Stratigraphic Revision of the Cache Formation (Pliocene and Pleistocene), Lake County, California

GEOLOGICAL SURVEY BULLETIN 1502-C

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By MICHAEL J. RYMER

CONTRIBUTIONS TO STRATIGRAPHY

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A redefinition of nonmarine sedimentary rocks and tuff beds in northern California

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STRATIGRAPHIC REVISION OF THE CACHE FORMATION (PLIOCENE AND PLEISTOCENE), LAKE COUNTY, CALIFORNIA

By MICHAEL J. RYMER

ABSTRACT

Recent geologic mapping in the Clear Lake area of California has subdivided the nonmarine Cache Formation of former usage into three units that are herein named the Cache, Lower Lake, and Kelseyville Formations. The three formations are geographically separate, except where the Lower Lake Formation locally unconformably overlies the geographically restricted Cache Formation. This study and revision of the Cache Formation provides a framework for understanding the late Cenozoic tectonic, geologic, and climatic histories of the Clear Lake area.

The geographically restricted Cache Formation is characterized by cross-stratified sandstone with interbedded reddish-brown conglomerate around the margins of its basin of deposition and by gray sandstone and persistent light-olive-gray conglomerate lower in the section, as it is exposed in the center of the basin. Minor amounts of basaltic tuff are present near the top of the Cache Formation in the present Clear Lake basin. The restricted Cache Formation is at least 1,500 m thick, and is Blancan (Pliocene and early Pleistocene) in age. The formation was deposited in streams and lakes in a fault-controlled, subsiding basin. The Lower Lake Formation is a heterogeneous deposit of pebble conglomerate, sandstone, siltstone, calcareous siltstone, limestone, tuff, and diatomite. This lacustrine unit is at least 130 m thick and is of Pleistocene age. The Kelseyville Formation is composed of lacustrine sandstone and siltstone, and locally interbedded fluvial pebble conglomerate and sandstone. It has a maximum thickness of at least 140 m and is of Pleistocene age. Several tuff beds, including the Kelsey Tuff Member, a newly named marker bed, occur in the Kelseyville Formation. The Kelsey Tuff Member has been recognized in water wells west and north of surface exposures of the Kelseyville Formation.

The lower part of the restricted Cache Formation is probably correlative with the late Pliocene Tehama Formation and is apparently unrelated to the sediment of Clear Lake. The Lower Lake and Kelseyville Formations intertongue with and are underlain by flows of the Clear Lake volcanic field. The Lower Lake and Kelseyville Formations are dominated by partly coeval lacustrine deposits that were presumably deposited in different subbasins of the same lake, and are possibly correlative with sediment concealed beneath Clear Lake.

INTRODUCTION

Recent study of the Cache Formation in the Clear Lake basin and in the North Fork of Cache Creek area (figs. 1, 2) suggests that the formation was deposited in intermontane basins similar to others now present in the Coast Ranges of California. Deposits within separate basins are lithologically dissimilar in detail, and they are not synchronous. Therefore, the deposits are subdivided and redefined to include a restricted Cache and the Lower Lake and Kelseyville Formations. The Lower Lake and Kelseyville Formations respectively correspond to the basin deposits of Wildcat Canyon and the lake deposits of Kelseyville, as mapped by Hearn, Donnelly, and Goff (1976). The distribution of the geographically restricted Cache Formation and the Lower Lake and Kelseyville Formations is shown in figures 3 and 4. Figure 5 shows the evolution of stratigraphic nomenclature applied to rocks herein assigned to the Cache, Lower Lake, and Kelseyville Formations.

Previous geologic mapping in the vicinity of Clear Lake (Becker, 1888; Anderson, 1936; Brice, 1953; McNitt, 1968a, 1968b; Hearn and others, 1976) has mainly been concerned with units other than the Cache Formation. The first geologic study of the area was that of Becker (1888), who named the deposit the "Cache Lake Beds." In his study of the volcanic history of the Clear Lake area, Anderson (1936) renamed Becker's Cache Lake Beds the "Cache Formation" because there was no "Cache Lake" in the area and because Becker's name had a genetic connotation that was not applicable for the entire deposit. Brice (1953) described and mapped the Cache Formation (the restricted Cache Formation and the Lower Lake Formation of this report) in the Lower Lake 15-minute quadrangle, and he included occurrences of supposed Cache rocks that extend southward from the main body of the formation. McNitt (1968b) assigned isolated strata consisting of siltstone, sandstone, and local conglomerate in the Kelseyville 15-minute quadrangle to the Cache Formation (Kelseyville Formation of this report). McNitt correlated these rocks with the Cache Formation in the Lower Lake quadrangle on the basis of diatoms tentatively dated as late Pliocene and on the supposed stratigraphic position of the rocks below flows of the Clear Lake volcanic field.

Several other reports contribute to knowledge of beds previously assigned to the Cache Formation. Parts of the Cache Formation were mapped in the Wilbur Springs and Morgan Valley quadrangles by Lawton (1956) and in the Bartlett Springs quadrangle by McNitt (1968a). The report written for the Lake County Flood Control and

