- OUATERNARY

QUATERNARY

- CRETACEOUS

- CRETACEOUS(?)

CRETACEOUS

CRETACEOUS(?)

AND JURASSIC

- MESOZOIO

– PENNSYLVANIAN

Morainal crests shown by dotted line. Present in southwest corner of

middle Pleistocene age consisting of rare cobbles and boulders of felsic

plutonic rocks in a matrix of coarse sand and fine gravel that locally con-

tains subhedral feldspar crystals 2 to 6 cm long. Horizontal exposures

undecomposed clasts. Most beds stained by iron oxides to colors ranging

contains veins of calcium carbonate. In some areas, unit acts as an aqui-

tard that forces ground water nearly to the surface, which supports thick

stands of vegetation where windblown silt and fine sand (not mapped)

unsorted rock debris interpreted to have been deposited as landslides;

deeply dissected by modern streams. Mass at east-central edge of quad-

rangle is composed of monolithologic debris of fine-grained granite de-

rived from the granite of French Spring (Dunne and Walker, 1993) ex-

posed in the Inyo Mountains to the east. Largest mass near west edge of

quadrangle composed of large boulders of plutonic rocks, many of which

are gneissic or mafic. Age of slides uncertain, probably early Pleistocene

Mount Whitney Intrusive Suite (Late Cretaceous)—Named by Moore and

Sisson (1987) for rocks in the Triple Divide Peak 15' quadrangle to the

Whitney Granodiorite—Porphyritic granodiorite and granite containing

phenocrysts of potassium feldspar 4 to 8 cm long. Average biotite K-Ar

age 83 Ma (Evernden and Kistler, 1970); Pb-U age 83 Ma (Chen and

Moore, 1982). Contains an average of about 71 weight percent SiO₂

Paradise Granodiorite—Porphyritic granodiorite and granite; contains po-

tassium feldspar phenocrysts 1 to 3 cm long that are characterized by

abundant, zonally arranged inclusions of biotite and hornblende. Biotite

K-Ar age 78 Ma; hornblende K-Ar age 84 Ma (Evernden and Kistler,

1970). Pb-U ages 86 to 83 Ma (Chen and Moore, 1982). Contains an

Granodiorite of Lone Pine Creek—Dark granodiorite containing abun-

dant mafic inclusions. Finer grained, darker, and mixed facies shown by

stipple. Pb-U age 87 Ma (Chen and Moore, 1982). Contains an average

zonite. Pb-U age 103 Ma (Chen and Moore, 1982). Contains an average

112 Ma (Chen and Moore, 1982). Contains an average of about 74

an average of about 72 weight percent SiO₂. Intruded by granodiorite of

nor metabasalt. Intruded by Independence pluton, Dragon pluton, and

granodiorite of Lone Pine Creek. Most probable age is Late Triassic or

gabbro. Intruded by Independence pluton and granodiorite of Lone Pine

Survey 7.5' topographic quadrangles within

118°45' 118°30' 118°15' 118°00' 117°45'

MINERAL KERN OLANCHA KEELER

Figure 3. Index map showing location of Lone Pine

15' quadrangle (shaded) in relation to adjacent and

area of Lone Pine 15' quadrangle.

Metavolcanic rocks (Mesozoic)—Chiefly metarhyolite and metadacite; mi-

Dragon pluton (Early Cretaceous)—Quartz monzodiorite and quartz mon-

Kcc Granite of Carroll Creek (Cretaceous?)—Coarse-grained granite. Contains

Mafic plutonic rocks (Mesozoic)—Quartz diorite, diorite, and hornblende

Independence pluton (Early Cretaceous)—Light-colored granite. Pb-U age

or older. Arrows indicate inferred directions of debris movement

BEDROCK UNITS, EXCLUDING DIKES

west. In Lone Pine quadrangle, consists of:

average of about 70 weight percent SiO₂

of about 64 weight percent SiO₂

of about 69 weight percent SiO₂

Lone Pine Creek. Exact age unknown

Jurassic (Moore, 1981)

Glacial moraines (Pleistocene)—Massive, very poorly sorted, bouldery grav-

el deposits in Sierra Nevada. Includes both Tahoe and Tioga glacial till.

