Prepared in cooperation with the National Park Service

Geologic Map of Southwestern Sequoia National Park, Tulare County, California

By Thomas W. Sisson and James G. Moore

Open-File Report 2013–1096

2013

U.S. Department of the Interior
U.S. Geological Survey

Contents

Figure

Tables

Geologic Map of Southwestern Sequoia National Park, Tulare County, California

By Thomas W. Sisson and James G. Moore

Introduction

This map shows the geology of 675 km^2 (260 mi^2) on the west slope of the Sierra Nevada, California, mainly in Sequoia National Park and Sequoia National Forest. It was produced by the U.S. Geological Survey (USGS) at the request of the National Park Service to complete the geologic map coverage of Kings Canyon and Sequoia National Parks. The area includes the Mineral King 15′ topographic quadrangle (sheet 1) and strips along the east and northeast edges of the Kaweah 15′ topographic quadrangle (sheet 2), both in Tulare County. Mapping was performed mainly on the 1:24,000-scale Mineral King, Silver City, Quinn Peak, Moses Mountain, Case Mountain, and Dennison Peak 7.5′ topographic quadrangle bases.

Rocks within the study area are chiefly Cretaceous granites and granodiorites of the Sierra Nevada batholith that intruded coherent masses of Mesozoic metasedimentary and metavolcanic rocks. Quaternary till and talus are the principal surficial deposits, with the exception of a large bouldery alluvial apron near the southwest corner of the map area. The study area includes the headwaters of the Kaweah River (East and South Forks), Tule River (North Fork and North Fork of the Middle Fork), and the Little Kern River. Relief is considerable, with elevations spanning from 1,500 feet along the Middle Fork Kaweah River to 12,432 feet at the summit of Florence Peak along the crest of the Great Western Divide.

Previous Work

The map area abuts previously mapped areas to the north (Giant Forest and Triple Divide Peak 15′ geologic quadrangles; Sisson and Moore, 1994; Moore and Sisson, 1987) and east (Kern Peak 15′ geologic quadrangle; Moore and Sisson, 1985). Metamorphic rocks near the village of Mineral King in the headwaters of the East Fork Kaweah River were mapped in reconnaissance by Knopf and Thelen (1905) and in detail by Christensen (1959, 1963), Dillon (unpub. data 1969), and Busby-Spera (1983, 1984a, 1984b). These maps agree in the distribution and general types of metamorphic rocks, but differ in purpose and emphasis. The Christensen map (1959, 1963) highlights structures and metamorphic assemblages; the J. Dillon map (unpub. data, 1969) groups metamorphic rocks into informal formations on the basis of their protoliths and recognizes additional map-scale folds not shown by Christensen (1959, 1963); the Busby-Spera map (1983, 1984a, 1984b) emphasizes eruptive and depositional environments of the metamorphic protoliths. The present map benefits from those previous studies, as well as from 1:24,000-scale topographic bases and high-resolution digital orthophoto quadrangles that were unavailable for the earlier efforts. Other previous studies include geologic maps supporting USGS mineral-resource assessments by M.G. Sawlan and K.M. Ort (unpub. data, 1982) in the headwaters of the Tule River and by du Bray and Dellinger (1981) in the Golden Trout Wilderness in the southeast part of the map area. Matthes (1965) discusses the Pleistocene glacial history and landforms of Sequoia National Park and vicinity, including the headwaters of the East and South Forks of the Kaweah, the Little Kern, and Kern Rivers. Previous work on paleontology and mineral deposits is addressed in following sections.

Metamorphic Rocks

Five large areas of metamorphic rock, commonly referred to in the Sierra Nevada as "metamorphic roof pendants" or "pendants," underlie about 15 percent of the map area. Like elsewhere in the Sierra Nevada, these are steep-sided, elongate masses of diverse metamorphic rocks that lie between, and are intruded by, granitic rocks. The Mineral King pendant spans the north-south length of the map area near its eastern margin, extending short distances north into the Triple Divide Peak 15′ quadrangle (Moore and Sisson, 1987) and south into the Camp Nelson 7.5′ quadrangle (du Bray and Dellinger, 1981). The south ends of the Sequoia and Sheep Ridge pendants enter the map area from the north and northwest, respectively, near Paradise Ridge and Ash Peaks Ridge (Sisson and Moore, 1994), and the north end of the Tule River pendant enters the map area from the south at Mountain Home State Forest. The South Fork Kaweah pendant is the only large mass of metamorphic rocks wholly enclosed in the map area and lies between resistant granites that support Homers Nose and Dennison Mountain. Previous workers assigned the metamorphic rocks to the Triassic to Jurassic Kings sequence (Bateman and Clark, 1974; Saleeby and others, 1978) or to the Kings terrain (Nokleberg, 1983), but recent results discussed herein indicate that metamorphic rocks that have Cretaceous protoliths are also present.

Metasedimentary Rocks

Most metamorphic rocks within the map area were deposited as submarine sediments that lithified to mudstones, siltstones, and sandstones, with thin bands of limestone and local areas of quartz-rich sandstone. Graded and rippled sedimentary bedding and primary clastic textures are well preserved in metasandstones and metasiltstones in the Mineral King pendant (Busby-Spera, 1985). Elsewhere, metamorphism and deformation have variably destroyed primary sedimentary structures, but relict bedding is widely preserved as compositional bands, typically centimeters to tens of centimeters thick. Mudstone and siltstone were metamorphosed to slate, phyllite, and argillaceous hornfels (slp); areas of abundant thin-bedded fine-grained sandstone and siltstone, with subordinate mudstone, were metamorphosed to siliceous hornfels (slhf); appreciably calcareous sandstones and siltstones were metamorphosed to calc-silicate hornfels and schist (cs). Thick sections of metasandstone having well-preserved clastic textures and sedimentary structures are present on the east and west sides of the Mineral King pendant. The region on the east, from Franklin Lakes through Tulare Peak to Bullfrog Lakes, consists of folded thin- and medium-bedded turbidity current strata (ss) from a submarine fan complex (Busby-Spera, 1985). To the southeast these sandstones grade to finer grained and thinner bedded metasandstone and metasiltstone with interstratified metaargillites and calc-silicate rocks (qbcs, undivided quartzofeldspathic-micaceous and calc-silicate metasedimentary rocks). Volcaniclastic metasandstones (vss) on the west side of the pendant are thin to medium-bedded and have well-preserved metavolcanic felsite grains and locally interstratified metavolcanic breccia beds. These volcaniclastic metasandstones appear to grade northward to thin-bedded siliceous hornfels (slhf) that crosses the ridge west of Timber Gap, but the area between these exposures is concealed by till. To the south, the volcaniclastic metasandstones grade to, or are closely interstratified with, schistose metarhyolite on the west side of Farewell Gap (K?smr).

Marbles (m), recrystallized after limestones, are present in all of the metamorphic pendants. Calc-silicate interbands are common in marble and constitute as much as half of some areas shown on the map as marble. Marbles are distinctly continuous along strike, but their thicknesses vary considerably; in some places, meter-thick bands of marble, or of mixed marble and calc-silicate rock, stretch across hillsides for hundreds of meters and connect thicker marble exposures. Marble bands also divide or merge along strike, enclosing areas of other metasedimentary rocks, probably a result of tight folding. Marble dissolves and weathers cavernously to karst, particularly where marble bands cross or follow stream beds, producing sinkholes, dry stream beds, springs, and caves. Karst is not well developed where marbles cross hillsides and ridge crests, probably indicating that the present configuration of ridges and valleys has great, though not quantified, antiquity.

Metasedimentary rocks have not been subdivided in detail outside of the Mineral King region because of poorer exposures and greater degrees of metamorphic recrystallization. Quartzofeldspathic biotite schist and hornfels encompass metaargillites with interstratified metasiltstones and metasandstones (qb) in some areas. In other areas, metasedimentary sections include appreciable but subordinate calc-silicate hornfels and schist (qbcs).

Fossils

Fossils are rare in metamorphic rocks of the Sierra Nevada, but marine invertebrates of Late Triassic age have been found at several places within the northeastern part of the Mineral King pendant. Reported locations are restricted to narrow belts mainly of siliceous and calc-silicate hornfels (but containing lesser amounts of slate, argillaceous hornfels, and marble) along the east wall of the Mineral King and uppermost Little Kern valleys, spanning from Crystal Creek south to Bullfrog Lakes (Franklin and Crystal Creek units of Busby-Spera, 1984a). Before metamorphism, the fossiliferous rocks were chiefly thin-bedded fine-grained sandstones and siltstones, with subordinate mudstone, and minor limestone (Christensen, 1963), interpreted to have been deposited in a marine continental-shelf environment (Busby-Spera, 1984a); pebble conglomerate is present near the south end of the belt. Fossils have not been reported from the other metamorphic pendants in the map area.

Turner (1894) and Durrell (1940) report ammonites and the pelecypod *Halobia* at about 9,000 ft elevation along the creek draining Franklin Lakes. Christensen (1959) reports fossils from eight localities in this belt including the ammonite *Clionites*? sp., pelecypods *Halobia superba*, *Halobia* sp., *Monotis*? sp., and *Paleoneilo* sp., and brachiopod *Spiriferina* sp. Busby-Spera (1983, 1984a) collected Late Triassic brachyopods along Crystal Creek from the first marble bed west of the thick metarhyolite tuff (about 9,000 ft elevation). Slate containing the pelecypod *Monotis* sp. (identified by S. Starratt, USGS) and indeterminate weakly deformed ammonites was found during the present work at 10,480 ft elevation on the southwest side of the small basin northwest of Tulare Peak. Smith (1927) also reported *Pseudomonotis subcircularis*? and *Paleoneilo*? sp. from the Mineral King area but does not provide locations.