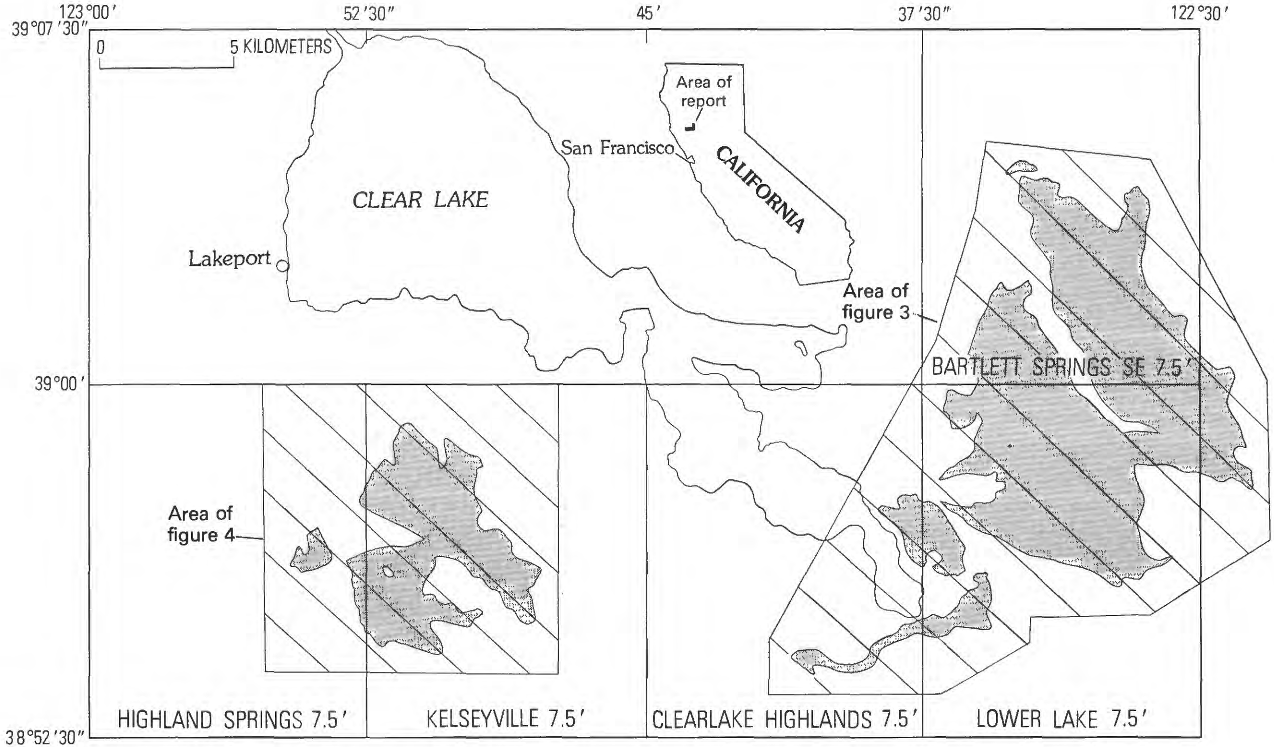


FIGURE 1.—Location map of report area and distribution of outcrops of rocks formerly assigned to the Cache Formation (stippled pattern). Modified after Koenig (1963) and Jennings and Strand (1960).

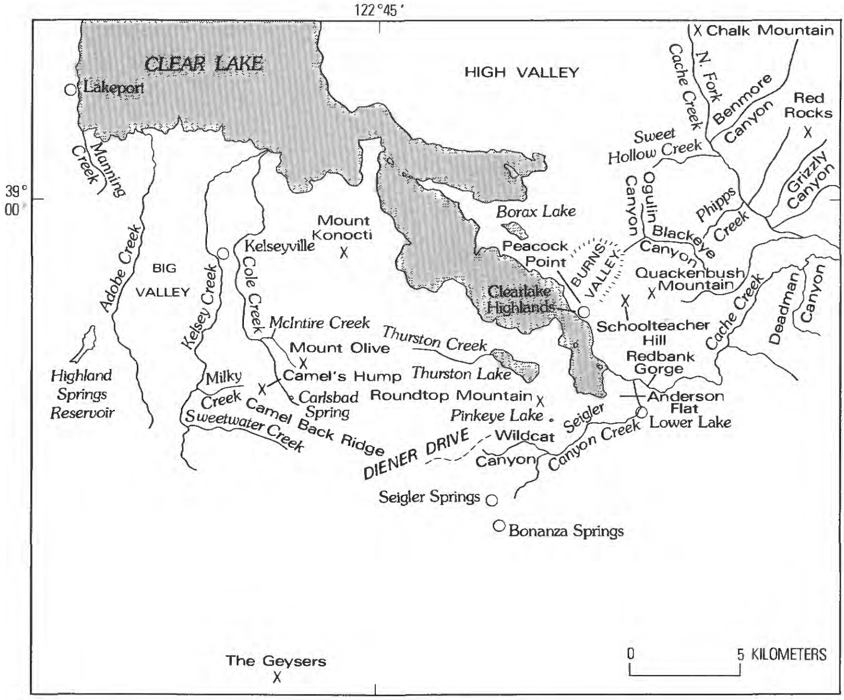


FIGURE 2.—Index map of geographic features referred to in this report.

Water Conservation District (1967) noted the subsurface presence of the Cache Formation (Kelseyville Formation of this report) in Big Valley, and delineated faults in the valley that act as local ground-water barriers. Hearn, Donnelly, and Goff (1975, 1976), Donnelly (1977), and Donnelly-Nolan and others (1980) mapped and dated rocks of the Clear Lake volcanic field, which helped determine the ages of units named in this report.

Generalized age and facies relations of the Cache, Lower Lake, and Kelseyville Formations are shown in figures 6 and 7. Figure 6 illustrates the stratigraphic relations of the formations and adjoining units, and figure 7 shows the generalized distribution of inferred depositional environments in the three formations.

Three stratigraphic sections were measured; one for each formation. All three sections are incomplete owing to poor exposure. The locations of the measured sections are shown in figure 8, and lithologic descriptions are listed under "Measured Sections."

ACKNOWLEDGMENTS

Reviews of and comments on earlier versions of this report were made by D. W. Anderson, R. L. Rose, and C. H. Stevens, all from San Jose State University. Identifications of various fossil taxa first reported herein were made by C. A. Repenning and J. A. Wolfe.

CACHE FORMATION

NAME, TYPE LOCALITY, AND REFERENCE SECTION

Redefinition of the Cache Formation is necessitated because of the lack of a type area and the lack of stratigraphic limits used for the Cache in previous studies (Brice, 1953; McNitt, 1968b). The Cache Formation as used in this report is essentially that of Becker (1888), Anderson (1936), and Brice (1953) except for the exclusion of beds herein named the rhyolitic tuff of Bonanza Springs and the Lower Lake Formation. Both Becker and Anderson emphasized the lithologic dissimilarity of rocks herein assigned to the Lower Lake Formation with those of the Cache exposed farther to the east.

The revised Cache Formation is a thick sequence of fluvial and partly lacustrine sandstone, conglomerate, and siltstone that is exposed in the Clear Lake basin and along the North Fork of Cache Creek. To avoid confusion, the name Cache used in the rest of this report shall refer to the rocks as defined above unless indicated otherwise.

A representative stratigraphic section exposed along the North Fork of Cache Creek, between Cache Creek and Benmore Canyon (T. 14 N., R 6 W., and T. 13 N., R. 6 W., Lower Lake and Bartlett Springs SE 7.5-minute quadrangles), is designated the type locality. The reference section was measured in the west-trending part of Blackeye Canyon, from the large bend in the canyon westward to its mouth, in the N ½ N ½ sec. 13, T. 13 N., R. 7 W., Lower Lake 7.5-minute quadrangle (fig. 8). This measured section (p. C30) is representative of the formation as exposed in the Clear Lake basin, but it is not necessarily representative of exposures farther to the east. For this reason the section is referred to as a reference section and not the type section.