Landslide deposits (Quaternary or Tertiary)—Large, hummocky masses of

from grayish orange or deep reddish brown to greenish gray. Locally

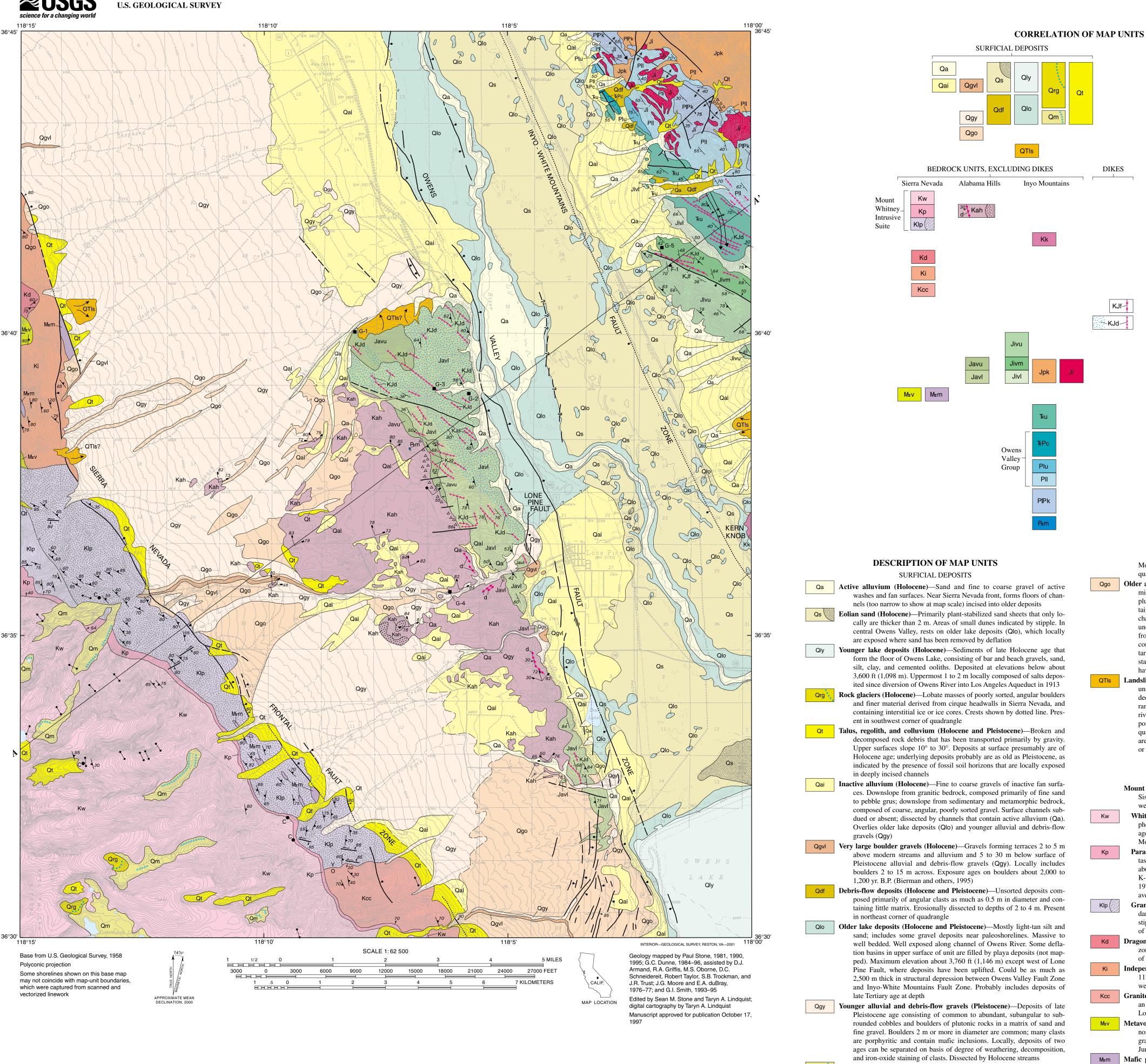
characterized by 0 to 10 percent boulders; vertical exposures show few

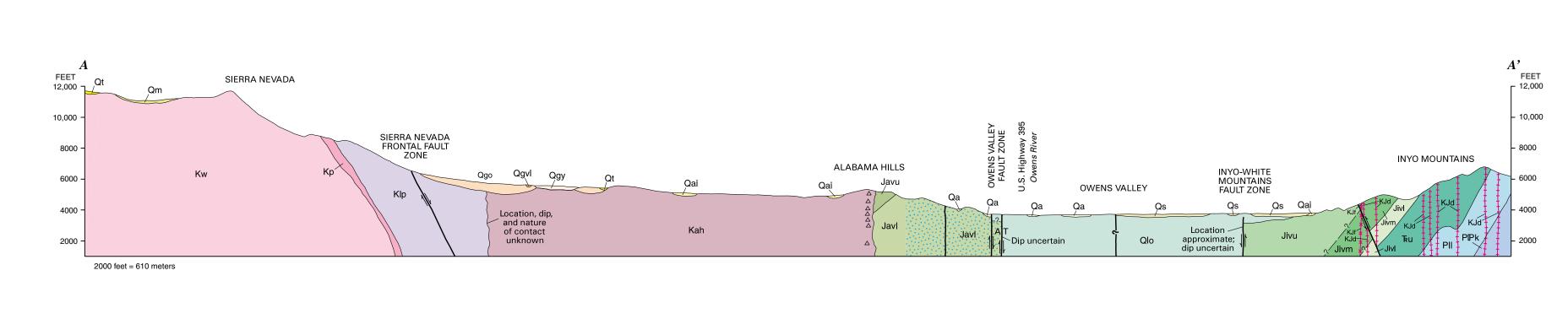
Qgo Older alluvial and debris-flow gravels (Pleistocene)—Deposits of early to

PALEOZOIC(?)

Triassic

OR TERTIARY





GEOLOGIC MAP OF THE LONE PINE 15' QUADRANGLE, INYO COUNTY, CALIFORNIA

By

Paul Stone, George C. Dunne, James G. Moore, and George I. Smith 2000

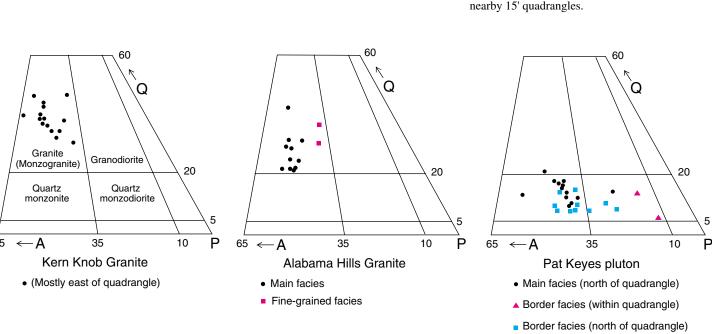


Figure 1. Index map showing selected geographic features

in the Lone Pine 15' quadrangle.

Figure 4. Triangular diagrams showing volume proportions of quartz (Q), alkali feldspar (A), and plagioclase feldspar (P) of samples from the Pat Keyes pluton, Alabama Hills Granite, and Kern Knob Granite

Alabama Hills Granite (Late Cretaceous)—Hypidiomorphic seriate to faintly porphyritic, medium-grained biotite monzogranite that locally contains equant, pale-pink phenocrysts of potassium feldspar as large as 1 cm. Outcrop color very pale orange to pinkish gray. Stipple indicates local fine-grained, hypabyssal(?) facies. Areas of complexly mixed country rocks and granite present locally along pluton margin. Locally, contains abundant aplite and rare pegmatite dikes, most of which are gently dipping. A few prominent dikes are shown on map (d); the dip is shown where known. Biotite K-Ar age 82 Ma (Evernden and Kistler, 1970); preferred Pb-U age 85 Ma (Chen and Moore, 1982) (Locality G-4)