Metavolcanic Rocks

The Mineral King area is notable for the abundance, diversity, degree of preservation, and accessibility of metamorphosed volcanic rocks. Accordingly, these rocks have been studied and interpreted in considerable detail (Christensen, 1959; Busby-Spera, 1983, 1984b, 1986). Major units consist of (1) thick sections of light-colored metarhyolite tuffs, commonly with relict pyroclastic textures and relict quartz and plagioclase phenocrysts; (2) metadacite tuffs, lava flows, and breccias that are darker colored than the metarhyolites (because of greater biotite and amphibole abundances) and lack relict quartz phenocrysts; and (3) even darker metaandesites that include coarse, thick-bedded breccias and lava flows, commonly with prominent relict phenocrysts of plagioclase. Metavolcanic units characteristically grade into interstratified volcaniclastic and nonvolcanic metasedimentary rocks, leading to somewhat arbitrary contact locations, but indicating subaqueous deposition (Busby-Spera, 1984b, 1986).

The ages of Mineral King metavolcanic rocks and the structure of the pendant are considerably revised based on the present and other recent investigations (Starnes and others, 2010; Klemetti and others, 2011). Busby-Spera (1983, 1984a, 1986) interprets the Mineral King pendant as an eastward-younging homocline of Triassic to Early Jurassic metavolcanic and metasedimentary rocks. This conclusion is based on Triassic fossils, interpreted stratigraphic continuity between metasedimentary and metavolcanic rocks, concordant U-Pb zircon ages from metavolcanic rocks in upper Crystal Creek (Late Triassic) and upper Cliff Creek (Early Jurassic), and multiple low-precision $^{206}Pb/^{207}Pb$ zircon age estimates. Concordia plots of the U-Pb results of Busby-Spera (1983), however, are consistent with ~135 Ma eruption ages (Early Cretaceous) for the thick metarhyolite tuffs that pass through the village of Mineral King, Vandever Mountain, and Timber Gap–lower Monarch Creek, and for a metarhyolite sill that intrudes metasandstones near Tulare Peak (fig. 1). Age discordance can be attributed to a minor inherited zircon component ~1.6 Ga old, similar to ages inferred for inherited zircons in other Sierra Nevada igneous rocks (Saleeby and others, 1990). Direct redating of the major metarhyolite tuffs by ion-microprobe U-Pb zircon methods confirms their ~135 Ma eruption ages and Proterozoic (1.6 Ga) inheritance (Starnes and others, 2010; Klemetti and others, 2011). Additional age revisions are summarized in table 1, and are based on concordia plots that assume that discordance is due to a common 1.6±0.3 Ga inherited zircon component. These revisions indicate that the majority of Mineral King metavolcanic rocks are Cretaceous and Jurassic, although Triassic rocks (Ƭma) are present in the eastern part of the pendant. Hence, there is no simple age progression across the pendant, indicating that substantial structural (and possibly stratigraphic) complexity exists, although this complexity is only partly resolved at the present map scale.

Structure

Compositional banding in the metamorphic rocks, relict after bedding, has predominantly steep to vertical dips with strikes of N. 10° to 30° W., matching the overall outcrop trends of the metamorphic pendants and their steep contacts with flanking granites. Foliation in schists and slates, and cleavage in hornfels, are parallel to compositional banding. Outcrop-scale tight folds can be seen locally in well-bedded units (Christensen, 1963); folds with steeply plunging hinges are readily recognized on near-horizontal exposures, but folds with near-horizontal hinges are also present. Map-scale folds are present in the Mineral King pendant in metasandstones between Franklin and Bullfrog Lakes, and in calc-silicate metasandstones and metasiltstones near Monarch Lakes and Mineral Peak (Christensen, 1963; J. Dillon, unpub. data, 1969; Busby-Spera, 1983, 1984a, 1986).

Folds are less easily recognized in metavolcanic rocks owing to their obscure bedding and lateral facies changes. Nevertheless, J. Dillon (unpub. data, 1969) identified a large internally folded synform passing through Vandever Mountain, confirmed by the present mapping. The nose of this synform lies north of Vandever Mountain and is marked by a distinctive unit of dark thin-to-medium bedded carbonate-silicate pebble conglomerates with interstratified thin-bedded pebbly sandstones (ccgl) that wraps around the nose of the fold. A Cretaceous metarhyolite tuff (Kmrt) that caps Vandever Mountain cores the synform and overlies this bedded metacongomerate-sandstone unit. A subordinate syncline and anticline in the metaconglomerate and metatuff are well exposed on the north ridge of Vandever Mountain, and a south-plunging anticline within interstratfied metatuffs and metasedimentary rocks is well exposed on Vandever Mountain's upper southwest slope. The northward termination of the metarhyolite tuff at Vandever Mountain was interpreted as a caldera margin (Busby-Spera, 1984b), but a proposed caldera ring fault could not be located during the present mapping, and the fine clast size and well-bedded character of the conglomerate-sandstone unit are dissimilar to caldera-margin megabreccias.

The thick Cretaceous metarhyolite tuff (Kmrt) that spans from Timber Gap Creek south-southeast across Monarch Creek and Crystal Creek may also core a syncline, at least near its south end. This interpretation is based on the Late Triassic age (established by fossils) of metasedimentary rocks that flank the Cretaceous metatuff directly to its east and west (Christensen, 1959; Busby-Spera, 1983, 1984a), as well as a concordant Late Triassic U-Pb zircon age for a metavolcanic rock (Ŧma) east of the metatuff in upper Crystal Creek (Busby-Spera, 1983). The nose of the syncline would lie about 0.5 km north of Franklin Creek, where marble with interlayered calc-silicate bands wraps the south end of the metarhyolite tuff. No fold hinge has been observed in the metatuff, however, so juxtaposition against Triassic strata by faulting cannot be ruled out.

All previous geologic maps of Mineral King identify a shear zone running down the bed of upper Farewell Canyon within slates and phyllites (Farewell Fault of Busby-Spera, 1984 a, b, 1985). Thin, discontinuous sections of marble lie along this zone. Shearing is well exposed in slates at Farewell Gap and in a zone of schistose metarhyolite (K?smr) slightly west of Farewell Gap. The total displacement on this fault is inferred to be small (perhaps less than a kilometer) because slates and argillaceous hornfels in the bed of lower Farewell Canyon are not strongly sheared, but instead have folded and preserved relict bedding, and because metarhyolite tuffs of very similar age (~135 Ma), uncommon in the Sierra Nevada, are present on both sides of the fault. The northward continuation of this fault or fracture system is marked by active soda springs and tufa deposits near Aspen Flat and by modest shearing in a thin belt of slate to the west of Timber Gap. A parallel minor fracture system transects slate in the next gully to the west, and fluids exploiting this fracture probably created the now-inactive tufa knob beside the Mineral King road at 7,700 ft elevation. The shear's continuation south of Farewell Gap is also limited, as shown by Cretaceous metarhyolite tuff and a pluton of tourmaline-bearing aplite that cross the projected trace of the fault without displacement. Instead, the fault zone steps about 1 km southwest to a parallel fault along the margin of the Mineral King pendant, but that fault also fails to offset rock units that cross its southern projection along the Little Kern River. Numerous small soda springs and tufa deposits along the bed of the upper Little Kern River indicate fluid flow along a north-south striking joint system, but rock exposures in the bed of the river are not sheared, and contacts between rock units cross the river without mappable offsets, indicating minimal displacement.

A northeast-dipping fault crosses the upper west slope of Mineral Peak and the upper Crystal Creek basin and separates meta-andesites in the footwall from chiefly calc-silicate metasandstones in the hanging wall. Busby-Spera (1983, 1984a) connects this fault with a shear zone to the east of Timber Gap at about 10,100 ft elevation. At that location a roughly 10-m-thick, vertically dipping section of strongly foliated-to-mylonitic rock separates Cretaceous metarhyolite on the west from Jurassic metadacite tuffs on the east. Although strongly foliated metamorphic rocks are locally exposed between the two faults, as well as elsewhere, a continuous structure could not be traced during the present mapping.

Timing of Deformation

Near-vertical dips of Early Cretaceous metarhyolite tuffs and metaandesite, and the involvement of metarhyolite tuffs in folding, show that some of the deformation in the metamorphic rocks is Cretaceous or younger. Some deformation is demonstrably associated with emplacement of large, Late Cretaceous plutons. A locality on the west side of the Mineral King pendant close to its contact with the 98-Ma granodiorite of Castle Creek (Kcc) exposes vertically dipping metasedimentary rocks that contain isoclinally folded aplite dikes. A U-Pb zircon age of 98 Ma was also obtained from one of these dikes (table 2), indicating that they must have been intruded and tightly folded at about the time of pluton emplacement. Similar tightly folded aplite-pegmatite dikes cut metaandesite on the east side of the pendant adjacent to the large 99–100 Ma granite of Coyote Pass (Kccp, Kcp), but they did not yield zircons, so their age is unknown. Transposition of Cretaceous metavolcanic rocks to vertical dips during emplacement of Cretaceous plutons has also been described for metamorphic pendants elsewhere in the Sierra Nevada (Saleeby and others, 1990).

Metamorphism and Metamorphic Assemblages

Mineral assemblages within the map area are indicative of metamorphism at low pressures, corresponding to shallow depths, and at moderate to locally high temperatures owing to the emplacement of voluminous hot granitic magmas. The rocks can be assigned to the upper greenschist and amphibolite metamorphic facies. Most metapelitic rocks consist of quartz, plagioclase, biotite, muscovite, and opaque oxides, sporadically accompanied by minor andalusite and either chlorite or cordierite. Accessory minerals include apatite, tourmaline, zircon, and secondary titanite where biotite has partially retrograded to chlorite. Cordierite (altered to pinite), or less commonly andalusite, locally forms prominent ovoid porphyroblasts (as large as 5 mm) visible in outcrop. Close to granitic contacts metapelites may contain minor garnet and fibrous sillimanite instead of andalusite, but such rocks are uncommon. Discontinuous granitic veins in metapelitic rocks on the west side of the South Fork Kaweah pendant may result from local partial melting. The widespread presence of andalusite and cordierite, as opposed to kyanite and garnet, are diagnostic of low-pressure metamorphism (Spear, 1995) corresponding to depths of less than about 12 km beneath the surface.