DISTRIBUTION AND THICKNESS

The Cache Formation crops out east of Clear Lake. The best exposures of the formation are along Cache Creek, the North Fork of Cache Creek, and their tributaries. Good exposures occur locally in scarps of landslides and steep erosional scarps, both of which are com-

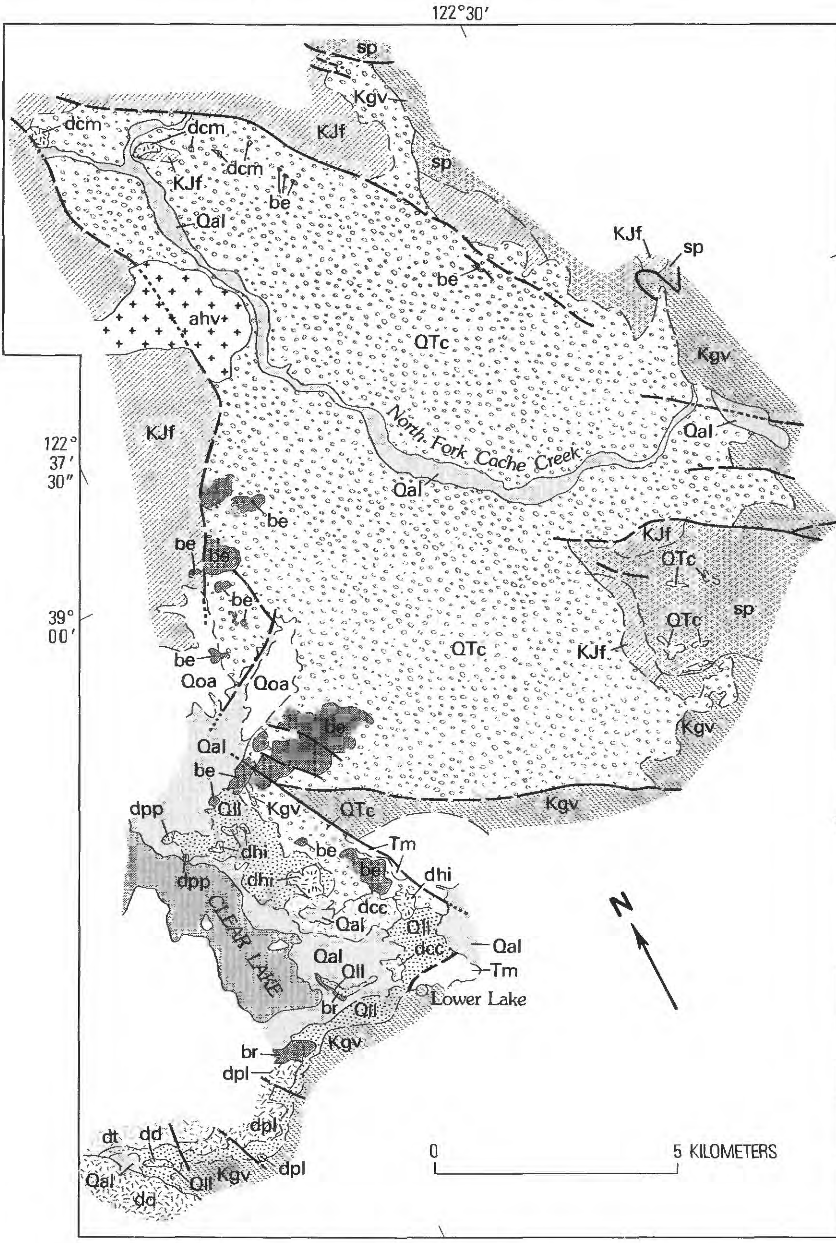
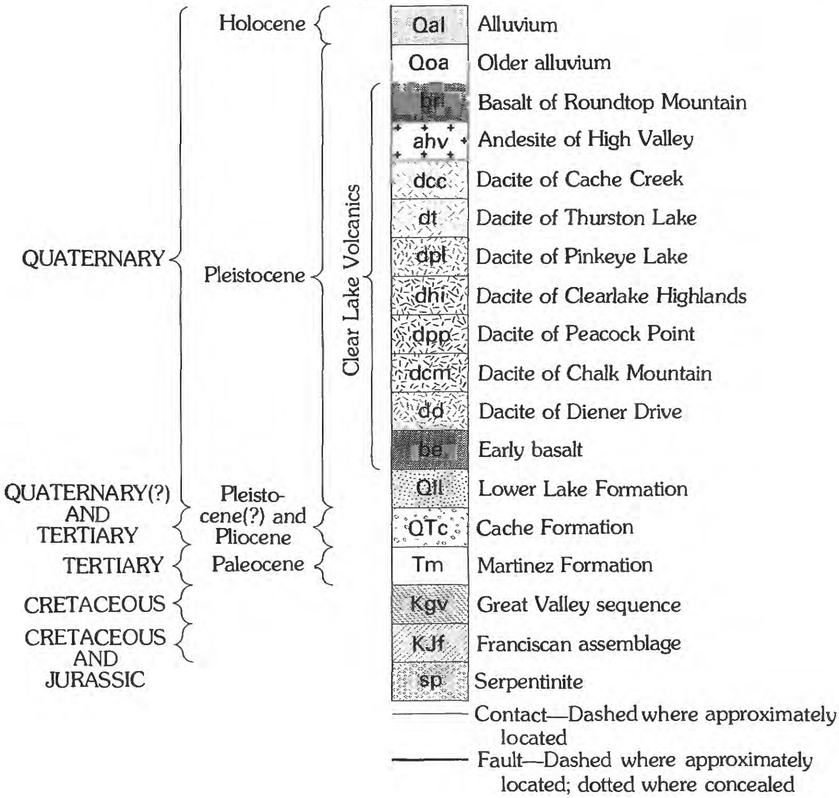


FIGURE 3.—Geologic map of the Cache Formation, Lower Lake Formation, and surrounding rocks. Geology by the author (from 1974 to 1977) and from Hearn, Donnelly, and Goff (1976), Brice (1953), McNitt (1968a), and Lawton (1956).

EXPLANATION



mon in the Grizzly Canyon-Benmore Canyon area.

