite of Giant Forest, from tonalite through the dominant granodiorite to granite. Their modal measurements were made on standard thin-sections, and Ross (1958) shows that some of the modal variability is due to the small area of individual thin-sections. The volume percent of dark minerals in the granodiorite of Giant Forest is generally 15-20, but ranges up to 25 and down to 10; the biotite to hornblende ratio is generally between 3 : 1 and 2 : 1. Plagioclase crystals are compositionally zoned. The bulk of each crystal has a compositional range from An_{28} to An_{34}, and most crystals have sodic rims with An compositions as low as An_{22}; rarely the crystals have calcic cores with compositions of An_{58} to An_{35}.

The rock is variable in texture and mineral proportions. A common type contains variable amounts of prominent stubby hornblende euhedra. The roadcuts within 1/2 km south of Little Baldy Saddle expose numerous small, sharply-margined masses of granodiorite of Giant Forest rich in hornblende euhedra that intrude more biotite-rich granodiorite of Giant Forest. The intimate association and intergradational textures suggest that the small intrusions were simply more mafic Giant Forest magma that penetrated an earlier solidified, more felsic part of the magma chamber. Similar degrees of variation are exposed elsewhere with gradational rather than intrusive contacts.

Swarms of mafic inclusions are scattered in the granodiorite of Giant Forest. A particularly well-preserved and well-exposed swarm occurs on slabs about 100m south-southwest of Little Baldy Saddle. This swarm occupies a sharply margined oval area 8m long and 6m wide consisting of several cross-cutting zones extremely rich in mafic inclusions. The zones show a crude size grading of inclusions from 4 to 10cm in diameter along zone margins to as much as 50cm in zone centers. Hornblende forms rims up to 5mm thick on many of the inclusions in this swarm and also forms a thin coating along the contact where a younger size graded zone cuts an older zone. Similar inclusion swarms are marginal to the granodiorite of Emerald Lake and cut the granite of Lodgepole. The field relations of these inclusion swarms show that they are subvertical pipe- or chimmney-like intrusions within which inclusions have been mechanically sorted, the larger inclusions concentrated near the center. The well-exposed swarm near Little Baldy Saddle is shown on the map as an orbicular granite locality because many of the inclusions have amphibole rims.

A porphyritic granodiorite and granite facies 1/4-2km wide occurs along the contacts of the granodiorite of Giant Forest with older rocks. The K-feldspar phenocrysts are up to 4cm across and the inward transition to equigranular granodiorite is gradational over several meters. Quartz joins K-feldspar as a phenocrystic phase at high elevations, such as the upper Silliman Creek drainage.

The contacts with all younger units are sharp, except for that with the granodiorite of Big Meadows in Dorst Creek. Here there is a transition over several tens of meters from light-colored granodiorite with prominent stubby hornblende crystals to light-colored biotite granodiorite and granite characteristic of the Big Meadows intrusion.

Granite of Big Meadows (Kbm). The granite of Big Meadows is the second oldest member of the concentrically zoned Sequoia intrusive sequence. It has been dated at 98my (U-Pb; Chen and Moore, 1982). Thin-section modes (Ross, 1958; Tracey, 1968) indicate a large degree of variation between granodiorite and granite, volume percent of dark minerals ranges between 5-12. The rock contains only minor amounts of hornblende, and plagioclase compositions range from An_{37-30} in the cores of crystals, to An_{27-24} in the bodies, and An_{20-14} in the rims.

The granite of Big Meadows is a homogeneous medium-grained hypidiomorphic-granular biotite granite and granodiorite with a low mafic inclusion content (0-3 per m^2). However at the 7000-7200 ft elevation along Dorst Creek mafic inclusions range as high as 20 per m^2, sphene is prominent, and hornblende is abundant as thin prismatic euhedra. This more mafic facies is gradational with the typical granite of Big Meadows. Small biotite schist and calc-silicate schist inclusions are present but very rare in the granite of Big Meadows and appear to be fragments of metamorphic country rock. The granite of Big Meadows is porphyritic to the north-northeast, outside of the map area. The granite of Big Meadows sends dikes into, and encloses small blocks of, the granodiorite of Giant Forest .

The granite of Big Meadows is intruded by synplutonic mafic diorite dikes near el. 8173 in the northwest corner of the map area.