Calc-silicate rocks range widely in appearance and mineral assemblage. The purest calc-silicates are white- to cream-colored porcelaneous rocks consisting of fine-grained quartz, plagioclase, and colorless amphibole, commonly with diopside. Minor phases may include carbonate, scapolite, zoisite, and epidote. Carbonate-rich calc-silicate rocks typically have pitted weathered surfaces, owing to preferential dissolution of carbonate. Some metasiltstones have compositions intermediate between metapelites and calc-silicates, or consist of thinly interlayered metapelitic and calc-silicate bands. Calc-silicate assemblages in such rocks consist chiefly of quartz, plagioclase, and pale green amphibole, accompanied by opaque oxides and minor biotite.

Metaandesites through amphibolites (metabasalts and metabasaltic andesites) consist of plagioclase, quartz, green-to-brown amphibole, biotite, and opaque oxides. Biotite is commonly partly retrograded to chlorite, with accompanying precipitation of granular titanite. Metarhyolites consist mainly of fine-grained granoblastic quartz and plagioclase, with minor biotite and muscovite, and accessory opaque oxides, apatite, and zircon. Relict phenocrysts of quartz and plagioclase are sparse but widespread. Some metarhyolites contain isolated clusters of epidote grains, probably after calcareous vug fillings. Volcaniclastic metasandstones contain subangular detrital grains of quartz, felsite (granoblastic quartz plus plagioclase), and plagioclase, accompanied by biotite, muscovite, opaque oxides, and in some samples, interstitial carbonate.

Granitic Rocks

Mesozoic granitic rocks of the Sierra Nevada batholith underlie about 85 percent of the map area. The granitic rocks form discrete, spatially extensive plutons that are relatively uniform in texture and composition, and that have sharp contacts against adjacent plutons and metamorphic rocks. Crosscutting intrusive relations between plutons are indicative of their relative ages. Individual plutons are interpreted as the cooled and solidified products of magmas (hot, molten rock) of restricted composition and age that accumulated in particular areas beneath the Earth’s surface. Plutons in the map area are about evenly divided between light-colored granites (less than about 8 percent dark minerals) and medium-colored to dark granodiorites (8 to 20 percent dark minerals), with only about 2 percent of the region consisting of very dark intrusions encompassing gabbros, diorites, and quartz diorites (Streckeisen, 1976). The granites are similar in composition to rhyolites and rhyodacites, and the granodiorites are similar to dacites and silicic andesites (table 3). The darker intrusive rocks are compositionally similar to andesites, basaltic andesites, and basalts. Ages of the larger plutons were determined by the U-Pb zircon method, using the USGS–Stanford ion-microprobe facility (table 2); all of the plutons dated in this study are Cretaceous.

The oldest plutons are three small bodies of deformed granodiorite that lie along the west edges of the Mineral King and South Fork Kaweah pendants. These are the granodiorites of White Chief Mine (Kwc), Camelback Ridge (Kcr), and Burnt Camp Creek (Kbcc). These plutons resemble, but are younger than, Jurassic intrusions of the Sierra Nevada in their degree of deformation and the presence of sheared and offset dark-colored mafic dikes (Chen and Moore, 1982; Moore and Sisson, 1985). However, their U-Pb zircon ages cluster at 133±1 to 135±1.5 Ma (Early Cretaceous), similar to the 130–140 Ma ages of the voluminous metarhyolite tuffs of the Mineral King pendant. Rocks of this age are rare in the Sierra Nevada batholith, which grew over two protracted periods: the first mainly during the Jurassic but spanning from the Late Triassic to the Early Cretaceous (~215–145 Ma), and the second during the Cretaceous (~125–80 Ma) (Chen and Moore, 1982; Irwin and Wooden, 2001). The lull in Sierra Nevada igneous activity was centered at 130–140 Ma, so the presence of plutonic and volcanic rocks of ~135 Ma in this spatially restricted region is evidence that those granodiorites and metarhyolites are related. The ~135 Ma plutonic and metavolcanic rocks are here informally named the "volcano-plutonic suite of Mineral King," after the Mineral King pendant that contains most of the known exposures. Parts of the granodiorite of Camelback Ridge have porphyry textures, suggestive of shallow emplacement, and resemble dacite porphyry dikes that cut nearby metamorphic rocks.

Plutons next intruded into the southern part of the map area as the 120 to 122 Ma granodiorites of Windy Ridge (Kwr) and Pecks Canyon (Kpc). Their U-Pb ages overlap within analytical uncertainty (table 2), and glacial till conceals their contact, but the Windy Ridge pluton is probably the older of the two based on the presence of common mafic dikes that are absent in the granodiorite of Pecks Canyon. The granodiorite of Windy Ridge is atypically fine-grained (compared to other Sierra Nevada granodiorite plutons) and was probably emplaced at subvolcanic depths. The granodiorite of "Nev Point" (Knp) then intruded the south flanks of these plutons at about 116 Ma. The granodiorites of "Nev Point" and Pecks Canyon are cut by near-vertical post-magmatic shears and foliations, striking N. 20° to 40° W., with mainly downdip lineations. Magmatic foliation has a similar attitude in the adjacent southern part of the large ~98 Ma granodiorite of Castle Creek, possibly indicating that the granodiorites of "Nev Point" and Pecks Canyon were deforming while the magmas that produced the granodiorite of Castle Creek (Kcc) intruded and solidified. In the adjacent Kern Peak 15′ quadrangle, the east margin of the 99–100 Ma granite of Coyote Pass is cut by the late-plutonic Coyote Peaks Fault (Moore and Sisson, 1985), which may have formed during the same tectonic event. The granodiorite of Windy Ridge is also deformed but in a brittle and irregular fashion consisting of decimeter-sized polygonal blocks bounded by thin (<1 cm) joints and shears.

The next major intrusive event after the granodiorite of "Nev Point" was emplacement of the quartz diorite of Empire Mountain (Kem) into the north end of the Mineral King pendant. Busby-Spera (1983) reports concordant U-Pb ages of 108 and 106 Ma for two zircon splits from a single sample. The present study obtained an age of 106±1 Ma (Table 2). The quartz diorite of Empire Mountain is cut by sparse mafic dikes, as is the adjacent but undated granodiorite of Spring Lake (Ksl), which is provisionally interpreted to be a light-colored (felsic) facies of the quartz diorite of Empire Mountain. Nearby, the coarse-grained hornblende gabbro at Black Rock Pass (Kgb), also undated, is cut by all flanking intrusive rocks, but it partly encircles the granodiorite of Spring Lake and may be part of the Empire Mountain intrusive event. If so, the intrusive event shows an exceptional degree of compositional zoning. An undated gabbro sill on the lower east wall of the Mineral King valley is variably deformed and probably is not related to the gabbro at Black Rock Pass.

Most of the younger plutons are much larger and are part of an irregular but overall west to east progression of granitic magmatism across the Sierra Nevada (Chen and Moore, 1982). The granite of Frys Point (Kfp) intruded the far-northwestern part of the map area mainly at 105 Ma, with phases of activity as young as 103 Ma (Holland and others, 2010). This was followed eastward by the granodiorite of Milk Ranch Peak (Kmr, 103±1.5 Ma), which was then intruded on its eastern and southern margins by the light-colored granite of Case Mountain (Kcm, 102±2 Ma). The granite of Case Mountain is probably related to the similar looking granite of Dennison Peak (Kdp, 103±2 Ma) located a short distance to the south across the South Fork Kaweah pendant. Evernden and Kistler (1970) report biotite and hornblende K-Ar cooling ages of 88.5–87.4 Ma and 87 Ma, respectively, for samples now known to be the granite of Case Mountain.

Plutonism then shifted to the east side of the Mineral King pendant with emplacement of the large, zoned, granite of Coyote Pass (Kcp). The granite of Coyote Pass is an elongate pluton spanning 32 km on a N. 20º W. axis from the southwestern part of the Kern Peak 15′ quadrangle to the southeastern part of the Triple Divide Peak 15′ quadrangle (Moore and Sisson, 1985, 1987). This pluton is distinctive in many respects: (1) unlike most light-colored granites of the Sierra Nevada batholith, it contains abundant dark-colored disc-shaped mafic inclusions; (2) the granite has a faint igneous layering defined by intermittent thin (centimeter-thickness) variations in the abundance of dark- and light-colored minerals; (3) the mineral layering and disk-shaped mafic inclusions dip inward toward the axis of the intrusion, defining a trough or synformal structure; (4) an indistinctly K-feldspar-porphyritic facies (Kcpp) with few to no mafic inclusions occupies the core of the intrusion and the synform; and (5) masses of fine-grained hornblende quartz diorite to hornblende gabbro (Kmcp) intrude the granite at various locations and are themselves intruded by small-volume fine-grained granodiorites (Kcpgd) of presumed hybrid granite-diorite origin. Mafic inclusions, layering, and the synformal structure are absent north of Big Five Lakes where the rock becomes uniform light-colored granite (alaskite) cut by small synplutonic mafic intrusions. A sample from the porphyritic core of the pluton yielded a concordant U-Pb age of 100.3±0.6 Ma, whereas a sample from the equigranular margin resulted in an age of 98.9±1.2 Ma (table 2). These ages overlap within analytical uncertainty, and thus the preferred age for the intrusion is 99–100 Ma, although Busby-Spera (1983) also reported a concordant age of 97–99 Ma for a sample from the margin of the pluton ("Sawtooth Peak granite" of Busby-Spera, 1983). Biotite and hornblende K-Ar cooling ages obtained from the granite of Coyote Pass are 93.2–87.4 Ma, and 93.0–86.4 Ma, respectively (Evernden and Kistler, 1970). Two additional plutons that intruded at about this time in the south part of the map area are the granodiorite of Mountain Home (Kmh, 99±0.9 Ma) and the very light colored granite of Maggie Mountain (Kmm, 99±0.7 Ma), which flank the Tule River pendant on its western and eastern sides, respectively.