The total thickness of the Cache Formation is unknown. Along Phipps Creek and Blackeye Canyon the formation dips to the southwest. Using an average dip of 26° for these strata, an approximate thickness of 1,600 m is estimated across the reference area. However, fieldwork in the area of the North Fork of Cache Creek suggests that the Cache Formation may be considerably thicker. The above thickness should, therefore, be considered a minimum for the formation. Brice (1953) concluded that there is a maximum thickness of 2,000 m of the Cache Formation (old usage) in the same area, but he apparently used an average dip of 25° south of Blackeye Canyon, where beds have subsequently been found having a dip perpendicular to his line of measurement.

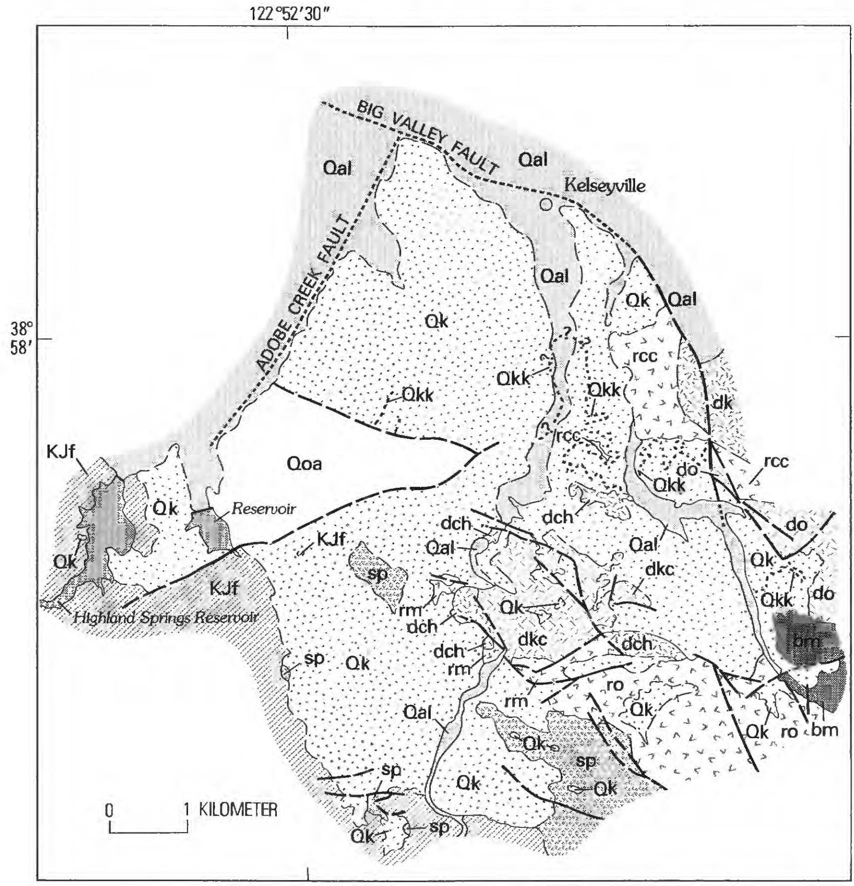
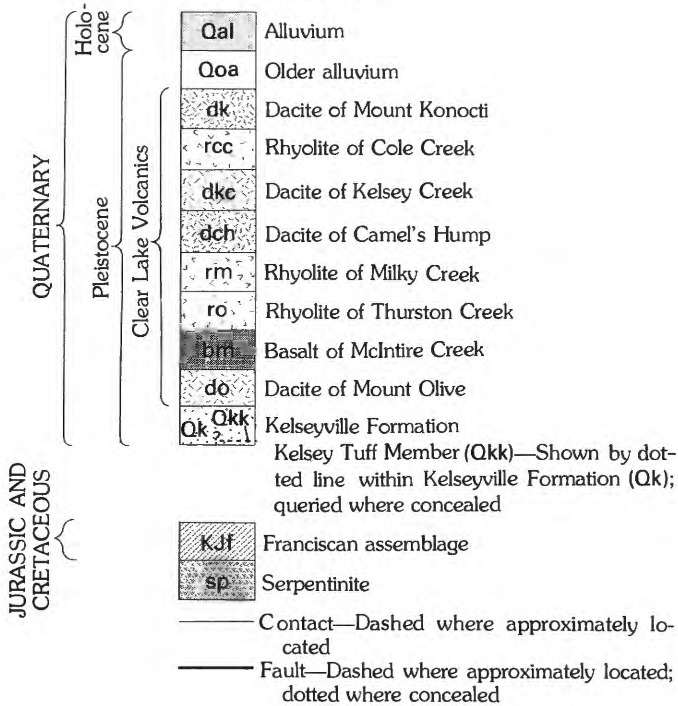


FIGURE 4.—Geologic map of the Kelseyville Formation and surrounding rocks. Geology by the author (from 1974 to 1977) and from Hearn, Donnelly, and Goff (1976).

LITHOLOGY

Along the North Fork of Cache Creek, the type area, the Cache Formation is composed of sandstone, siltstone, and conspicuous, resistant pebble to cobble conglomerate. The sandstone is a light-gray (*N*6 to *N*7) fine- to coarse-grained poorly sorted lithic wacke. Lithic grains present in the wacke are metagraywacke; vein quartz; red, green, and gray chert; greenstone; schist; and, rarely, arkosic arenite. The beds are continuous throughout the exposures, moderately well bedded, and rarely cross stratified. Siltstone in this section is dominantly composed of angular fragments of quartz, chlorite, clay, and a few percent of epidote and opaque grains.

EXPLANATION



Approximately 20 percent of the exposures along the North Fork of Cache Creek consist of conspicuous, resistant, poorly sorted pebble to cobble conglomerate. The conglomerate is light olive gray (5*Y*6/1) and has subangular to rounded pebbles, cobbles, and, locally, boulders similar in composition to the lithic fragments in the wacke. Beds in the conglomerate are from about 0.5 to 9 m in thickness, and these rocks are poorly stratified (fig. 9).

In the reference section, approximately 1,000 m higher in the Cache than the type locality, the formation is dominantly composed of medium- to coarse-grained lithic arenite and lithic wacke and their pebbly facies. Pebble conglomerate is also common in the reference section; present in minor amounts are siltstone and tuff.

The lithic arenite and lithic wacke in the reference section are generally yellowish gray (5*Y*7/2) to medium light gray (*N*6), poorly consolidated, and moderately to poorly stratified. The beds are 0.3 to 1.4 m thick, are commonly lenticular, and show indistinct to conspicuous, medium- and large-scale cross-stratification.