Volcanic complex of the Alabama Hills (Middle Jurassic)—Divided into: **Upper part**—Consists chiefly of light- to medium-light-gray, massive, slightly welded tuff at least 450 m thick. Tuff contains 18 to 28 percent phenocrysts consisting of subequal amounts of quartz and potassium feldspar and sparse plagioclase and biotite. Flattened pumice lapilli generally rare but locally abundant near base of tuff. Medium- to darkgray, aphanitic lithic lapilli typically compose less than 2 percent of tuff but locally form diffuse clusters composing as much as 20 percent. Top of tuff intruded by Alabama Hills Granite. Basal part of unit locally consists of muscovite schist, quartzite, and rare volcanogenic conglomerate having a maximum thickness of about 10 m. Lower contact of unit probably unconformable in southern exposure area but of uncertain character in northern exposure area. Minimum Pb-U age of tuff about 170 Ma (Dunne and Walker, 1993) (Locality G-1). Small part of northern outcrop area contains abundant dikes (KJd) as shown by pat-

Lower part—Consists of an upper subunit of volcanogenic sedimentary and volcanic rocks and a lower subunit of rhyolite tuff. Unit characterized by intense hydrothermal alteration over much of its exposure area, which obscures many details of its stratigraphy. Upper subunit consists primarily of weakly bedded to massive, predominantly matrix supported pebble to cobble conglomerate, siltstone, sandstone, and pebbly sandstone. These rocks are interlayered with about 10 percent felsic tuff and, in southernmost outcrops, rare vesicular lava flows. Rhyolite tuff of lower subunit, present in northeasternmost exposures of unit, is grayish pink to yellowish gray, massive, and slightly welded. Tuff contains 15 to 35 percent phenocrysts consisting of subequal amounts of quartz and potassium feldspar and sparse plagioclase and biotite, and 1 to 2 percent volcanogenic lithic lapilli. Minimum Pb-U age of tuff about 167 Ma (Dunne and others, 1998) (Locality G-2). Unit cut by abundant dikes (KJd) as shown by pattern

Kk Kern Knob Granite (Late Cretaceous)—Leucocratic, medium-grained biotite monzogranite having a hypidiomorphic inequigranular texture. Sparse varietal minerals include biotite, muscovite, fluorite, hematite, and garnet. Contains locally abundant, northwest-striking aplite dikes and pegmatite lenses and dikes that consist primarily of microcline and quartz, with less abundant amazonite. Biotite ⁴⁰Ar/³⁹Ar plateau age 91 Ma (Griffis and others, 1986). Exposed only at Kern Knob, which is at western base of Inyo Mountains and lies mostly east of quadrangle Inyo Mountains Volcanic Complex of Dunne and others (1998)—Divided

Upper part (Late and Middle Jurassic)—Massive to faintly bedded, matrix-supported volcanogenic conglomerate (about 65–70 percent of unit), parallel-bedded to crossbedded sandstone and siltstone (about 30 percent), and rare lenses of felsic to intermediate-composition welded tuff that become more abundant southeast of quadrangle. Freshwater pelecypods and gastropods present locally (Dunne, 1986) (Locality F-1). Minimum thickness in quadrangle about 900 m, increasing to more than 2,200 m southeast of quadrangle. Andesite lava flow about 450 m above base of unit southeast of quadrangle has a Pb-U age of about 163 Ma; two samples of dacite tuff about 1,100 m below faulted top of unit southeast of quadrangle have minimum Pb-U ages of about

148 and 150 Ma (Dunne and others, 1998) Middle part (Middle Jurassic)—Andesite and rhyolite lava flows (about 50 percent of unit), bedded to massive volcanogenic sandstone and conglomerate (about 30 percent), and welded rhyolite ash-flow tuff (about 20 percent). Conglomerate ranges from matrix supported to clast supported. Unit thickness about 750 m. In quadrangle, preferred Pb-U age of uppermost part of unit is 168 Ma (Locality G-5); preferred Pb-U ages of middle and uppermost parts of unit southeast of quadrangle are 169 and 168 Ma, respectively (Dunne and Walker, 1993)

Lower part (Middle Jurassic?)—Faintly bedded to predominantly massive, mostly matrix supported, volcanogenic pebble, cobble, and rare boulder conglomerate (about 75–80 percent of unit), parallel-bedded to crossbedded volcanogenic sandstone and pebbly sandstone (about 20 percent), and sparse lenticular lava flows of vesicular basalt or basaltic andesite. Basal several meters consist of bedded conglomerate that contains clasts of sedimentary rocks. Unit thickness about 300 m. Undated; age is probably Middle Jurassic but could be as old as Middle Triassic. Lower contact with Union Wash Formation unconformable

Jpk Pat Keyes pluton (Middle Jurassic)—Medium- to light-gray, mediumgrained, hypidiomorphic granular to seriate plutonic rocks of variable composition. Main mass, exposed largely north and east of quadrangle, consists predominantly of ±clinopyroxene-biotite-hornblende monzogranite and quartz monzonite. These rocks grade irregularly into a relatively mafic border facies of clinopyroxene-biotite-hornblende quartz monzodiorite and less common quartz diorite, diorite, and monzodiorite (Ross, 1969; Dunne, 1970, 1971). Exposures in quadrangle are primarily of the mafic border facies. Hornblende K-Ar ages 178 and 163 Ma (Ross, 1969); Rb-Sr (whole-rock plus mineral separate) age 183 Ma

(Dunne, 1970, 1971) **Intrusive rocks marginal to Pat Keyes Pluton (Middle Jurassic?)**—Primarily dark-gray, reddish-brown-weathering, fine-grained, altered and recrystallized diorite and tonalite that have been intensely sausseritized and sericitized. Composed principally of plagioclase, epidote, clinozoisite, calcite, and sericite; quartz is minor. Primary intrusive texture partly to completely destroyed by recrystallization. Includes minor light-colored intrusive rocks and small, irregular masses of metasedimentary rocks that are not mapped separately. Provisionally interpreted as cogenetic with

mafic border facies of Pat Keyes pluton Union Wash Formation (Middle? and Early Triassic)—Consists of an upper member of dark-gray micritic limestone, pink shale, and light-brown siltstone about 90 m thick; a middle member of medium- to dark-gray, thinbedded mudstone, siltstone, very fine grained to fine-grained sandstone, and micritic limestone about 680 m thick; and, in part of the area, a lower member of ledge-forming, light-gray to brown limestone and silty to finegrained sandy limestone as much as 60 m thick (Stone and others, 1991). Ammonoids locally abundant in basal parts of middle and upper members. Basal 25 m of unit on ridge 1 km southeast of Fossil Hill consists of argillite, silty limestone, minor granule to pebble conglomerate, and hydrothermal or metamorphic talc; this sequence previously was interpreted as Permian in age and assigned to the Conglomerate Mesa Formation by Stone and Stevens (1987) and Stone and others (1991)