The Mineral King pendant was then intruded on the west by the large granodiorite of Castle Creek (Kcc). This is the outermost and oldest member of the zoned Mitchell Intrusive Suite of Moore and Sisson (1987) that is centered to the north in the Triple Divide Peak 15′ quadrangle. Total north-south mapped extent of the pluton is 45 km. The granodiorite of Castle Creek is a medium-colored hornblende-biotite granodiorite with about 3–7 flattened mafic inclusions per square meter, typical for hornblende-biotite granodiorites of the Sierra Nevada. Samples of the granodiorite of Castle Creek were dated from three widely separated localities (table 2). Two samples yielded ages of 98±0.7 Ma and 98±1.5 Ma; the age of the third sample was 96±0.8 Ma, but re-collection and redating of that outcrop yielded an age of 98±1.3 Ma, suggesting an analytical issue with the first result. Aplite dikes (98±0.5 Ma) intruded the eastern metamorphic wall of the pluton and then were folded, and Busby-Spera (1983) reported an age of 98–99 Ma for a sample near the east edge of the Castle Creek pluton ("Eagle Lake quartz monzonite" of Busby-Spera, 1983). These results indicate that, despite its large size, the granodiorite of Castle Creek intruded over a relatively brief period at 98 Ma. A single K-Ar hornblende cooling age of 88.9 Ma was reported for a sample now known to be of the granodiorite of Castle Creek (Evernden and Kistler, 1970). A sample of tourmaline-bearing aplite (Kap) from an intrusion on the southeast flank of the granodiorite of Castle Creek did not yield zircons, but is interpreted to be associated with that intrusion and thus has a similar age.

Magmatic activity then ceased in the area for 6 or 7 million years until the granodiorite of Chagoopa (Kc) intruded on the east side of the granite of Coyote Pass at 91.5±0.7 Ma. This is a hornblende-biotite granodiorite that forms the outer, equigranular member of a zoned composite intrusion centered to the east in the Kern Peak 15′ quadrangle (Moore and Sisson, 1985). The youngest dated pluton is the coarsely K-feldspar-porphyritic granite of White Mountain (Kwm) that lies near the southeast corner of the map area. Contact relations show that flanking metamorphic rocks overlie the granite along a shallowly dipping roof, now partially dissected. Erosion into the granite of White Mountain created the broad basin of the Little Kern River drainage. Zircon age results for the granodiorite of White Mountain sample are more scattered than for the other dated plutons, but the TuffZirc routine of the Isoplot dating analysis program (Ludwig, 2001) indicates an age of 90±1 Ma. The TuffZirc age for a sample is the median of the greatest number of individual zircon ages that agree within a specified uncertainty, whereas a concordia age of 92±2 Ma is obtained assuming an inherited zircon component of ~1.6 Ga.

Mineral Deposits

Construction of the trans-Sierra Hockett Trail up the South Fork Kaweah River, commencing in 1862, eased access to the Mineral King area, but mineral exploration did not begin in earnest until 1873, when James Crabtree and associates filed a mining claim in the headwaters of White Chief Creek. Prospectors quickly found many additional mineralized areas, mostly consisting of combinations of galena (lead sulfide) and sphalerite (zinc sulfide), as well as pyrite (iron sulfide) or arsenopyrite (arsenic-iron sulfide) (Goodwin, 1958). Silver often is associated with galena and sphalerite, which prompted the prospecting boom, but silver and gold concentrations in Mineral King ores proved to be low, the ores difficult to refine, and the mineralized areas small. The largest excavations were the White Chief, Lady Franklin, and Empire mines, but many small, hopeful prospects decorate the slopes and ridges of the Mineral King valley (Goodwin, 1958). Concerted mining activity ended at Mineral King by 1881.

All sizeable mines and prospects in the Mineral King area are in or are associated with marble. Mineralization at the Empire and White Chief mines developed where granitic magmas intruded marble and created dark reddish brown rocks known as tactite (tc) or skarn that consist chiefly of coarse crystals of garnet, epidote, idocrase, and pyroxene. Large isolated masses of tactite also cap Empire Mountain and the crest of its northwest summit ridge. Although the tungsten mineral scheelite (calcium tungstate) is common in tactite in the Sierra Nevada and has been reported from the Empire Mine locality, it was not sought during the 1870s Mineral King prospecting boom. Additional minerals reported from the Mineral King area include chalcopyrite (copper-iron sulfide) and pyrrhotite (iron sulfide), stibnite (antimony sulfide), and minute amounts of gold. Pyrite is also widespread in the metamorphic rocks, causing many to weather rusty brown. Small galena-sphalerite occurrences are also known in the metasedimentary rocks of the upper Tule River metamorphic pendant in Mountain Home State Forest (Goldfarb and others, 1985; Goodwin, 1958). The last mining activity in the map area was at the Pine Tree tungsten mine in the southern part of the Mineral King metamorphic pendant, where scheelite was extracted from thin marble bands and calc-silicate rocks close to the contact with the porphyritic granite of White Mountain. This mine operated as recently as 1982 (Dellinger and others, 1983).

Surficial Deposits

Glaciation

Ice fields and glaciers widely covered regions higher than about 7,000 ft elevation during the Pleistocene. Glacially eroded cirques, U-shaped valleys, and ground-mantling deposits of unconsolidated bouldery till are the principal records of those glaciers. Ridges of till, known as moraines, mark the positions of the sides and lower ends of former glaciers in many high-elevation valleys. Ice advanced and retreated multiple times during the Pleistocene, and nested sets of moraine crests record successive glacial events. Locally, exposures and landforms are sufficiently developed to subdivide the glacial deposits by age, allowing the extent of the last major Pleistocene ice advance, referred to in the Sierra Nevada as the Tioga glaciation, to be distinguished from the older Tahoe and earlier glaciations. Tioga-age deposits (Qti) are probably also widespread in areas mapped as undivided Pleistocene till (Qw). Smaller glacial deposits with minimal to no vegetation and well-preserved moraines (Qrpm) are generally restricted to north-facing slopes and cirques above 10,000 feet elevation. These are products of both the latest Pleistocene Recess Peak and late Holocene Matthes (Little Ice Age) ice advances recognized elsewhere in the Sierra Nevada (Clark and Gillespie, 1996). High-elevation talus fields merge with these young tills and probably mainly grew during times of more abundant ice.

Landslides and Debris Flows

Landslide and debris-flow deposits (Qls) form a bouldery mantle on the steep south slope of Ash Peaks Ridge above Sequoia National Park's Ash Mountain headquarters. The deposits follow current topography, so postdate uplift of the Sierra Nevada and incision of the Kaweah drainage, but the deposits are themselves deeply incised indicating that they are not recent. A broad, gently dipping alluvial apron of bouldery debris (Qal) fills the headwaters of the North Fork Tule River in the southwestern part of the map area. Some boulders, as big as ~10 meters across, are much larger than could be carried by historical stream flows. Neither the Ash Peaks landslide nor the North Fork Tule River debris flow apron head in extensively glaciated drainages, so enhanced meltwater discharge from Pleistocene glaciers cannot account for these deposits. Possibly, the deposits were generated by high rainfall during the Pleistocene.

Acknowledgments

This work received partial support from the National Park Service's Geologic Resources Evaluation Program under the direction of B. Heise. J. Wooden and J. Vazquez assisted with zircon U-Pb measurements and derivation of age results. E. Klemetti and J.S. Lackey shared unpublished U-Pb zircon age determinations of Mineral King metavolcanic rocks, and S. Starratt identified Late Triassic fossils. J. Dillon (deceased) and M.G. Sawlan provided unpublished geologic mapping of Mineral King metamorphic rocks, and of the southwesternmost part of the field area, respectively. A. Van Dyne assisted with geologic mapping, and J. Robinson guided GIS map preparation. The map and report benefited by reviews from R. Evarts, D. John, and G. Mack, and editing by C. Landowski.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Qal **Alluvial deposits (Holocene and Pleistocene)**—Alluvium underlying meadows; gravel, sand, and boulders in stream valleys

Qtf **Tufa (Holocene)**—Porous travertine deposited from soda springs

Qr **Rock glaciers (Holocene)**—Small active rock glaciers in cirques northwest of Florence Peak and southeast of Rainbow Mountain

Qt **Talus and colluvium, undivided (Holocene and Pleistocene)**—Steep slopes of angular talus blocks with little or no interstitial soil, commonly above 7,000 ft elevation; intermixed soil and rock fragments (colluvium) on gentler slopes, commonly forested

Qls **Landslide deposits (Holocene and Pleistocene)**—Bouldery and hummocky landslide debris on south slope of Ash Peaks Ridge

Qrpm **Recess Peak and Matthes Tills, undivided (Holocene and late Pleistocene)**—Small, non-vegetated tills with small, sharp moraine crests in cirques above ~10,000 ft elevation

Qti **Tioga Till (Pleistocene)**—Innermost of large nested tills having well-defined moraine crests

Qw **Tioga and Tahoe Tills, undivided (Pleistocene)**—Tills generally having large, well-defined moraine crests