Interbedded with the sandstone in the reference section are conglomerate and pebbly sandstone. The conglomerate is moderately well

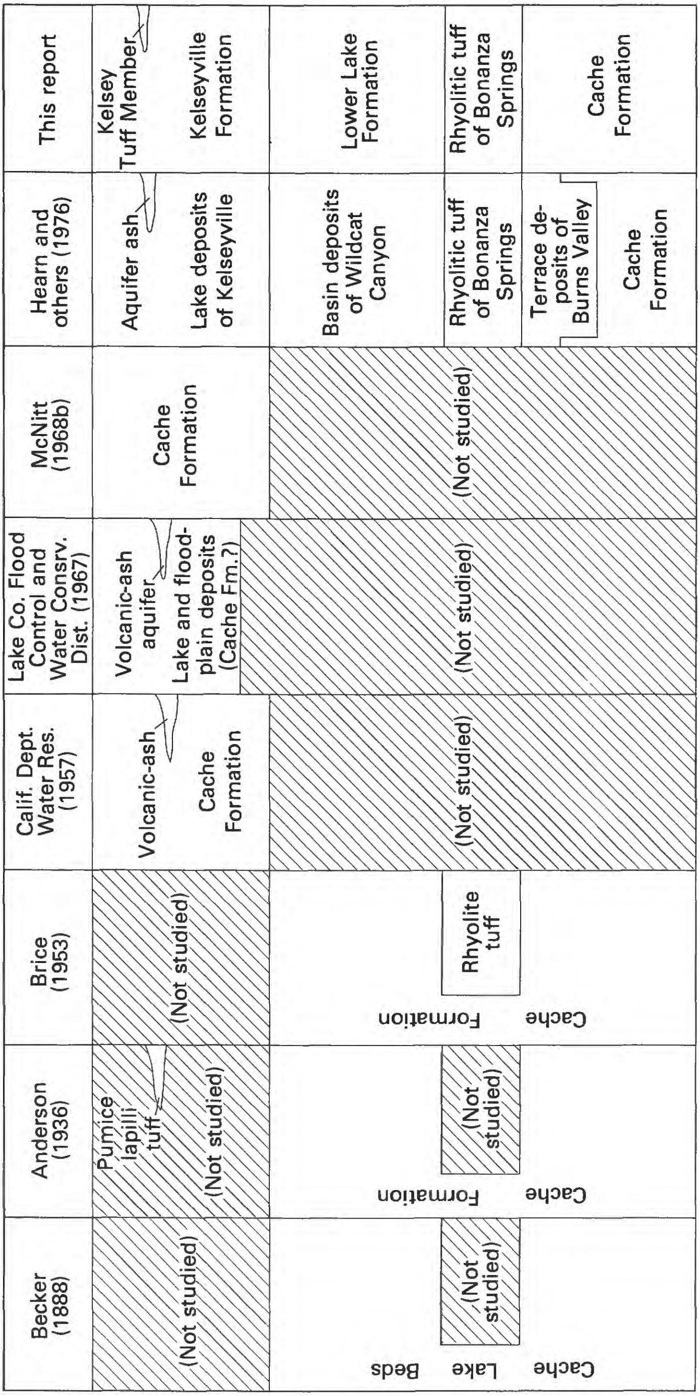


FIGURE 5.—Evolution of nomenclature of the Cache, Lower Lake, and Kelseyville Formations.

sorted and has clasts that range in size from pebbles to occasional boulders in a matrix that is dominantly lithic arenite. Red chert and vein quartz are the most common large clasts in the conglomerate and pebbly sandstone. Metagraywacke derived from the Franciscan assemblage forms 5–20 percent of the large clasts, and there are small amounts of green and gray chert, metabasalt, greenstone, and foliated metaconglomerate.

The reference section contains interbedded tuff, but the tuff occurs only within the Clear Lake basin, high in the Cache Formation. The tuff ranges in composition from basaltic lithic tuff to hypersthene-bearing vitric tuff, and ranges in color from white (*N*9) to pale grayish orange (10*YR*8/4). The beds are as thick as 3.5 m but are generally less than 1 m thick, and the beds are commonly poorly stratified, moderately to well sorted, and poorly consolidated. Most of the tuff seen in the reference section and farther northwest is genetically related to immediately overlying or nearby quartz-bearing olivine basalt. None of the tuff has been radiometrically dated, and none has proved to be of use as a correlative marker bed.

AGE

Fossil vertebrates from the Cache indicate a Blancan (Pliocene and Pleistocene) age, but the age of the oldest beds of the formation is unknown (fig. 6).

No fossils of stratigraphic significance were found in the Cache Formation during this study. However, Becker (1888) found a few bone fragments, which were tentatively identified by O. C. Marsh as parts of a pelvis, apparently from a horse; the lower part of a scapula, possibly from a camel; and the head of a large femur, probably of an elephant or a mastodon. The material suggested a late Pliocene age to Marsh (Becker, 1888, p. 221). Unfortunately, the precise location and detailed lithology of rock containing these bone fragments were not described. The remains of a lower jaw, without teeth, of *Elephas* sp. (*Mammuthus* sp., C. A. Repenning, written commun., 1978) was found by W. M. Davis and identified by V. L. Vander Hoof (Anderson, 1936, p. 639). The presence of the mammoth indicates an early to late Pleistocene age. This fossil may have come from the Lower Lake Formation, which is younger than the restricted Cache Formation (fig. 6), but the precise location was not given.

The presence of *Equus (Dolichohippus) simplicedens* (Cope), *Equus (Hemionus) calobatus* Troxell?, and *Equus (Hemionus)* sp. cf. *E. (H.) conversidens* Owen in the Grizzly Canyon–Cache Creek area suggests an age of about 1.8–2.9 m.y. (million years) (late Pliocene) based on available approximations of time (C. A. Repenning, written commun.,