Granodiorite of Clover Creek (Kcl). The granodiorite of Clover Creek, a porphyritic hornblende granodiorite containing phenocrysts of both plagioclase and k-feldspar, forms a fascinating group of small intrusions younger than the granite of Big Meadows and older than the granite of Weaver Lake. It is younger than the granodiorite of Big Meadows and older than the granite of Weaver Lake. The volume percent of dark minerals is estimated in the field at 14-17, hornblende occurs as small thin needles, and biotite as small flakes. Mafic inclusions are common (2-5 per m^2), and have some textural similarities to their host granodiorite.

Rounded quartz xenocrysts rimmed by amphibole are present in both the granodiorite and in the mafic inclusions in the stock of granodiorite of Clover Creek in upper Clover Creek. A few xenoliths of the granodiorite of Big Meadows have been found; quartz crystals within the outer 2cm of these xenoliths are also rimmed with amphibole, suggesting that the quartz is from disintegrated xenoliths (assimilation) or incompletely solidified granodiorite of Big Meadows (hybridization). Some of the mafic inclusions contain granite or granodiorite xenoliths, which indicates that some (mostμ) of the mafic inclusions are recrystallized fragments of mafic intrusions or blobs of coeval mafic magmas. Mafic magma could have hybridized with or assimilated granodiorite of Big Meadows to produce the granodiorite of Clover Creek. The intrusions of the granodiorite of Clover Creek and the synplutonic mafic diorite dikes (in the granodiorite of Big Meadows) demonstrate the continued availability of mafic magma in a plutonic system otherwise becoming progressively more felsic with time.

Granite of Weaver Lake (Kwl). Dikes and sills of the granite of Weaver Lake intrude the granodiorites of Giant Forest, Big Meadows, and Clover Creek. The granite of Weaver Lake (dated at 97-99my, U-Pb, Chen and Moore, 1982) is characteristically a very fine-grained leucogranite with less than 10 percent dark minerals and with variable development of small (<2cm) K-feldspar phenocrysts. Included in the granite of Weaver Lake are several areas of medium-grained equigranular-to-porphyritic alaskite, such as at Sunset Rock, el 7014, and immediately southwest of Colony Meadow. Tracey (1968) reports plagioclase compositions of An_{20-23} with crystal cores of An_{30} and rims of An_{14}. Mafic inclusions are present in trace amounts, with a few inclusion-rich dikes as peculiar exceptions.

North of the map area, the granites of Weaver Lake and of Big Meadows appear more similar. As noted above, the granite of Big Meadows is porphyritic to the north-northest of the map area. It is intruded by myriad dikes and sills of the granite of Weaver Lake that are also porphyritic with groundmass grain-size varying from very-fine to medium-grained. The color indices of dikes and septa also converge. This convergence of texture and color index suggests that, to the north, the granites of Weaver Lake and of Big Meadows were formed from a single progressively fractionating body of magma that was continuously sending dikes into its solidifying walls. Synplutonic diorite and mafic granodiorite dikes are present in the granite of Weaver Lake to the north-northeast of the map area, again demonstrating small-scale injection of mafic magmas into an otherwise typical zoned plutonic sequence.

Granodiorite of Castle Creek (Kcc). A thin, north-northwest trending intrusion of hornblende biotite granodiorite makes up the bedrock of Heather Lake and Tokopah Falls and separates the two masses of the granite of Lodgepole. This hornblende biotite granodiorite is called the granodiorite of Castle Creek after exposures to the south of the map area in the Castle Creek drainage where it intrudes the granodiorite of Giant Forest. The thin intrusion is the northernmost end of a large hornblende biotite granodiorite pluton that crops out extensively in the Mineral King area. It has been dated at 96±2 my (U-Pb; C.Busby-Spera, written communication 1982).

The volume percent of dark minerals in the granodiorite of Castle Creek ranges between 12 and 17. The mafic inclusion content ranges up to 3 per m^2. Diffuse planar concentrations of mafic minerals (wispy schlieren) are common and particularly abundant in the narrower parts of the intrusion where they roughly parallel the walls. Otherwise, the intrusion is a homogeneous medium-grained hypidiomorphic-granular hornblende granodiorite. A few stoped blocks of the granite of Lodgepole occur in the granodiorite. The trace of the granite-granodiorite contact near Mehrten Meadow is angular and stepped, perhaps resulting from the removal of granite blocks by stoping. Nonetheless, the flattened shape of mafic inclusions suggests forcible emplacement.