GRANITIC ROCKS

DARK-COLORED ROCKS

[Generally more than 15 percent dark minerals]

Kmh **Granodiorite of Mountain Home (Late Cretaceous)**—Medium-grained hornblende-biotite granodiorite near southwest corner of map area. U-Pb zircon age of 98.8±0.9 Ma

Kmcp **Diorite associated with granite of Coyote Pass (Late Cretaceous)**—Fine- and medium-grained hornblende diorite and quartz diorite intrusive into granite of Coyote Pass (Kccp, Kcp); commonly includes angular granite blocks

Kmr **Granodiorite of Milk Ranch Peak (Early Cretaceous)**—Dark and very dark, medium-grained granodiorite with conspicuous hornblende crystals and abundant mafic inclusions; locally contains plagioclase phenocrysts as large as 1.5 cm. U-Pb zircon age of 103.2±1.5 Ma

Kd **Diorite (Cretaceous)**—Small intrusions of fine- and medium-grained hornblende diorite and quartz diorite associated with the granite of Ash Peaks Ridge near the northwest corner of the map area, as well as isolated dioritic intrusions elsewhere

Kem **Quartz diorite of Empire Mountain (Early Cretaceous)**—Medium-grained quartz diorite cut by sparse mafic dikes. U-Pb zircon age of 107±1 Ma (Busby-Spera, 1983) and 106.2±1.1 Ma (this study)

Kgb **Hornblende gabbro (Early Cretaceous)**—Medium- and coarse-grained hornblende gabbro and diorite at Black Rock Pass and a sill intrusive into Mineral King metamorphic pendant. Mineral King sill is vuggy and finer grained to the west, and may be sub-volcanic equivalent of similar appearing Cretaceous meta-andesites (Kma) near Timber Gap

Knp **Granodiorite of "Nev Point" (Early Cretaceous)**—Medium-grained, equigranular hornblende-biotite granodiorite with consistent north-northwest striking, near vertical post-magmatic foliation. U-Pb zircon age of 115.9±1.7 Ma

Kwr **Granodiorite of Windy Ridge (Early Cretaceous)**—Fine-grained hornblende-biotite granodiorite with sheared mafic dikes. U-Pb zircon age of 120.1±2.1 Ma

Kwc **Granodiorite of White Chief Mine (Early Cretaceous)**—Sheared, medium-grained hornblende-biotite granodiorite with sheared and offset mafic and aplitic dikes. Contact with granodiorite of Castle Creek (Kcc) locally indistinct. Part of volcano-plutonic suite of Mineral King. U-Pb zircon age of 135±1 Ma

Kcr **Granodiorite of Camelback Ridge (Early Cretaceous)**—Sheared, medium-grained hornblende-biotite granodiorite with sparse sheared mafic dikes. Locally developed porphyry texture. Part of volcano-plutonic suite of Mineral King. U-Pb zircon age of 133±1 Ma

Kbc **Granodiorite of Burnt Camp Creek (Early Cretaceous)**—Locally sheared, medium-grained hornblende-biotite granodiorite with sparse sheared mafic dikes. Part of volcano-plutonic suite of Mineral King. U-Pb zircon age of 134.8±1.5 Ma

KJmd **Mafic dikes (Cretaceous and (or) Jurassic)**—Fine-grained, dark-colored mafic dikes of indeterminate age that cut metamorphic and granitic rocks

KJgd **Sheared granodiorite (Cretaceous or Jurassic)**—Schistose dark granodiorite near northeast corner of map area; cut by schistose mafic dikes. Unit is correlative with Jurassic-Triassic sheared granodiorite in the Triple Divide Peak 15′ quadrangle (Moore and Sisson, 1987), but unit has been here reassigned to Cretaceous or Jurassic on the basis of the discovery of Cretaceous-age sheared, diked granodiorites

MEDIUM-COLORED ROCKS

[Generally 8–15 percent dark minerals]

Kc **Granodiorite of Chagoopa (Late Cretaceous)**—Fine- to medium-grained hornblende-biotite granodiorite with indistinct plagioclase phenocrysts. U-Pb zircon age of 91.5±0.7 Ma

Kcc **Granodiorite of Castle Creek (of Mitchell Intrusive Suite [Moore and Sisson, 1987]) (Late Cretaceous)**—Medium-grained hornblende-biotite granodiorite that has prominent grains of hornblende and titanite (sphene); locally contains indistinct plagioclase phenocrysts. Includes domains zoned to light-colored granodiorite. U-Pb zircon ages of 98±2 Ma (Busby-Spera, 1983), 97.8±0.7, and 98.4±1.3 Ma (this study)

Kcciz **Injection zone along margin of the granodiorite of Castle Creek (of Mitchell Intrusive Suite [Moore and Sisson, 1987]) (Late Cretaceous)**—Steeply dipping sheets of fine-grained granodiorite, 1–3 m thick, closely interleaved with metamorphic rocks along eastern contact with the granodiorite of Castle Creek (Kcc)

Kgfdc **Dome Creek facies of the Giant Forest Granodiorite (of Sequoia Intrusive Suite [Moore and Sisson, 1987]) (Early Cretaceous)**—Medium-grained, weakly gneissic granodiorite and granite. Interpreted as southward-narrowing extension of the Giant Forest Granodiorite north of map area

Kcpgd **Granodiorite dikes associated with the granite of Coyote Pass (Early Cretaceous)**—Fine-grained, medium- and light-colored granodiorite dikes associated with diorite intrusions into the granite of Coyote Pass (Kcpp, Kcp). Interpreted to be diorite-granite hybrids

Kss **Granodiorite of Shepherds Saddle (Cretaceous)**—Medium-grained, equigranular hornblende-biotite granodiorite in northwestern part of map area; undated, but possibly darker-colored facies of the granite of Frys Point (Kfp)

Ksl **Granodiorite of Spring Lake (Cretaceous)**—Medium- to fine-grained granodiorite with sparse mafic dikes; undated, but possibly lighter-colored facies of the quartz diorite of Empire Mountain (Kem)

Kpc **Granodiorite of Pecks Canyon (Early Cretaceous)**—Medium- to coarse-grained granodiorite that contains indistinct potassium-feldspar phenocrysts. U-Pb zircon age of 121.6±1.6 Ma; probably younger than the nearby granodiorite of Windy Ridge (Kwr)

Kpy **Granodiorite porphyry dikes (Early Cretaceous)**—Fine-grained porphyry dikes with abundant plagioclase phenocrysts intrusive into metamorphic rocks of the southern part of Mineral King pendant; probably correlative to the granodiorite of Camelback Ridge (Kcr) of the volcano-plutonic suite of Mineral King

LIGHT-COLORED ROCKS

[Generally less than 8 percent dark minerals]

Kwm **Granite of White Mountain (Late Cretaceous)**—Medium-grained, coarsely porphyritic biotite granite that contains abundant, well-formed, potassium feldspar megacrysts (4–8 cm), and lacks mafic inclusions. U-Pb zircon age of 89.9±1.0 Ma

Kap **Aplite (Late Cretaceous)**—Fine-grained, very light colored aplitic granite that has conspicuous blue-black tourmaline; intruded between the granodiorite of Castle Creek (Kcc) and the Mineral King pendant; lack of deformation and mafic dikes indicate Late Cretaceous age. Unit also includes aplite dike swarm that intruded metavolcanic roof rocks of the granodiorite of Spring Lake (Ksl)

Kmm **Granite of Maggie Mountain (Late Cretaceous)**—Coarse-grained, very light colored biotite granite that lacks mafic inclusions. U-Pb zircon age of 98.8±0.7 Ma

Kcpp **Porphyritic core facies of the granite of Coyote Pass (Early Cretaceous)**—Coarse-grained biotite granite that contains indistinct potassium-feldspar phenocrysts and lacks mafic inclusions. Forms a central domain within the equigranular facies of the granite of Coyote Pass (Kcp). Contacts the surrounding equigranular facies both gradationally and as sills and dikes, hence porphyritic unit is younger. Foliation and layering in the equigranular facies dip beneath the porphyritic core facies. U-Pb zircon age of 100.3±0.6 Ma

Kcp **Equigranular facies of the granite of Coyote Pass (Early Cretaceous)**—Medium- and coarse-grained biotite-hornblende granite and alaskite. Mafic inclusions and igneous mineral layering dip shallowly inward and define a northwest-trending magmatic synform cored by the porphyritic core facies of the granite of Coyote Pass (Kcpp). Mafic inclusions are rare and mineral layering is absent north of Lost Canyon and Cyclamen Lake where the rock is nonfoliated alaskite. U-Pb zircon ages of 98.9±1.2 Ma (this study) and 97±2 Ma. (Busby-Spera, 1983); field relations indicate unit is older than porphyritic core facies (100.3±0.6 Ma)

Kcm **Granite of Case Mountain (Early Cretaceous)**—Medium- and coarse-grained biotite granite, generally lacking in mafic inclusions; locally contains indistinct potassium-feldspar phenocrysts. Weathers to broad slabs and domes; also forms extensive grus. U-Pb zircon ages of 101.6±1.6 and 102.3±2.1 Ma

Kdp **Granite of Dennison Peak (Early Cretaceous)**—Medium-grained biotite-hornblende granite with sparse mafic inclusions (0–3 per square meter). Probably correlative with the granite of Case Mountain (Kcm). U-Pb zircon age of 102.8±2.0 Ma

Kfp **Granite of Frys Point (Early Cretaceous)**—Medium- and coarse-grained, equigranular biotite granite that lacks mafic inclusions but is locally cut by diorite and hybrid granodiorite dikes containing diorite blocks. U-Pb zircon age of granite is 105 Ma; late granodioritic intrusions are as young as 103 Ma (Holland and others, 2010)