Owens Valley Group—In this area, divided into: Conglomerate Mesa Formation (Early Triassic and Late Per**mian**)—Consists of an upper and a lower unit equivalent to members C and B of Conglomerate Mesa Formation as defined by Stone and Stevens (1987). Upper unit (member C), about 40 m thick, consists of brown, ochre, and gray chert-pebble conglomerate, pebbly calcareous sandstone, and sandstone. Lower unit (member B), about 130 m thick with the base covered, consists of gray to brown limestone, silty to sandy limestone, and minor grayish-orange to maroon siltstone and shale. Limestone in member B contains locally abundant brachiopods, gastropods, bryozoa, and echinoderm debris. Member C is apparently conformable with lower member of Union Wash Formation and is here interpreted as Early Triassic in age. Formation was assigned a Late Permian age by Stone and Stevens (1987) on the basis of fossils in member B. Contact between members C and B (not shown) is interpreted as

Lone Pine Formation (Early Permian)—In descending order, consists of Reward Conglomerate Member and members C, B, and A of Lone Pine Formation as defined by Stone and Stevens (1987). Divided into: **Upper part**—Reward Conglomerate Member and member C, undivided. Reward Conglomerate Member, about 200 m thick, consists of dark-gray to brown, thick-bedded, medium- to coarse-grained quartzite and chert- and quartzite-pebble conglomerate; basal few meters consist of light-gray sandy limestone and marble. Member C, about 120 m thick, consists of darkbrown, massive quartzose siltstone and hornfels interbedded with minor fine- to coarse-grained quartzite and rare chert- and quartzite-pebble conglomerate. Unit is truncated southeastward by angular unconformity beneath Union Wash Formation Lower part—Members B and A, undivided. Member B, about 180 m

thick, consists of greenish-gray to reddish-brown, thin-bedded calcareous mudstone, siltstone, and calc-hornfels, and a few widely spaced beds of gray bioclastic limestone or marble 1 to 3 m thick. Member A, about 500 m thick, generally is metamorphosed and consists primarily of gray to reddish-brown, thin-bedded argillite, siltite, fine-grained quartzite, and calc-hornfels. Metamorphic grade decreases near east edge of quadrangle, where member A consists of light- to medium-gray, siliceous to calcareous mudstone, calcareous siltstone to very fine grained sandstone, and silty limestone

PPk Keeler Canyon Formation (Early Permian and Pennsylvanian)—Light- to medium-gray, medium- to thick-bedded limestone and silty to sandy limestone, generally metamorphosed to marble and calc-hornfels. Thickness about 500 m; base not exposed

Metasedimentary rocks (Paleozoic?)—Calcitic marble and calc-hornfels forming small pendant in northern part of Alabama Hills Granite

KJf

Felsic dike (Cretaceous or Jurassic)—Very light gray, aphanitic, felsic dike 4 m thick in Invo Mountains. May correlate with Early Cretaceous (about 140 Ma) felsic dikes or the Late Jurassic (148 Ma) granite of French Spring east of quadrangle (Dunne and Walker, 1993)

KJd Mafic, intermediate-composition, and minor felsic dikes (Cretaceous? and Jurassic)—Aphanitic to fine-grained, commonly porphyritic dikes in Alabama Hills and Inyo Mountains that range in composition from diorite to granite. Mafic to intermediate compositions predominate. Majority of dikes are vertical to subvertical and strike northwest; a few strike east-northeast. Only the largest, most prominent dikes are shown. Interpreted primarily as part of the Independence dike swarm, which is considered mainly Late Jurassic in age (Chen and Moore, 1979) but locally contains dikes of Late Cretaceous age (Coleman and others, 2000). Pb-U age of one dike in northern Alabama Hills is 148 Ma (Chen and Moore, 1979) (Locality G-3). Includes some dikes similar in lithology to felsic dike mapped separately in Inyo Mountains (KJf); such dikes could be of

Early Cretaceous age. In northern Alabama Hills, dikes and irregular hypabyssal intrusions constitute more than 50 percent, and locally as much as 90 percent, of the total rock volume over a large area (indicated by pattern). Some of these dikes may be genetically associated with the lower part of the volcanic complex of the Alabama Hills (Javl)

ment toward viewer). Bar and ball on downthrown side; direction of

downthrown side locally changes along scarps that mark the Owens Val-

ley Fault Zone, probably as a result of horizontal offset that has influ-

Contact—Showing dip where known. Dashed where approximate; dotted where concealed; queried where inferred or not field-checked. Y, younger plutonic rock; O, older plutonic rock Fault—Showing dip where known. Dashed where inferred; dotted where concealed; queried where uncertain. Arrows show relative horizontal displacement (in cross section: A, movement away from viewer; T, move-

enced vertical separation (Beanland and Clark, 1994) Small shear fault—Showing dip. Arrow shows direction of relative horizon-

← _ Anticline—Showing trace of axial surface and direction of plunge of axis Syncline—Showing trace of axial surface and direction of plunge of axis where known

Strike and dip of beds

Strike and dip of foliation

← Strike of foliation or bearing of lineation—Dip or plunge unknown Strike and dip of intersecting joints—Indicated by two or more symbols

joined at point of observation

Zone of intermixed plutonic and country rocks

Landslide—Unit QTls. Arrow indicates inferred direction of debris move-

• Copper mineralization locality

Geochronologic (Pb-U, zircon) sample locality

DISCUSSION

The Lone Pine 15' quadrangle encompasses an area of about 620 km² that extends from the Sierra Nevada on the west across the Alabama Hills and Owens Valley to the Inyo Mountains on the east (fig. 1). Owens Valley, a closed depression, is the westernmost basin of the Basin and Range physiographic province, and the Sierra Nevada forms the western bounding range of this province. A small part of Owens Lake, a playa that marks the low point and southern end of Owens Valley, is in the southeast corner of the quadrangle. Elevations in the quadrangle range from about 3,560 ft (1,085 m) on the floor of Owens Lake to 14,027 ft (4,275 m) at Mount Langley on the Sierran crest. Mount Whitney (14,494 ft; 4,418 m), highest point in the conterminous United States, is 4 km west of the quadrangle boundary. Elevations in the Inyo Mountains are as high as about 9,700 ft

U.S. Highway 395 crosses the quadrangle from north to south along the west side of Owens Valley, passing through the town of Lone Pine at the base of the Alabama Hills. California State Highway 136 branches east from U.S. 395 2 km south of Lone Pine. Another well-traveled paved road, the Whitney Portal Road, leads west from Lone Pine to Whitney Portal at the head of the Mount Whitney Trail (fig. 1). Numerous additional roads, most of which are light-duty or unimproved, provide access to many localities in Owens Valley and along the flanking range fronts. Most of the mountainous parts of the quadrangle are not accessible by road.