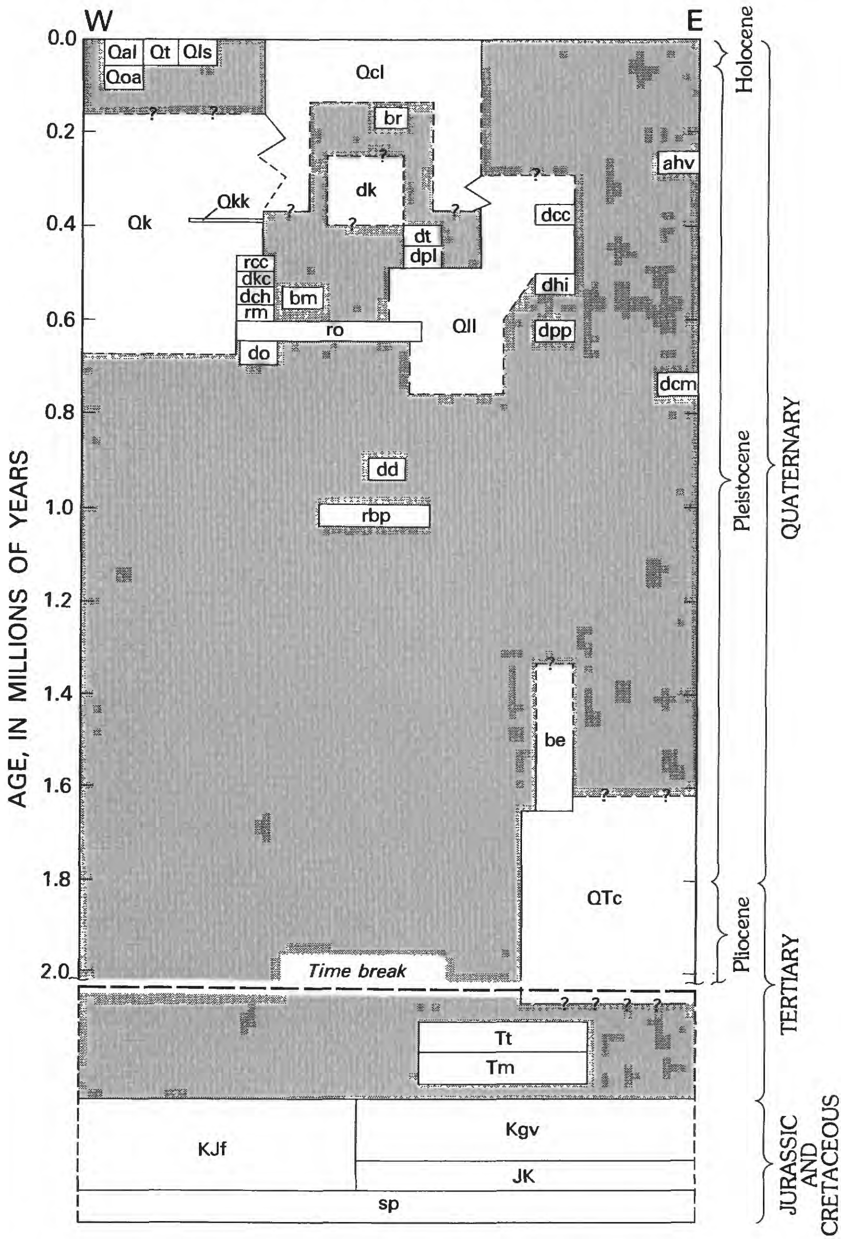


FIGURE 6.—Schematic stratigraphic section of the revised Cache, Lower Lake, and Kelseyville Formations showing units that are in the Clear Lake area and are mentioned in this report. Modified from Hearn, Donnelly, and Goff (1976).

EXPLANATION

Qal	Alluvium
Qt	Terrace deposits
Qls	Landslide deposit
Qoa	Older alluvium
Qcl	Lacustrine sediment of Clear Lake
	UNITS OF THE CLEAR LAKE VOLCANICS
br	Basalt of Roundtop Mountain
ahv	Andesite of High Valley
dk	Dacite of Mount Konocti
dcc	Dacite of Cache Creek
dt	Dacite of Thurston Lake
dpl	Dacite of Pinkeye Lake
rcc	Rhyolite of Cole Creek
dhi	Dacite of Clearlake Highlands
dkc	Dacite of Kelsey Creek
dch	Dacite of Camel's Hump
bm	Basalt of McIntire Creek
rm	Rhyolite of Milky Creek
dpp	Dacite of Peacock Point
ro	Rhyolite of Thurston Creek
do	Dacite of Mount Olive
dcm	Dacite of Chalk Mountain
dd	Dacite of Diener Drive
rbp	Rhyolite tuff of Bonanza Springs
be	Early basalt
Qk	Kelseyville Formation
Qkk	Kelsey Tuff Member
Qll	Lower Lake Formation
QTc	Cache Formation
Tt	Tejon Formation
Tm	Martinez Formation
	UNITS OF THE GREAT VALLEY SEQUENCE
Kgv	Unnamed units
JK	Knoxville Formation
KJf	Franciscan assemblage
sp	Serpentinite

1976, 1978). Other elements of the fauna identified by Repenning (written commun., 1976), which are also compatible with a late Pliocene age are:

Testudinidae
megalonychid sloth, ?*Megalonyx* sp.
Carnivore, cf. canid
?*Procyon* sp.
Camelid, cf. *Camelops* sp.
Cervid.

Fresh-water gastropods and pelecypods in the Cache Formation of this report have been reported by Becker (1888), Hannibal (1912), Anderson (1936), and Brice (1953). Blancan age mollusks found in the Cache Formation by H. W. Turner (Taylor, 1966), include the following species:

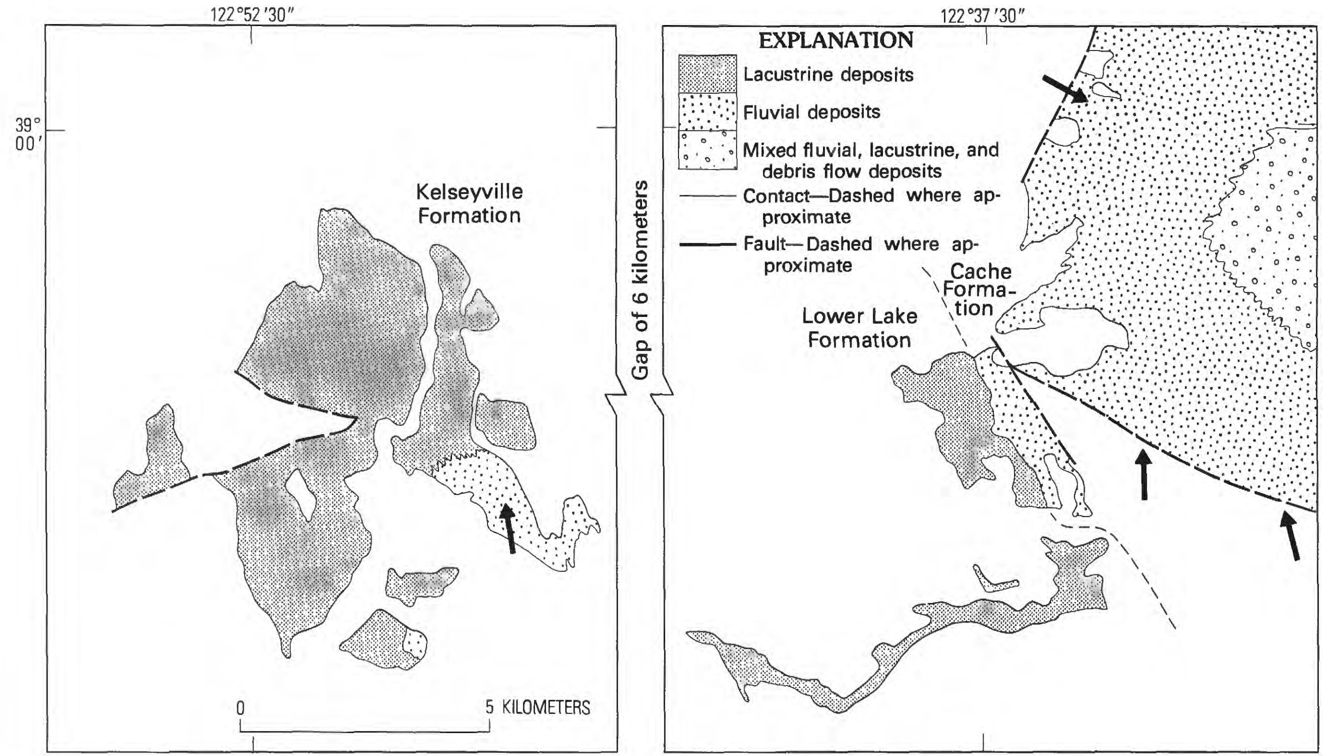


FIGURE 7.—Generalized map of depositional environments in the Cache, Lower Lake, and Kelseyville Formations. Arrows represent direction of fluvial transport as inferred from facies patterns and cross-stratification.

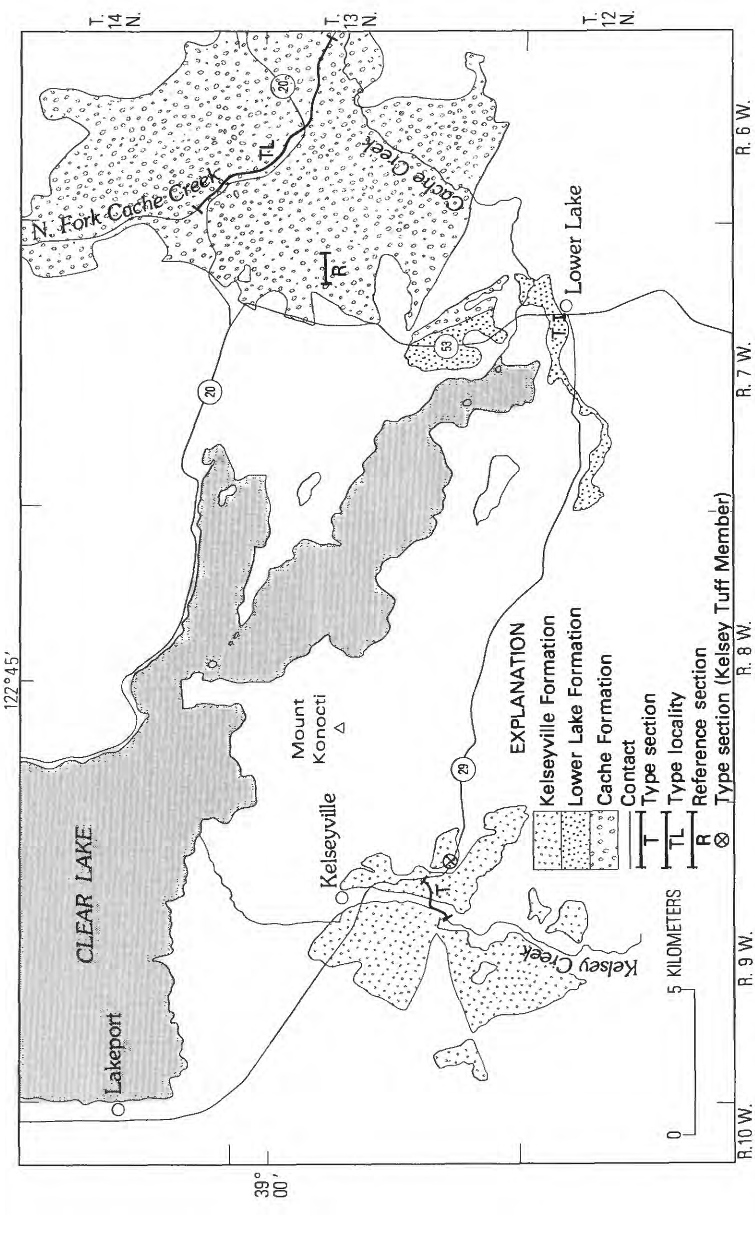


FIGURE 8.—Location map of measured sections of the Cache, Lower Lake, and Kelseyville Formations and the Kelsey Tuff Member of the Kelseyville Formation.

FIGURE 9.—Sandstone and resistant, poorly sorted conglomerate in the Cache Formation. Exposure is part of type locality along North Fork of Cache Creek and is approximately 20 m high.

Anodonta wahlamatensis Lea
Pisidium compressum Prime
Valvata humeralis Say
Hydrobia? cf. *H.*? *andersoni* Arnold
Planorbidae (fragment)
Physa.

These mollusks range in age from Pliocene to Holocene and are from Grizzly Canyon, probably about sec. 2 or 3, T. 14 N., R. 6 W. (Taylor, 1966, p. 37).

STRATIGRAPHIC RELATIONS

Basal relations of the Cache Formation are poorly known because of poor exposures and the common occurrence of faults along the margin of the formation that obscure underlying materials. East of the Clear Lake basin, basal beds of the Cache Formation unconformably overlie serpentinite and the Knoxville Formation near the intersection of Deadman Canyon and Cache Creek (Brice, 1953). The Cache Formation east of long 122° 30′ unconformably overlies Upper Jurassic and Cretaceous rocks of the Franciscan assemblage and other Cretaceous rocks (Lawton, 1956). The Cache Formation probably overlies serpentinite in the Benmore Canyon area, east of the North Fork of Cache

Creek, where the presence of serpentinite is inferred from a large gravity low (Isherwood, 1976) and high magnesium content in well water (F. E. Goff, oral commun., 1977). East of Clearlake Highlands the Cache Formation unconformably overlies the Paleocene Martinez Formation and a small area of feldspathic wacke and pebbly feldspathic wacke believed to be part of the Great Valley sequence of late Mesozoic age. In the Burns Valley–Ogulin Canyon area, the Cache unconformably overlies Franciscan rock.