Kf **Felsite (Early Cretaceous)**—Intrusion of fine-grained, very light colored granite or hypabyssal rhyolite exposed at outlet of lower Franklin Lake; cut by mafic dikes. Undated but probably correlative with meta-rhyolite tuffs of volcano-plutonic suite of Mineral King

METAMORPHIC ROCKS

METAVOLCANIC ROCKS

mm **Mafic metavolcanic rocks (Mesozoic)**—Amphibolite derived from basalt and basaltic andesite

ma **Meta-andesite (Mesozoic)**—Metamorphosed andesitic lava flows and breccias, commonly schistose

mrd **Felsic metavolcanic rocks (Mesozoic)**—Chiefly metarhyolite and metadacite tuffs, but also includes metarhyolite and metadacite lava flows

KJmt **Metarhyolite and metadacite tuffs, undivided (Cretaceous and Jurassic)**—Northern continuation of Cretaceous metarhyolite and Jurassic metadacite tuffs across Cliff Creek. Shown as Jurassic or Triassic metarhyolite on geologic map of Triple Divide Peak 15′ quadrangle (Moore and Sisson, 1987)

Kma **Meta-andesite (Early Cretaceous)**—Metamorphosed andesitic lava flows and breccias to the west of Timber Gap. U-Pb zircon lower-intercept concordia model age from included felsic tuff, 111 Ma (revised from Busby-Spera, 1983). Possibly correlative with similar-appearing hornblende gabbro (Kgb) sill to south

K?vbr **Metarhyolite and metadacite breccia (Early Cretaceous?)**—Lenses and beds of felsic volcanic breccia that contain well preserved relict angular clasts

Kmrt **Metarhyolite tuff (Early Cretaceous)**—Chiefly massive metarhyolite with relict pyroclastic texture; includes some interstratified metasedimentary rocks. U-Pb zircon lower-intercept concordia model ages of 131–140 Ma (revised from Busby-Spera, 1983); part of volcano-plutonic suite of Mineral King

K?smr **Schistose metarhyolite (Cretaceous?)**—Felsic schist that contains relict quartz and plagioclase phenocrysts (or coarse relict detrital grains) on west side of Farewell Gap. Foliation intensity decreases to the north, and unit passes along strike into bedded volcaniclastic metasandstones (vss)

Jmdt **Metadacite tuff (Jurassic)**—Massive metadacite with relict pyroclastic texture between Timber Gap and Empire Mountain, and metadacite tuff and breccia above Spring Lake. Distinguished from metarhyolite tuff (Kmrt) by more abundant biotite and hornblende, and by absence of relict quartz phenocrysts. U-Pb zircon lower-intercept concordia model ages of 171 and 189 Ma (revised from Busby-Spera, 1983)

Ŧma **Meta-andesite (Triassic)**—Metamorphosed andesitic lava flows and breccias to the west of Mineral Peak in upper Crystal Creek and in adjacent basins. U-Pb zircon lower-intercept concordia model ages of 214 and 236 Ma (revised from Busby-Spera, 1983)

METASEDIMENTARY ROCKS

m **Marble (Mesozoic)**—Coarsely crystalline, schistose to gneissose, white to blue-gray marble. Thin calc-silicate layers locally constitute as much as 50 percent of exposures. Blue lines on map denote location of marble bands too thin to show at map scale ccgl **Calc-silicate conglomerate (Mesozoic)**—Dark-weathering, well-bedded calc-silicate conglomerate and pebbly sandstone with white felsite clasts. Underlies Cretaceous metarhyolite tuff and marks nose of synclinorium through Vandever Mountain

cs **Calc-silicate hornfels and schist (Mesozoic)**—Bedded, light-colored calc-silicate hornfels and schist derived from calcareous quartzofeldspathic siltstone and sandstone. Commonly interstratified with subordinate argillaceous hornfels and schist derived from mudstone (not resolvable at map scale)

q **Quartzite (Mesozoic)**—Medium- to coarse-grained quartzite; massive to medium bedded

qb **Quartz-biotite schist and hornfels (Mesozoic)**—Encompasses quartzofeldspathic micaceous schist, phyllite, slate, and hornfels

qbcs **Quartz-biotite and calc-silicate schist and hornfels (Mesozoic)**—Undivided quartzofeldspathic micaceous and calc-silicate schist and hornfels

slp **Slate and phyllite (Mesozoic)**—Fissile slate, phyllite, and dark-colored argillaceous hornfels derived from mudstone

slhf **Siliceous hornfels (Mesozoic)**—Thin-bedded, fine-grained siliceous hornfels with subordinate interstratified meta-argillite derived from quartzofeldspathic siltstone and fine-grained sandstone

vss **Volcaniclastic metasandstone (Mesozoic)**—Medium- to thin-bedded metasandstone and rare interstratified lenses of volcaniclastic breccia, on the west side of Mineral King pendant; metasandstone contains relict detrital grains of felsite and of phenocryst fragments

ss **Metasandstone (Mesozoic)**—Rhythmically bedded arkosic metasandstones derived from turbidity current strata (Busby-Spera, 1985) on east side of Mineral King pendant

tc **Tactite (Mesozoic)**—Dark brown, coarse-grained rocks consisting of calcic garnet, epidote, diopside, and idocrase, developed along contacts between granite and marble or calc-silicate rocks

References

Bateman, P.C., and Clark, L.C., 1974, Stratigraphic and structural setting of the Sierra Nevada batholith, California: Pacific Geology, v. 8, p. 79–89.

Busby-Spera, C.J., 1983, Paleogeographic reconstruction of a submarine volcanic center; geochronology, volcanology and sedimentology of the Mineral King roof pendant, Sierra Nevada, California: Princeton, N.J., Princeton University, Ph.D. dissertation, 317 p.

Busby-Spera, C.J., 1984a, The lower Mesozoic continental margin and marine intra-arc sedimentation at Mineral King, California, *in* Crouch, J.K., and Bachman, S.B., eds., Tectonics and sedimentation along the California margin: Pacific Section of the Society of Economic Paleontologists and Mineralogists, v. 38, p. 135–156.

Busby-Spera, C.J., 1984b, Large-volume rhyolite ash-flow eruptions and submarine caldera collapse in the lower Mesozoic Sierra Nevada, California: Journal of Geophysical Research, v. 89, no. B10, p. 8417–8427.

Busby-Spera, C.J., 1985, A sand-rich submarine fan in the lower Mesozoic Mineral King caldera complex, Sierra Nevada, California: Journal of Sedimentary Petrology, v. 55, p. 376–391.

Busby-Spera, C.J., 1986, Depositional features of rhyolitic and andesitic volcaniclastic rocks of the Mineral King submarine caldera complex, Sierra Nevada, California: Journal of Volcanology and Geothermal Research, v. 27, p. 43–76.

Chen, J.H., and Moore, J.G., 1982, Uranium-lead isotopic ages from the Sierra Nevada batholith, California: Journal of Geophysical Research, v. B87, p. 4761–4784.

Christensen, M.N., 1959, Geologic structures of the Mineral King area, California: Berkeley, University of California, Ph.D. dissertation, 102 p.

Christensen, M.N., 1963, Structure of metamorphic rocks at Mineral King California: University of California Publications in Geological Sciences, v. 42, p. 159–198.

Clark, D.H., and Gillespie, A.R., 1996, Timing and significance of late-glacial and Holocene cirque glaciation in the Sierra Nevada, California: Quaternary International, v. 38/39, p. 21–38.

Dellinger, D.A., du Bray, E.A., Leach, D.L., Goldfarb, R.J., Jachens, R.C., and Zilca, N.T., 1983, Mineral resource potential map of Golden Trout Wilderness, southern Sierra Nevada, California: U.S. Geological Survey Miscellaneous Field Studies Map MF–1231–E, 10 p., scale 1:62,500

du Bray, E.A., and Dellinger, D.A., 1981, Geologic map of the Golden Trout Wilderness, southern Sierra Nevada, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1231-A, scale 1:48,000.

Durrell, C., 1940, Metamorphism in the southern Sierra Nevada northeast of Visalia, California: University of California Publications in Geological Sciences, v. 24, p. 1–118.

Evernden, J.F., and Kistler, R.W., 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U.S. Geological Survey Professional Paper 623, 42 p.

Goldfarb, R.J., Leach, D.L., Sawlan, M.G., and Lipton, D.A., 1985, Mineral resource potential of the Moses and Dennison Peak roadless areas, Tulare County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF–1651–A, scale 1:48:000.