The geology of the quadrangle was mapped by a combination of field methods and

the interpretation of aerial photographs. Individual responsibilities for the geologic mapping are as follows: Moore, Sierra Nevada; Dunne, Alabama Hills; Stone and Dunne, Inyo Mountains; and Smith, Owens Valley, including the piedmont slopes flanking the Sierra Nevada and Inyo Mountains. Some traces of the Owens Valley Fault Zone were taken from the more detailed mapping of Beanland and Clark (1994). The 15' topographic quadrangle map, used as a base for the geologic map, is out of print and has been superseded by four 7.5' topographic quadrangle maps at a scale of 1:24,000 (fig. 2). These maps should be consulted for more recent information on the locations of roads and other cultural features than is shown on the 15' map. The location of the Lone Pine 15' quadrangle in relation to adjacent and nearby 15' quadrangles is shown

PALEOZOIC AND TRIASSIC SEDIMENTARY ROCKS

The oldest widespread rocks in the quadrangle are sedimentary rocks of Pennsylvanian, Permian, and Triassic age that underlie much of the western slope of the Inyo Mountains. These rocks are part of the Cordilleran miogeocline, a thick and extensive assemblage of mostly marine sedimentary rocks that accumulated along the North American continental margin from late Precambrian through early Mesozoic time. Rocks in the Inyo Mountains represent one of the most southwesterly preserved segments of the mio-

Miogeoclinal rocks in the quadrangle represent a range of depositional environments and a complex geologic history (Stone and Stevens, 1984, 1987; Stone and others, 1991; Stevens and others, 1997). The Keeler Canyon Formation and lower part of the Lone Pine Formation consist of turbidites and related fine-grained sediments deposited in a deep marine basin during the Pennsylvanian and Early Permian. The coarse-grained, conglomeratic upper part of the Lone Pine Formation, in contrast, reflects an abrupt change to a

shallow-water, probably nonmarine depositional setting in late Early Permian time. This change likely resulted from uplift of the continental margin. The area remained relatively high during deposition of the overlying Conglomerate Mesa Formation of Late Permian and Early Triassic age, which is exposed at Fossil Hill (fig. 1). Limestone in member B of this formation contains fossils and sedimentary features indicating a shallow-water marine setting, and the overlying conglomerate and sandstone (member C) indicate nonmarine deposition. The fine-grained calcareous rocks of the overlying Union Wash Formation reflect renewed subsidence of the continental margin in Early and Middle(?) Triassic time and a return to open-marine deposition. An angular unconformity that is well exposed 1 km southeast of Fossil Hill reflects

northwestward tilting and subaerial erosion of the Lone Pine Formation before deposition of the overlying Triassic strata, probably as part of a regional tectonic event. Stone and Stevens (1987, 1988) interpreted this event to have predated deposition of Upper Permian limestone in member B of the Conglomerate Mesa Formation, which was thought to be present above the unconformity. Fossils (conodonts) from the lowest limestone beds above the unconformity, however, were later identified as Early Triassic (B.R. Wardlaw, written commun., 1996). These beds and a thin underlying sequence directly above the unconformity, consisting primarily of argillite and hydrothermal or metamorphic tale, are therefore reassigned to the Union Wash Formation. At Fossil Hill, the unconformity is now interpreted to separate the Upper Permian limestone unit (member B) of the Conglomerate Mesa Formation from the overlying conglomerate and sandstone unit (member C) of the same formation, which is herein considered to be Early Triassic. Thus, the age of tectonism represented by the unconformity is now interpreted as latest Permian or ear-

liest Triassic (Stevens and others, 1997). Calcareous metasedimentary rocks that form a very small pendant in the Alabama Hills Granite (NE1/4 sec. 13, T. 15 S., R. 35 E.) probably are miogeoclinal strata of Paleozoic age, but these rocks are too thoroughly metamorphosed and limited in areal extent to permit a definite unit or age assignment.

MESOZOIC PLUTONIC AND VOLCANOGENIC ROCKS, EXCLUDING DIKES Plutonic, volcanic, and volcanogenic sedimentary rocks exposed in the quadrangle are in the eastern fringe of the Sierran magmatic arc that was active in this region throughout much of middle to late Mesozoic time. In the quadrangle, most of these rocks are of two broad age groups, Middle to Late Jurassic and late Early to Late Cretaceous. Some metavolcanic and mafic plutonic rocks (Mzv, Mzm) enclosed as small pendants by Cretaceous plutons in the Sierra Nevada could be as old as Triassic, but these are not included in the following discussion because of their limited outcrop area and lack of age

Volcanic and volcanogenic sedimentary rocks of Middle to Late Jurassic age are

widespread in the Inyo Mountains and Alabama Hills (Dunne and Walker, 1993; Dunne and others, 1998). The sedimentary rocks accumulated in various subaerial environments, mostly by fluvial and debris-flow processes in alluvial-fan and river-floodplain settings, and less commonly in slightly evaporative lakes and as eolian dunes. Sparse paleocurrent indicators reflect northerly to northeasterly directions of sediment transport. Episodic volcanism during this time consisted mainly of explosive eruptions of silicic ash deposited as welded ash flows. Lava flows are less abundant and are primarily of intermediate composition; silicic and mafic flows are rare. The principal phase of volcanic activity took place during the Middle Jurassic and was broadly coeval with a widely recognized period of intense magmatism reported from many parts of the Sierran igneous arc (Evernden and Kistler, 1970; Saleeby and Busby-Spera, 1992).