Aplite (Kap). Mappable aplite sill complexes are peripheral to the granodiorite of Castle Creek on the ridge between Heather Lake and Meherten Meadows. These are thought to be related to the granodiorite of Castle Creek because of close geographic association, but they could also be aplites associated with the granodiorite of Emerald Lake.

Granodiorite of Emerald Lake (Ke). The granodiorite of Emerald Lake lies as an elongate belt in the east and northeast parts of the map area. Though undated, its texture, mineralogy, location, and intrusive relations indicate that it is closely related to the granodiorite of Mitchell Peak. It is younger than all the plutons along its west side, and is older than, and surrounds, the two mapped Mitchell units.

The granodiorite of Emerald Lake is a uniform, medium-grained hypidiomorphic-granular hornblende biotite granodiorite. The volume percent of dark minerals ranges from 15 in the south to up to 20 in the north. The mafic inclusion content ranges from 4 per m^2 in the south to up to 20 per m^2 in the north. Numerous inclusion swarm pipes, satellitic to the granodiorite, have intruded the granite of Lodgepole immediately west of Crescent Lake.

The contact between the granite of Lodgepole and the granodiorite of Emerald Lake, where it is exposed in the slabs and cliffs surrounding Emerald Lake, dips shallowly (~10°) to the southeast, with the Lodgepole granite roofing the granodiorite. Sharply defined bands of rhythmic schlieren layers in the granodiorite lie roughly parallel to the granite-granodiorite contact. The modal and grain-size changes in layers and the sense of layer truncation indicate that the layers are progressively younger upward toward the contact. Bands of rythmic schlieren layers are separated from the granite of Lodgepole by aplite bands. This idealized sequence outward (upward) from granodiorite to schlieren layers to aplite to wallrock is usually disrupted by more aplite intrusions. In some localities aplite lies directly between granodiorite and wallrock without intervening schlieren. Apparently aplitic liquid has migrated along the contact between wallrock and partly solidified granodiorite of Emerald Lake and has locally ponded and crystallized in place. Presumably the schlieren originated as accumulations of crystals at the base of the still liquid aplite magma.

Coarse and Fine Granodiorites of Mitchell Peak (Kmcp and Kmfp). The granodiorite of Emerald Lake is intruded to the east-northest by the coarse porphyritic granodiorite of Mitchell Peak. The coarse porphyritic granodiorite of Mitchell Peak is characterized by large (~4cm) K-feldspar phenocrysts set in a medium-to-coarse grained hornblende biotite granodiorite groundmass. The volume percent of dark minerals ranges from 16 to 18 and the content of mafic inclusions, from 2 per m^2 (light rocks) to 8 per m^2 (dark rocks). A separate, distinctly lighter-colored facies that does not crops out east of the map area.

Tne coarse porphyritic facies is suceeded inward (east) by the fine porphyritic granodiorite of Mitchell Peak (U-Pb age: 91my; Chen and Moore, 1982). The transition from the coarse to the fine facies is in places sharp and intrusive (fine is consistently younger) and in places gradational over as much as 3 m. It is marked by 1) a sharp decrease in the number of K-feldspar phenocrysts, 2) a decrease in the size of most of the mafic minerals, 3) the appearance of widely scattered large plagioclase phenocrysts (~4cm), and 4) an overall increase in the size of euhedral groundmass plagioclase grains. The fine porphyritic granodiorite of Mitchell Peak is thus characterized by bimodal sizes of K-feldspar, hornblende, biotite, and plagioclase. Mafic inclusions are abundant and commonly large (up to 1.5m). Some mafic inclusions contain plagioclase megacrysts identical to those in the granodiorite.

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Large stoped blocks of the granodiorite of Emerald Lake and of the coarse porphyritic granodiorite of Mitchell Peak are common in the fine porphyritic granodiorite of Mitchell Peak; one such block lies in the far northeast corner of the map area. As discussed previously, these blocks possess the same flattening foliation as the surrounding granodiorite and were apparently deformed along with it during lateral expansion of the magma chamber.

The Mitchell Peak and Emerald Lake units comprise the the Mitchell Peak intrusive sequence which apparently began as a standard zoned intrusion that was interrupted by a massive upwards surge of core magma. The initial intrusion is represented by the granodiorite of Emerald Lake. With moderate fractionation this was succeeded by the coarse porphyritic granodiorite of Mitchell Peak and its more felsic facies (not present in the map area). Upwards surging of lower crystal-rich core magma was associated with foundering of roof blocks; lateral spreading of core magmas flattened inclusions and semi-solidified foundered blocks. Depressurization forced intercrystalline melt to crystallize, producing the bimodal sizes of all major minerals in the fine porphyritic granodiorite of Mitchell Peak. The youngest intrusions in the Mitchell Peak system are aplite dikes and small stocks (not shown).