Goodwin, J.G., 1958, Mines and mineral resources of Tulare County, California: California Journal of Mines and Geology, v. 54, p. 317–492.
Holland, J., Surpless, B., Lackey, J.S., Lowey, S.L., and Wooden, J.W., 2010, Intrusive history of the Ash Mountain complex, Sequoia National Park [abs.]: Geological Society of America Abstracts with Programs, v. 42, no. 5, p. 627.
Irwin, W.P., and Wooden, J.L., 2001, Map showing plutons with accreted terranes of the Sierra Nevada, California, with a tabulation of U/Pb isotopic ages: U.S. Geological Survey Open File Report 01–229, 1 sheet, scale 1:100,000.
Klemetti, E.W., Lackey, J.S., Starnes, J., and Wooden, J.W., 2011, Ancient and modern rhyolite—using zircon trace element compositions to examine the origin of volcanic rocks [abs.]: Eos (American Geophysical Union Transactions), v. 92, Fall meeting supplement, abs. V53B-2619.
Knopf, A., and Thelen, P., 1905, Sketch of the geology of Mineral King, California: University of California Publications in Geological Sciences, v. 4, p. 227–262.
Ludwig, K.R., 2001, Isoplot 3.0—a geochronological toolkit for Microsoft Excel: Berkeley, Calif., Berkeley Geochronology Center Special Publication no. 4, 71 p.
Matthes, F.E., 1965, Glacial reconnaissance of Sequoia National Park, California [prepared posthumously by F. Fryxell]: U.S. Geological Survey Professional Paper 504-A, 58 p.
Moore, J.G., and Sisson, T.W., 1985, Geologic map of the Kern Peak quadrangle, Tulare County, California: U.S. Geological Survey Geologic Quadrangle Map GQ–1584, scale 1:62,500.
Moore, J.G., and Sisson, T.W., 1987, Geologic map of the Triple Divide Peak quadrangle, Tulare County, California: U.S. Geological Survey Geologic Quadrangle Map GQ–1636, scale 1:62,500.
Nokleberg, W.J., 1983, Wallrocks of the central Sierra Nevada batholith, California—a collage of accreted tectono-stratigraphic terrains: U.S. Geological Survey Professional Paper 1255, 28 p.
Saleeby, J.B., Goodin, S.E., Sharp, W.D., and Busby, C.J., 1978, Early Mesozoic paleotectonic-paleogeographic reconstruction of the southern Sierra Nevada region, *in* Howell, D.G., and McDougal, K.A., eds., Mesozoic paleogeography of the Western United States: Los Angeles, California, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 311–336.
Saleeby, J.B., Kistler, R.W., Longiaru, S., Moore, J.G., and Nokelberg, W.J., 1990, Middle Cretaceous silicic metavolcanic rocks in the Kings Canyon area, central Sierra Nevada, California, *in* Anderson, J.L., ed., The nature and origin of Cordilleran magmatism: Geological Society of America Memoir 174, p. 251–270.
Sisson, T.W., and Moore, J.G., 1994, Geologic map of the Giant Forest quadrangle, Tulare County, California: U.S. Geological Survey Geologic Quadrangle Map GQ–1751, scale 1:62,500.
Smith, J.P., 1927, Upper Triassic marine invertebrate faunas of North America: U.S. Geological Survey Professional Paper 141, 262 p.
Spear, F.S., 1995, Metamorphic phase equilibria and pressure-temperature-time paths: Washington, D.C., Mineralogical Society of America Monograph, 2d printing [corrected], 799 p.

Starnes, J.K., Klemetti, E.W., Lackey, J.S., Lowey, S.L., and Wooden, J.W., 2010, New U-Pb zircon ages of Mineral King roof pendant rhyolite units revise the volcanic history of the Sierra Nevada, California [abs.]: Geological Society of America Abstracts with Programs, v. 42, p. 626.

Streckeisen, A., 1976, To each plutonic rock its proper name: Earth-Science Reviews, v. 12, p. 1–33.

Turner, H.W., 1894, The rocks of the Sierra Nevada: U.S. Geological Survey Fourteenth Annual Report 1892–93, p. 435–495.

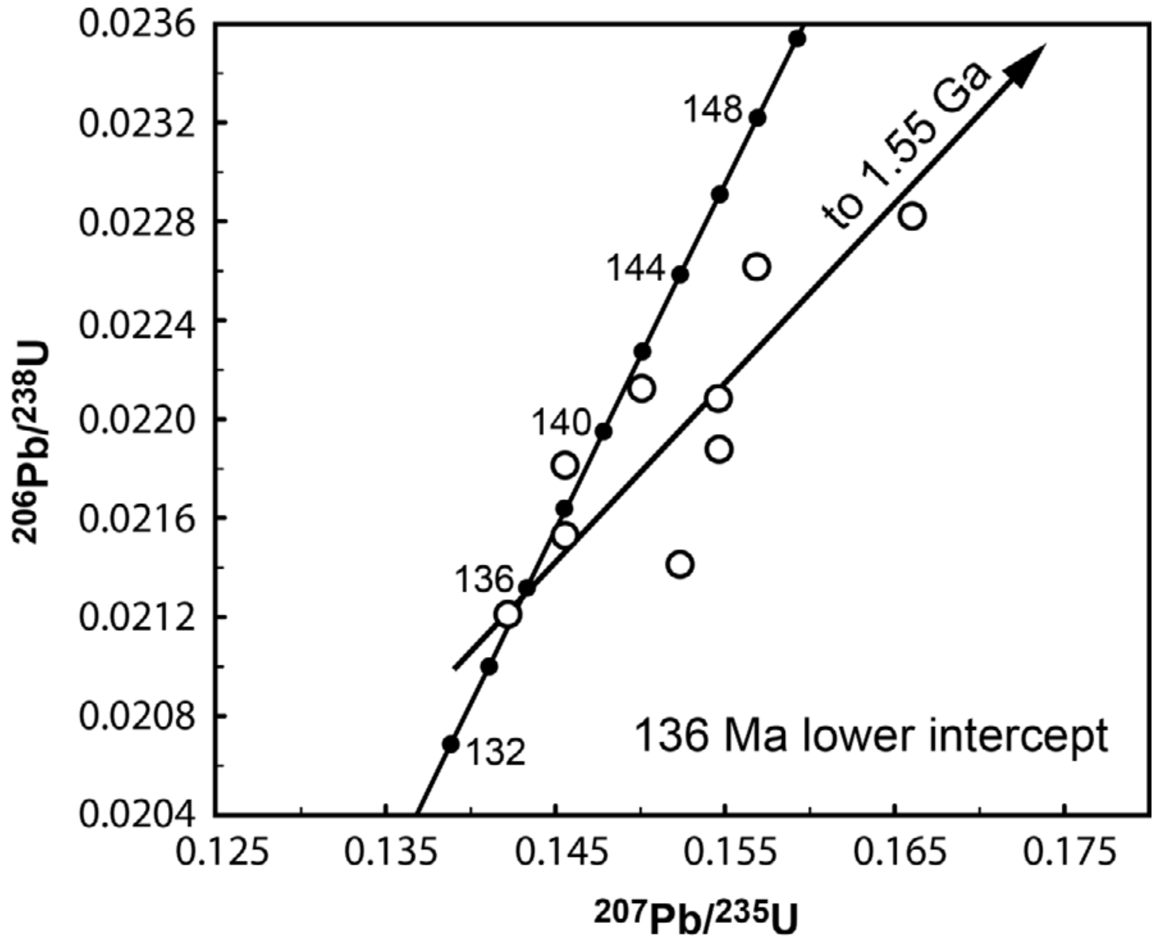

Figure 1. Concordia plot of U-Pb zircon results for Mineral King pendant metarhyolites (Busby-Spera, 1983). Curve with solid dots is U-Pb concordia with ages in millions of years (Ma). Open circles are thermal-ionization U-Pb results for individual zircon splits from metarhyolite tuffs (Kmrt), and a metarhyolite sill, collected from the Mineral King pendant. Regression line (arrow) intersects concordia at 136 Ma and 1.55 billion years (Ga), interpreted respectively to be the approximate ages of a period of Early Cretaceous rhyolitic eruptions and of a widespread Proterozoic inherited zircon component.

Table 1. Lower-intercept concordia ages for Mineral King metavolcanic rocks derived from U-Pb zircon results of Busby-Spera (1983).

sample	map unit	N latitude	W longitude	age (Ma)	+2σ	-2σ	n
MK-540	₮ma	36.4550	118.5843	235.8	5.8	5.6	3
MK-1700	₮ma	36.4396	118.5758	214.2	5.6	6.2	2
MK-910	Jmdt	36.4650	118.5898	188.8	5.4	5.4	2
MK-980	Jmdt	36.4718	118.5667	170.9	4.7	5.1	2
MK-530	Kmrt	36.4555	118.5878	140.3	5.4	6.3	1
MK-822	Kmrt - sill	36.4082	118.5647	138.4	3.7	3.9	2
MK-900	Kmrt	36.4605	118.5900	137.9	3.6	3.6	2
MK-1	Kmrt	36.3987	118.5743	135.2	4.1	5.6	2
MK-520	Kmrt	36.4536	118.6050	131.0	4.2	4.9	2
MK-920	Kma	36.4673	118.6027	110.6	2.4	2.9	3
MK-1010	Kmrt	36.3625	118.5493	101.7	3.4	4.9	2

Comments: lower intercept ages and 2σ uncertainties by Monte Carlo regression using Isoplot 3.4.1 (Ludwig, 2001) assuming a 1.6±0.3 Ga inherited zircon component, 2σ uncertainties of 3.7% and 1.2% on $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$, and Pb/U error correlations of 0.25; *n* is number of zircon splits; sample coordinates are NAD27 datum.