The Pat Keyes pluton, an intrusive representative of this Middle Jurassic magmatic episode, has been described in detail by Ross (1969) and Dunne (1970). An accompanying triangular diagram (fig. 4) shows the proportions of quartz, alkali feldspar, and plagioclase feldspar in 25 samples from this unit as determined by thin-section point counts; the samples examined are largely from areas north of the quadrangle. Most samples fall within the quartz monzonite and quartz monzodiorite fields of Streckeisen (1973). Later magmatic activity in the quadrangle is represented by granitic plutons that were emplaced during late Early and Late Cretaceous magmatic episodes also widely rep-

resented elsewhere in the Sierra Nevada (Evernden and Kistler, 1970). Several plutons in the Sierra Nevada extend eastward into the quadrangle from the adjacent Mount Whitney 15' quadrangle, where they have been described by Moore (1981). A prominent Late Cretaceous pluton that underlies an area of about 35 km² in the Alabama Hills has not been described previously. Although broadly coeval with the pre-

dominantly granodioritic plutons of the Mount Whitney Intrusive Suite in the Sierra Ne-

vada, this pluton is distinctly less mafic and is interpreted to represent a separate intrusive mass. This lithologically distinctive pluton, bold outcrops of which have served as background scenery in many motion pictures, is herein named the Alabama Hills Granite. Its type locality is in S1/2 sec. 30, T. 15 S., R. 36 E., on the north side of Whitney Portal Road 400 m east of the junction with Movie Road (fig. 1; see Lone Pine 7.5' topographic quadrangle map for detailed road information). Modal analyses of 13 samples determined from thin-section point counts indicate a composition of monzogranite (fig. 4). Another intrusive mass of Late Cretaceous age, previously referred to as the Kern Knob pluton (Griffis, 1986, 1987), makes up a prominent hill at the base of the Inyo Mountains. This hill is mostly just east of the quadrangle boundary in secs. 19 and 30, T. 15 S., R. 37 E., and is designated Kern Knob on the adjacent New York Butte 15' quadrangle. The hill is named Haystack on the newer Dolomite 7.5' quadrangle, but it is referred to herein by the older name Kern Knob. The pluton has a total outcrop area of about 2.5 km², the westernmost part of which is in the Lone Pine 15' quadrangle. The pluton belongs to a small group of petrologically distinctive, extremely leucocratic plutons in eastern California that contain unusual varietal and accessory minerals such as muscovite, garnet, and fluorite (Miller and Bradfish, 1980). Because of its petrologic significance, we formally name this pluton the Kern Knob Granite. Its type locality is designated as a

small quarry at the northern base of Kern Knob in the New York Butte 15' quadrangle, in

SW1/4NE1/4 sec. 19, T. 15 S., R. 37 E., about 500 m east of the boundary with the Lone Pine 15' quadrangle. Modal analyses of 15 samples determined from stained-slab and thin-section point counts indicate that the unit is composed of monzogranite (fig. 4). Additional description and interpretation of this unusual pluton are provided by Griffis

The voluminous Mount Whitney Intrusive Suite (Moore and Sisson, 1987) was em-

placed near the end of the Late Cretaceous pulse of igneous activity in the Sierra Nevada (about 85 Ma). This suite, which constitutes most of the granitic rocks in the Sierran part of the quadrangle, makes up a massive, nested, northwest-trending composite intrusion that becomes progressively younger and more silicic inward. The suite also is exposed to the south in the Olancha 15' quadrangle (duBray and Moore, 1985), to the west in the Mount Whitney and Triple Divide Peak 15' quadrangles (Moore, 1981; Moore and Sisson, 1987), and to the northwest in the Mount Pinchot and Marion Peak 15' quadrangles (Moore, 1963, 1978) (fig. 3). After emplacement, this 1,100-km² mass began solidifying from the walls inward. Before complete solidification, the partly molten, and somewhat more differentiated, siliceous core surged upward, twice intruding its older, outer shell. Initially, the outer part of the composite pluton solidified as the granodiorite of Lone Pine Creek on the east and the granodiorite of Sugarloaf (Moore, 1981) on the west. The next surge emplaced the Paradise Granodiorite. The final surge emplaced the Whitney Granodiorite in the center such that only a thin shell of Paradise Granodiorite remained on the east, adjacent to the granodiorite of Lone Pine Creek. In places, this shell of Paradise

JURASSIC AND CRETACEOUS(?) DIKES

Granodiorite is no thicker than about 100 m.

the origin of the entire swarm to a single magmatic event.

Jurassic and older rocks of the Alabama Hills and Inyo Mountains are intruded by numerous dikes (KJd) of mafic, intermediate, and, less commonly, felsic composition. Most of these dikes probably belong to a regionally extensive, northwest-striking family of dikes known as the Independence dike swarm (Moore and Hopson, 1961). The Independence swarm includes several dikes that have been isotopically dated as Late Jurassic (148 Ma) (Chen and Moore, 1979), including one in the Alabama Hills (Locality G-3), and many dikes in the quadrangle probably are of this age. Chen and Moore (1979) interpreted the Independence dikes to have been emplaced along fractures produced by a regional crustal extension event in Late Jurassic time (Chen and Moore, 1979). Recently, however, the Independence swarm has been shown to contain dikes of Late Cretaceous as well as Late Jurassic age (Coleman and others, 2000), so it is no longer possible to relate

Some dikes in the northern Alabama Hills could be significantly older than 148 Ma and not genetically related to the Late Jurassic dikes of the Independence swarm. In this area, dikes are abundant in the lower part of the volcanic complex of the Alabama Hills (Javl), but are almost absent except locally in the upper part (Javu). This outcrop distribution suggests that many of these dikes are Middle Jurassic in age and may predate the upper part of the volcanic complex. Such dikes could have originated at volcanic centers where magma rose to the surface during deposition of the lower part of the volcanic com-

A prominent aphanitic dike of felsic composition in the Inyo Mountains is shown as a separate unit (KJf). Dikes of this type just east of the quadrangle cut across relatively mafic dikes of presumed Late Jurassic age, and one such felsic dike has been dated as about 140 Ma (Early Cretaceous) (Dunne and Walker, 1993). The mapped dike may be coeval with these dikes, or it may be an offshoot of the Late Jurassic (148 Ma) granite of French Spring, which also crops out just east of the quadrangle (Dunne and Walker,