Surficial Deposits

Alluvium. Stratified and non-stratified grit, sand, and silt occurs underlying meadows and stream valleys. As discussed above, some deposits have formed through ponding behind Tahoe moraines and probably are partly lake deposits.

Landslide. A small landslide has been mapped in metamorphic rocks near Marble Falls. It is distinguished by exposures of fragmented, jumbled blocks of biotite-feldspar-quartz schist and an overall lumpy or stepped surface.

Tioga Moraines. Tioga moraines are situated inboard of Tahoe moraines. Tioga moraines are characteristically bouldery with sharply defined crests. Surface boulders are fresh and commonly subangular with few weathering pits. Glacial polish and striations are rare, but present. The difference in morphology and weathering between the Tahoe and Tioga moraines is striking and suggestive of a significantly greater period of time between the Tioga and Tahoe glaciations than between the various pulses within the Tahoe. Tioga glaciers were smaller than Tahoe glaciers, as can be seen by the lower elevations of Tioga lateral crests and the shorter downvalley extent of Tioga till. The floor of Tokopah Valley is blanketed by glacial outwash and recessional moraines deposited during the retreat of the Tioga glaciers. Tioga moraines reach a lowermost elevation of 6400 ft in the Marble Fork canyon.

Tahoe Moraines. Tahoe lateral moraines flank Tokopah valley and several of the higher tributaries of the Marble Fork of the Kaweah. The Tahoe moraines are characterized by subdued but distinct sandy crests, boulders with abundant weathering pits and no glacial polish or striations. The Tahoe moraine between Wolverton and Lodgepole has as many as three crests, but the crests are not significantly different in morphology or degree of weathering.

Pre-Tahoe Till. Diamictite consisting of weathered granite clasts and fine, ill-sorted matrix forms a blanket of low relief peripheral to, outboard of, or downhill from well-formed glacial moraines. Isolated highly weathered exotic boulders (erratics) situated beyond the limits of Tahoe and Tioga tills are included as pre-Tahoe. The extent of pre-Tahoe till exceeds that of all younger glacial deposits, indicating that pre-Tahoe glaciers covered a significantly greater area than any younger glaciers. There is no evidence that the area of the present day Giant Forest has ever been glaciated. The lack of glacial morphology of the pre-Tahoe till shows that it is significantly older than the Tahoe deposits.

They probably record repeated maximum advances during a single period of glaciation. Tahoe moraines have dammed and diverted several creeks; sediment carried by these creeks has ponded to form Cahoon, Long, and an unnamed meadow near Wolverton. The Marble Fork Tahoe glacier reached a lowermost elevation of about 6000ft.

Geologic History

The geologic history of the map area can be divided into four sequential parts: 1) deposition of sedimentary and minor volcanic rocks in Paleozoic or Mesozoic time, 2) deformation, metamorphism, and possible long-distance transport of sedimentary and volcanic rocks in Mesozoic time, 3) intrusion and crystallization of granitic magmas in the late Mesozoic, and 4) uplift and erosion culminating in the mid-to-late Cenozoic, and glaciation in the Pleistocene epoch. Nokleberg (1983), Saleeby (1981), and Schweickert (1981) have formulated recent models of the Mesozoic history of the Sierra Nevada.

The metamorphic rocks in the map area are part of the Kings sequence of Bateman and Clark (1974). This is an assemblage of pelitic schist, quartzite, massive and banded marble, and minor calc-silicate schist. Some siliceous and mafic metavolcanic rocks are present. The Kings sequence has been dismembered and now occurs as isolated septa or roof pendants between granitic intrusions.

The rocks of the Kings sequence are interpreted by Saleeby (1981) and Nokleberg (1983) as having been deposited as a complex of submarine fan sediments shed from the North American craton in late Triassic and early Jurassic time. These sediments purportedly moved westward through and around a then-active continental magmatic arc situated along the western margin of North America. Saleeby (1981) interprets rocks of the Kings sequence as depositionally overlapping Permo-Triassic oceanic crustal rocks of the Kings-Kaweah ophiolite belt in the western foothills of the Sierra Nevada, while Nokleberg (1983) proposes that the oceanic crustal rocks were juxtaposed against the Kings sequence by faulting in the mid Jurassic. Both Saleeby (1981) and Nokleberg (1983) believe (on the basis of temporal and lithologic similarity) that the Kings sequence rocks originated well to the south in the Mohave region and were transported to their present position by right-lateral strike slip faulting in the late Jurassic, and both authors attribute much of the structure in these rocks to deformation during northward transport.