Table 2. Weighted-mean $^{206}Pb/^{238}U$ zircon ages of Mineral King region plutonic rocks, measured by ion-microprobe.

sample	map unit	N latitude	W longitude	n	$^{206}Pb/^{238}U$ age (Ma)	2σ	MSWD
08SMK035	Kwc*	36.4234	118.5992	9	135.0	1.0	1.2
09SMK049	Kcr*	36.3386	118.5492	14	133.0	1.0	1.3
04MMK10	Kbcc*	36.3512	118.7792	10	134.8	1.5	1.5
06SMK018	Kwr	36.3054	118.6208	8	120.1	2.1	1.9
06SMK021	Kpc	36.3035	118.6024	8	121.6	1.6	0.6
06SMK025	Knp	36.2502	118.5798	9	115.9	1.7	1.5
09SMK050	Kem	36.4693	118.5754	14	106.2	1.1	1.7
04MMK007	Kmr	36.4533	118.7889	12	103.2	1.5	2.6
04SMK002	Kdp	36.2924	118.7202	8	102.8	2.0	2.4
04MMK004	Kcm	36.4375	118.7320	12	101.6	1.6	3.5
04MMK008	Kcm	36.4530	118.8136	8	102.3	2.1	4.7
04SMK003	Kcp	36.4489	118.5608	11	98.8	1.2	2.4
09SMK054	Kcpp	36.3937	118.5009	13	100.3	0.6	0.6
04SMK006	Kmm	36.2616	118.6522	9	98.8	0.7	1.9
04SMK005	Kmh	36.2515	118.7382	9	98.8	0.9	1.4
04SMK001	Kcc	36.3085	118.6918	11	97.8	0.7	1.4
04MMK006**	Kcc	36.4606	118.6310	11	96.2	0.8	0.6
06SMK017**	Kcc	36.4606	118.6310	8	98.4	1.3	0.4
06SMK024	Kcc	36.3341	118.5882	7	98.2	1.5	1.3
08SMK036***	Kcc	36.4240	118.6022	10	98.4	0.5	1.6
09SMK052	Kc	36.4626	118.5019	13	91.5	0.7	1.5
07MMK011	Kwm	36.2639	118.5064	6	89.9	1.0	TuffZirc

*** volcano-plutonic suite of Mineral King; ** MMK006 locality was resampled and redated as SMK017; *** folded aplite in wallrock to Kcc. Averaged ages are ^{207}Pb-corrected $^{206}Pb/^{238}U$ results from Isoplot (Ludwig, 2001), which projects U-Pb values to the concordia from a present-day $^{207}Pb/^{206}Pb$ common lead component. Sample coordinates are NAD27 datum.**

Table 3. Major element oxide (wt.%) and trace element (ppm) analyses of plutonic rocks measured by X-ray fluorescence.

Map unit	Kcr	Kbcc	Kwr	Kmr	Kem	Kcp	Kcp	Kcp	Kcp	Kcp	Kcpp
Sample	9smk49	4mmk10	87m28	4mmk7	9smk50	85s63	85s67	9smk55	4smk3	9smk53	9smk54
N lat.	36.3386	36.3512	36.3050	36.4524	36.4693	36.4833	36.4883	36.4169	36.4489	36.4749	36.3937
W long.	118.549	118.7792	118.630	118.7878	118.5754	118.5167	118.550	118.544	118.5608	118.5122	118.5009
SiO_2	**68.86**	**68.73**	**66.10**	**64.01**	**61.43**	**75.00**	**76.10**	**74.33**	**74.82**	**75.94**	**77.14**
TiO_2	**0.57**	**0.54**	**0.79**	**0.76**	**0.91**	**0.19**	**0.12**	**0.20**	**0.18**	**0.09**	**0.09**
Al_2O_3	**15.66**	**14.94**	**15.60**	**16.36**	**16.61**	**13.40**	**13.20**	**13.60**	**13.31**	**13.16**	**12.74**
FeO*	**2.90**	**2.91**	**4.42**	**5.20**	**5.36**	**1.45**	**1.15**	**1.77**	**1.77**	**1.22**	**0.84**
MnO	**0.07**	**0.05**	**0.71**	**0.09**	**0.12**	**0.04**	**0.02**	**0.06**	**0.07**	**0.03**	**0.04**
MgO	**1.20**	**1.88**	**1.35**	**2.24**	**2.73**	**0.36**	**0.17**	**0.25**	**0.17**	**0.02**	**0.09**
CaO	**2.48**	**3.24**	**2.97**	**5.27**	**5.26**	**1.17**	**0.66**	**0.90**	**0.81**	**0.37**	**0.82**
Na_2O	**4.06**	**3.73**	**4.27**	**3.03**	**3.47**	**3.81**	**3.89**	**4.10**	**4.19**	**4.35**	**3.23**
K_2O	**4.03**	**3.81**	**4.12**	**2.84**	**3.89**	**4.61**	**4.74**	**4.75**	**4.60**	**4.81**	**4.98**
P_2O_5	**0.17**	**0.17**	**0.23**	**0.19**	**0.22**	**<0.05**	**<0.05**	**0.05**	**0.08**	**0.01**	**0.02**
Total**	**98.69**	**99.41**	**99.05**	**98.99**	**98.89**	**100.10**	**99.75**	**99.01**	**99.37**	**98.65**	**98.09**
Ni	**8**	**20**	**–**	**2**	**10**	**–**	**–**	**2**	**<0.7**	**1**	**0.4**
Cr	**14**	**56**	**–**	**18**	**25**	**–**	**–**	**3**	**<1.0**	**3**	**3**
V	**51**	**85**	**–**	**107**	**139**	**<10**	**<10**	**13**	**6**	**2**	**3**
Ba	**912**	**687**	**–**	**748**	**1096**	**850**	**640**	**522**	**481**	**218**	**285**
Rb	**146**	**116**	**–**	**90**	**148**	**230**	**250**	**203**	**180**	**102**	**286**
Sr	**332**	**325**	**–**	**397**	**495**	**150**	**68**	**101**	**72**	**11**	**71**
Zr	**305**	**204**	**–**	**129**	**296**	**160**	**160**	**219**	**227**	**157**	**91**
Y	**22**	**21**	**–**	**21**	**24**	**32**	**28**	**36**	**39**	**28**	**20**
Nb	**21**	**21**	**–**	**18**	**17**	**20**	**23**	**22**	**30**	**12**	**23**
Pb	**21**	**14**	**–**	**14**	**34**	**–**	**–**	**25**	**23**	**14**	**29**
U	**2**	**9**	**–**	**5**	**4**	**–**	**–**	**5**	**18**	**3**	**23**

* All Fe calculated as FeO, ** oxides normalized to 100 wt.%, Total reports original oxide sum, – not determined, NAD27 sample coordinates.

Table 3, continued.

Map unit	Kcc	Kcc	Kcc	Kcc	Kap	Kdp	Kdp	Kmh	Kmm	Kcm	Kcm	Kc
Sample	87mk1	87mk11	4mmk6	4smk1	9smk48	87mk10	4smk2	4smk5	4smk6	4mmk4	4mmk8	9smk52
N lat.	36.417	36.355	36.4606	36.3085	36.3677	36.3283	36.2924	36.2515	36.2601	36.4375	36.4530	36.4626
W long.	118.607	118.670	118.631	118.6918	118.568	118.7283	118.7202	118.7382	118.6489	118.732	118.8136	118.5019
SiO_2	**69.00**	**68.50**	**66.44**	**72.16**	**77.44**	**76.50**	**74.90**	**67.28**	**74.73**	**74.32**	**75.82**	**62.64**
TiO_2	**0.42**	**0.38**	**0.74**	**0.32**	**0.09**	**0.16**	**0.21**	**0.55**	**0.12**	**0.20**	**0.08**	**0.90**
Al_2O_3	**15.20**	**16.10**	**15.54**	**14.63**	**12.44**	**11.90**	**13.14**	**15.32**	**13.55**	**13.85**	**13.24**	**17.06**
FeO*	**2.66**	**2.89**	**3.86**	**2.30**	**1.01**	**2.24**	**2.10**	**4.32**	**1.69**	**1.82**	**1.15**	**4.92**
MnO	**0.06**	**0.06**	**0.07**	**0.05**	**0.02**	**0.08**	**0.06**	**0.09**	**0.05**	**0.03**	**0.04**	**0.08**
MgO	**1.27**	**1.10**	**1.87**	**0.72**	**0.02**	**0.12**	**0.27**	**1.96**	**<0.10**	**0.26**	**0.12**	**2.04**
CaO	**3.92**	**3.90**	**4.11**	**2.36**	**0.42**	**0.72**	**1.10**	**4.26**	**0.74**	**1.32**	**0.90**	**4.92**
Na_2O	**3.50**	**4.06**	**3.27**	**3.45**	**3.45**	**4.39**	**4.10**	**3.14**	**3.29**	**3.58**	**3.31**	**4.28**
K_2O	**3.20**	**2.94**	**3.88**	**3.90**	**5.10**	**3.90**	**4.04**	**2.92**	**5.77**	**4.54**	**5.30**	**2.85**
P_2O_5	**0.14**	**0.15**	**0.21**	**0.11**	**0.02**	**<0.05**	**0.06**	**0.16**	**0.05**	**0.07**	**0.05**	**0.32**
Total**	**99.37**	**99.35**	**98.86**	**99.34**	**98.67**	**99.40**	**99.16**	**99.02**	**99.07**	**99.10**	**99.05**	**98.97**
Ni	**–**	**–**	**5**	**<0.8**	**2**	**–**	**<0.8**	**3**	**<0.7**	**<0.8**	**<0.7**	**8**
Cr	**–**	**–**	**16**	**<5**	**2**	**–**	**<5**	**16**	**<1.0**	**<5**	**<5**	**7**
V	**–**	**–**	**94**	**20**	**1**	**–**	**<5.5**	**78**	**<4.8**	**10**	**<4.7**	**115**
Ba	**–**	**–**	**1070**	**752**	**433**	**–**	**1210**	**848**	**993**	**1970**	**931**	**1007**
Rb	**–**	**–**	**122**	**122**	**162**	**–**	**81**	**88**	**221**	**109**	**152**	**83**
Sr	**–**	**–**	**554**	**293**	**24**	**–**	**85**	**309**	**74**	**155**	**73**	**924**
Zr	**–**	**–**	**122**	**126**	**130**	**–**	**263**	**122**	**131**	**131**	**81**	**147**
Y	**–**	**–**	**16**	**14**	**19**	**–**	**39**	**16**	**30**	**14**	**36**	**10**
Nb	**–**	**–**	**22**	**19**	**11**	**–**	**19**	**18**	**22**	**19**	**18**	**10**
Pb	**–**	**–**	**17**	**17**	**21**	**–**	**17**	**12**	**21**	**13**	**23**	**12**
U	**–**	**–**	**14**	**7**	**3**	**–**	**8**	**<2.6**	**17**	**8**	**21**	**3**