LATE JURASSIC AND CRETACEOUS DEFORMATION Pre-Cretaceous rocks in the quadrangle were subjected to episodic contractional deformation beginning in Late Jurassic time, during which these rocks were compressed and shortened in a northeast-southwest direction (Dunne, 1986). This deformation took place in a zone called the East Sierran thrust system that trends southeastward through the quadrangle (Dunne and others, 1983). In the earliest phase of deformation, Mesozoic volcanogenic strata in the Inyo Mountains and Alabama Hills were tilted southwestward and locally were folded and cleaved along northwest trends. The age of this event is tightly bracketed in areas just southeast of the quadrangle, where deformation involved 150- to 148-Ma volcanic rocks and preceded emplacement of northwest-striking mafic dikes interpreted to represent the Late Jurassic (148 Ma) part of the Independence dike swarm (Dunne and others, 1998). The northwest-striking, northeast-dipping dip-slip fault that cuts the volcanic complex of the Inyo Mountains east of Owenyo probably formed at this time, because it is interpreted to be intruded by the 148-Ma granite of French Spring just east of the quadrangle (Dunne and Walker, 1993). Following their emplacement, some Independence dikes and their host rocks were affected by additional deformation. Cleavage was imposed on some dikes, and some are cut by a post-140 Ma thrust fault a short dis-

OUATERNARY DEPOSITS

tance southeast of the quadrangle (G.C. Dunne and J.D. Walker, unpub. data, 1995).

Nearly half the quadrangle is covered by surficial deposits of Quaternary age. Coarse-grained alluvial and debris-flow deposits derived from erosion of the Sierra Nevada, Alabama Hills, and Inyo Mountains are areally the most abundant, and most of these deposits are of Pleistocene age. Eolian sands of Holocene age and lake deposits of late Pleistocene and Holocene age are widespread in Owens Valley on both sides of the Owens River. Other surficial deposits, including a few glacial moraines in the Sierra Nevada, are of relatively limited areal extent.

Large landslide masses, some of which may be late Tertiary in age, are the oldest surficial deposits in the quadrangle. These deposits consist of jumbled masses of large and small rock fragments that are located downhill from steep outcrops of similar rock types, and most have hummocky surfaces. Interbedded alluvial and debris-flow gravels of Pleistocene age form broad, gentle slopes between the eastern base of the Sierra Nevada and the flat floor of Owens Valley. These deposits are particularly well exposed where cut by creeks in the Alabama Hills, especially along Lone Pine Creek, and where dissected by deep channels near the Sierran

range front 5 to 6 km north of Lone Pine Creek. Most of the alluvial gravels are distinctly bedded and contain moderately rounded clasts, rarely more than 0.5 m across, that rest in a matrix of finer material. Debris-flow gravels, usually considered a product of massive floods, most commonly are clast supported, indistinctly bedded, and characterized by angular fragments as much as 1 or 2 m across. Many or most of these deposits are inferred to be related to glaciation in the Sierra Nevada. The Pleistocene alluvial and debris-flow gravels are divided into older and younger deposits on the basis of weathering characteristics, especially on the surfaces of biotite-

bearing plutonic-rock boulders. Many boulders in the younger gravels are porphyritic, and these characteristically have weather-resistant potassium feldspar phenocrysts and small mafic inclusions that project 2 to 5 cm above weathered surfaces. Boulders of similar lithology in the older gravels, by contrast, generally are partially or totally weathered to loose grus. Boulders in some of the oldest deposits are entirely decomposed, and these sediments can be identified only by the high percentage of loose subhedral potassium feldspar phenocrysts, 2 to 6 cm long, derived from areas exposing the porphyritic Whitney Granodiorite or Paradise Granodiorite in the Sierra Nevada. Glacial moraines of the Sierra Nevada in the quadrangle extend nearly to the range front but do not reach it. Most of the moraines have easily identified crests and consist of totally unsorted angular debris that ranges in size from sand to clasts several meters long.

Good exposures of moraine gravels can be seen in cuts along Whitney Portal Road at an elevation of about 7,600 ft (2,317 m). Lake deposits crop out along the Owens River and along the edges and floor of Owens Lake. Lake deposits also underlie the thin layer of windblown sand that covers much of the notably flat center of the valley, and they are exposed where wind has excavated holes in that sand layer. Most of the lake deposits are well bedded and consist of light-tan clay, silt, and fine sand. Lake deposits in the quadrangle, and for another 10 km to the north, lie primarily at elevations below about 3,760 ft (1,146 m), the maximum elevation of the overflowing lake that filled the south end of Owens Valley during much of the late Pleistocene. That lake began to shrink sometime between 8,000 and 5,000 years ago (Smith and others, 1997). Fossil clams and snails are present locally in lake sediments at elevations just below 3,760 ft (1,146 m). West of the Owens Valley Fault Zone, lake sediments extend to slightly higher elevations because of fault-related uplift. Rock glaciers, talus, regolith, and colluvium in the quadrangle are largely products

of gravity acting on unconsolidated materials. Definitions of these deposits overlap somewhat, but the sediment size, upper-surface slope, and geologic setting usually provide a basis for the chosen name. Active and inactive alluvial deposits in the quadrangle were formed by running

streams. Active alluvium is found 1 to 2 m above the late summer stream levels because the most active deposition and transport have taken place during floods that followed exceptionally wet winters or intense summer and autumn storms. Inactive alluvium is lithologically similar to nearby active alluvium but is characterized by surfaces that commonly are 0.5 to 3 m higher than the active alluvium and are almost free of channels. Very thin desert varnish has coated the surfaces of many clasts in the inactive alluvium, making these deposits somewhat darker than the active alluvium. Conspicuous gravels containing very large boulders 2 to 15 m across (Qgvl) form

narrow terraces along several modern streams that drain the Sierra Nevada in the quadrangle. Because of the very large size of the boulders, their deposition might seem to be the product of debris-flow processes associated with glaciation. The deposits that contain these boulders, however, are deeply inset into the youngest Pleistocene gravel deposits (Qgy), suggesting that they are Holocene in age. This age is confirmed by radiometricexposure dating of large boulders adjacent to Lone Pine Creek 4.5 km east of the mountain front, which indicates that these boulders last came to rest about 2,000 to 1,200 years ago (Bierman and others, 1995). There is no evidence of major glaciation in the Sierra Nevada that recent. The inference that the transport and deposition of very large boulders did not require glaciation is further supported by the presence of debris-flow boulders 1 to 2 m across on fan surfaces east of the Sierra Nevada 27 km south of the quadrangle, 10 to 15 km south of the southernmost conspicuous Sierran glacial cirque at Olancha Peak. LATE TERTIARY AND QUATERNARY FAULTING