Schweickert (1981) presents a markedly different interpretation of Kings sequence rocks. He points out that no fossils have been found in the Kings sequence metamorphic pendants between the Permo-Triassic oceanic crustal rocks on the west, and the central parts of the Boyden Cave and Mineral King roof pendants on the east. He correlates these unfossiliferous Kings sequence rocks with lithologically similar upper Pre-Cambrian and lower Paleozoic miogeoclinal rocks exposed in the Inyo Mountains to the east of the Sierra

Nevada. The unfossiliferous rock are apparently unconformably overlain by the fossiliferous rocks to the east, and in fault contact with the oceanic crustal rocks on the west. The unfossiliferous Kings sequence rocks purportedly form part of the western limb of large synform whose axis lies along the center of the Sierra Nevada batholith. The structure within the Kings sequence rocks formed during collision with an oceanic magmatic arc in the late Jurassic. The Permo-Triassic oceanic crustal rocks (Kings-Kaweah ophiolite belt) formed the floor upon which this oceanic magmatic arc was built (Schweickert, 1981).

Mapping of the metamorphic rocks in the Marble Fork pendant has provided no information that directly favors any of these three interpretations. It has, however, underscored the structural complexity of these Kings sequence metamorphic rocks. Significantly, the marble units are known to have great along-strike continuity. They are much more sheet-like than block-like, which discounts the proposal that the marbles are slide-blocks or olistoliths within a submarine fan complex (Saleeby, et al., 1978).

As discussed above, most intrusive rocks show evidence of forcible emplacement. Thus, some of the structure within the metamorphic rocks may result from emplacement of the Cretaceous plutons and not from regional deformation. If the similar structural patterns in many metamorphic pendants (summarized by Nokleberg and Kistler, 1980) result from regional deformation events, then preservation of these patterns requires that pluton emplacement must be accompanied by some degree of wallrock extension.

Emplacement of plutonic rocks, resulting from eastward subduction of oceanic lithosphere off the west coast of North America, began in the map area before 115 my ago with the intrusion of the granite of Lodgepole and ended at 91 my as magmatism migrated eastward out of the area (Chen and Moore, 1982). The onset of granitic magmatism is probably close to 115 my ago in this area because 1) the granite of Lodgepole lacks the extensive foliation and faulting common in the older isolated Jurassic plutons (Moore, 1963, 1980) and thus is probably a part of the Cretaceous batholith, and 2) a 115my age for the oldest granitoid in the map area fits well with the regional pattern of magmatism in the Cretaceous (Chen and Moore, 1982). Plutonism in the Sierra Nevada ceased at roughly 80my (Stern and others, 1981; Chen and Moore, 1982), and was followed by extensive erosion and unroofing of the batholith.

Huber (1981) shows that 50 my ago the Sierra Nevada was an area of low relief. Uplift had commenced by 25 my at a slow, but increasing rate; approximately one-half of the uplift has taken place in the last 7my, and the central Sierra Nevada may have been too low to support glaciers before roughly 1.5 my ago.

Three age-distinct glacial deposits have been separated in the map area. These are the Tioga, Tahoe, and pre-Tahoe tills. Geographically, the pre-Tahoe is the most extensive deposit and could easily have been produced by more than one glacial advance. The pre-Tahoe till could correlate with either (or both) the McGee or Sherwin tills produced between roughly 1.5 and 0.75my (Huber, 1981). The Tioga moraines are distinctly fresher than the older Tahoe moraines. A recent re-evaluation of field and radiometric age relations (Burke and Birkeland, 1979) brackets the Tahoe glaciation as younger than 0.126±0.025my and older than 0.062±0.013my, and the Tioga glaciation as younger than this but older than 9,800±800y. Chappell (1983) presents sea-level data that indicate glacial maxima at approximately 16,000-20,000y and 150,000-156,000y; these periods fit well with the Tioga and Tahoe glacial advances respectively. Very small and fresh moraines lie on the ridge east of Aster Lake; these have been mapped as Tioga, but could well be post-Tioga neo-glacial deposits.

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