The quadrangle is traversed by three major northwest-striking fault zones that have been active in late Tertiary and Quaternary time: the Sierra Nevada Frontal Fault Zone,

the Owens Valley Fault Zone, and the Inyo-White Mountains Fault Zone. Cumulative displacements on these faults during about the last 6 m.y. are responsible for the present physiography of the quadrangle and for the subsurface structure of Owens Valley (Gillespie, 1991; Hollett and others, 1991). The Sierra Nevada Frontal Fault Zone separates the western part of Owens Valley, including the Alabama Hills, from the Sierra Nevada block of pre-Quaternary basement rocks on the west. The Owens Valley Fault Zone (Carver, 1970; Beanland and Clark, 1994) separates the western part of Owens Valley, in which bedrock generally is within 300 m of the land surface, from a structurally much deeper eastern graben, in which bedrock is as much as 2,500 m below the surface (Pakiser and others, 1964; Hollett and others, 1991). The buried Inyo-White Mountains Fault Zone is inferred to separate this deep graben from the Inyo Mountains block of pre-Quaternary

The Sierra Nevada Frontal Fault Zone, which is poorly exposed along much of its trace in or adjacent to Sierran plutonic rocks, is mapped as a discontinuous series of exposed segments that dip 60° to 80° E. Along some fault segments that cut Quaternary sediments, a scarp 1 to 3 m high is developed, with the east side down, but in other places the fault zone has little surface expression. Overall, the fault zone is interpreted to have normal, east-side-down displacement with little or no strike-slip component (Hollett and others, 1991). Total vertical displacement on the fault zone is thought to be about 3 km (Beanland and Clark, 1994).

basement rocks to the east.

The most active fault zone in the quadrangle is the Owens Valley Fault Zone, movement on which caused the Lone Pine earthquake of March 26, 1872. This great earthquake (Richter magnitude about 8) is one of California's largest historic earthquakes, exceeded only by the 1857 Fort Tejon and the 1906 San Francisco earthquakes (Beanland and Clark, 1994). The Owens Valley Fault Zone extends north-northwestward across the quadrangle near the eastern base of the Alabama Hills and can be traced about 55 km north and 25 km south of the quadrangle for a total of about 110 km. The surface trace of the fault zone is marked by a nearly continuous zone of scarps, depressions, pressure ridges, and other linear features, some of which coincide with differences in ground-water level across the fault zone (Hollett and others, 1991; Beanland and Clark, 1994; Danskin, 1998). Most of the fault traces shown on the map are readily identified on the ground or aerial photographs; some were taken from Beanland and Clark (1994), who also describe the fault features in detail at many localities. Many of the scarps and other surface fea-

tures that define the fault zone experienced movement or were initiated at the time of the Most traces of the Owens Valley Fault Zone in the quadrangle cut inactive alluvium (Qai) and older lake deposits (Qlo). Some scarps, however, cut active alluvial deposits (Qa) that fringe the Alabama Hills north of Lone Pine, and the most southeasterly trace of the fault zone mapped in the quadrangle is a scarp that cuts younger lake deposits (Qly) on the floor of Owens Lake; the locations of these scarps are from Beanland and Clark (1994). In addition, two inferred faults are mapped in an area of ground-water seepage

north of the Alabama Hills; the locations of these faults are from Hollett and others (1991) and Danskin (1998). The Owens Valley Fault Zone shows evidence of dominantly right-lateral displacement, with a subordinate vertical component that is generally down to the east. Scarps commonly show several meters of vertical displacement, with most but not all scarps facing east. The Lone Pine Fault, a major western strand of the Owens Valley Fault Zone, is marked by a prominent east-facing scarp as high as 6.5 m and has undergone 10 to 18 m of late Quaternary right-lateral offset (Lubetkin and Clark, 1987, 1988). Total right-lateral displacement on the Owens Valley Fault Zone is estimated as 10 to 20 km, as compared with about 2.5 km of total down-to-the-east vertical displacement (Beanland and Clark, 1994). The dip of the fault zone, although presumably steep (Beanland and Clark, 1994), is not accurately known at depth, and it is shown as vertical in cross section A-A'. Near the southeast corner of the quadrangle, the Owens Valley Fault Zone includes a

west-facing scarp on the floor of Owens Lake that has been interpreted as resulting from vertical displacement during the 1872 earthquake (Beanland and Clark, 1994). This scarp is in an area that lay submerged beneath as much as 7 m of water (Gale, 1914) until shortly after the Los Angeles Aqueduct was completed in 1913, when the lake began to desiccate. It is surprising that this scarp, if formed in 1872, could have been preserved despite being exposed to subaqueous erosion for more than 40 years prior to construction of the aqueduct. Instead, this scarp may have developed after 1913, conceivably during a moderate earthquake that shook southern Owens Valley on July 6, 1917 (Townley and Allen, 1939). It is likewise possible that other traces of the fault zone have undergone similarly recent displacement, although such displacement would be minor compared to that of 1872. The Inyo-White Mountains Fault Zone was identified by Pakiser and others (1964) on the basis of gravity data that require a sharp, steeply dipping boundary between the

known surface expression in the quadrangle and apparently has undergone no significant Holocene displacement. Because of its lack of exposure, the subsurface location and vertical dip of the fault zone as shown on the map and cross section A-A' should be consid-Geodetic measurements of active crustal deformation in the Owens Valley area and adjoining parts of eastern California have been made by several methods in recent years (Dixon and others, 1995; Miller and others, 1995; Savage and Lisowski, 1995). These measurements reveal that the map area is undergoing active right-oblique extension by

Owens Valley depression and the mountain block to the east. This fault zone has no

combined dip-slip and strike-slip motions of the Sierra Nevada Frontal Fault Zone and Owens Valley Fault Zone. The general pattern of deformation established in the area as early as 6 Ma is thus continuing today.

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