Faults are common along the margins of the Cache Formation (fig. 3). South of Quackenbush Mountain and east of Clearlake Highlands the unit is in fault contact with undivided Jurassic and Cretaceous wacke of the Great Valley sequence (unit IIIa of Swe and Dickinson, 1970). Farther to the southeast along the same fault, the Cache Formation is in contact with the Knoxville Formation (Brice, 1953). The Cache is also in contact with the Franciscan assemblage in the Burns Valley–Sweet Hollow Creek area.

Approximately 1 km east of Clearlake Highlands the Lower Lake Formation and at least four units of the Clear Lake volcanic field locally overlie the Cache Formation. The Lower Lake Formation unconformably overlies the Cache Formation between Quackenbush Mountain and Cache Creek, and although the contact is poorly exposed, the bedding indicates that the contact is an angular unconformity of approximately 5° to 20°. Micrite and calcareous siltstone of the Lower Lake Formation locally overlap the better bedded, more consolidated Cache Formation. Olivine basalt of unknown age at 18th Avenue (labeled "be" in figs. 3, 6), 2 km east of Clearlake Highlands, probably overlies the Cache Formation conformably. It and the underlying Cache have been tilted to the west. Another volcanic unit that unconformably overlies the Cache Formation in the same area is the hypersthene dacite of Clearlake Highlands, 0.52±0.06 m.y. (Donnelly-Nolan and others, 1980). It is exposed north and south of Cache Creek and southeast of Clearlake Highlands. Olivine basalt flows, dated at 1.66±0.10 m.y. at Schoolteacher Hill (Donnelly-Nolan and others, 1980), and at Quackenbush Mountain and near Sweet Hollow Creek (all labeled "be" in figs. 3, 6), overlie the Cache Formation, although Anderson (1936) thought that these flows were intercalated with rock herein assigned to the Cache prior to removal of overlying material. The presence of the flow dated at 1.66 m.y. B.P. (Before Present) that overlies the Cache suggests that the Cache in this area is as young as early Pleistocene. Other olivine basalts in the region are of unknown age, and they overlie, intrude, or are intercalated with the Cache Formation; small exposures of these basalts are seen at the Red Rocks, in Burns Valley, and between Ogulin Canyon and Burns Valley. Beyond Clear Lake basin, the Cache is unconformably overlain by andesite of High Valley, estimated to be from 10,000 to 40,000 years old (B.C. Hearn, Jr., written commun., 1978), and dacite of Chalk Mountain, including its outliers to the southeast (Donnelly, 1977).

Beds herein assigned to the Cache Formation were suggested by Russell (1931) to be correlative with the late Pliocene Tehama Formation exposed along the west side of the Sacramento Valley. Anderson (1936), in contrast, stated that in spite of the lithologic similarity of the two formations the lack of *Elephas (Mammuthus)* in the Tehama suggests that the formations may not be correlative. However, in light of the faunal assemblage reported here for the Cache Formation and that of Vander Hoof (1933) for the Tehama Formation, at least a partial correlation of the two formations indeed is likely.

RHYOLITIC TUFF OF BONANZA SPRINGS

The rhyolitic tuff of Bonanza Springs as mapped and described by Hearn, Donnelly, and Goff (1976), and as first shown separately by them (1975), is here excluded from the Cache Formation (fig. 5). The tuff was originally included in the unrestricted Cache Formation by Brice (1953) because of "resemblance to known Cache deposits and a comparable degree of deformation." Brice concluded that the tuff may have been deposited in a basin of unrestricted Cache deposition. However, Hearn, Donnelly, and Goff (1976) showed that the tuff is neither continuous nor contemporaneous with the nearby part of the unrestricted Cache Formation, referred to as basin deposits of Wildcat Canyon in their report and as the Lower Lake Formation in this report. In addition, the tuff is lithologically dissimilar to the Lower Lake Formation.

The rhyolitic tuff of Bonanza Springs is a pumiceous tuff and lapilli tuff. Individual beds of the tuff range in color from pinkish white (5*YR*9/1) to white (*N*9) on fresh surfaces, and yellowish gray (5*Y*8/1) to white (*N*9) on weathered surfaces. The tuff contains fragments of obsidian and rhyolite and phenocrysts of plagioclase, orthopyroxene, and ilmenite scattered throughout a light, fine-grained matrix (Hearn and others, 1976). Clasts are either subangular or subrounded and are as much as 50 cm in diameter. Individual beds are generally moderately sorted, but both well-sorted and poorly sorted beds are common. The tuff grades into a chaotic tuff-breccia near its vent area northwest of Seigler Springs (Hearn and others, 1976).

LOWER LAKE FORMATION

NAME AND TYPE SECTION

West, northwest, and northeast of the town of Lower Lake is a thin sequence of lacustrine siltstone, sandstone, and pebbly sandstone with minor limestone, calcareous siltstone, diatomite, and interbedded tuff and lapilli tuff. This sequence is here named the Lower Lake Formation. These strata were included in the unrestricted Cache Formation by Becker, who referred to them as "light-colored, calcareous, soft, and excessively fine-grained material, manifestly a lake deposit" (Becker, 1888, p. 220). The lithologic dissimilarity of these beds to the Cache Formation exposed near the North Fork of Cache Creek was also emphasized by Anderson (1936). Strata of the Lower Lake Formation and the rhyolitic tuff of Bonanza Springs were referred to as "upper Cache beds" by Brice (1953). More recently, Hearn, Donnelly, and Goff (1976) informally referred to the strata of the Lower Lake Formation as "basin deposits of Wildcat Canyon" (fig. 5).

The type section of the Lower Lake Formation is along the west side of State Highway 53 in the town of Lower Lake, in the W½SW¼SW¼ sec. 2, T. 12 N., R. 7 W., Lower Lake 7.5-minute quadrangle (figs. 8, 10).

DISTRIBUTION AND THICKNESS

The Lower Lake Formation is exposed on the north side of Wildcat Canyon, on the slopes northwest and north of Seigler Canyon Creek, in and near the town of Lower Lake, and north and northwest of the town of Clearlake Highlands. Good exposures of the formation are in Wildcat

FIGURE 10.—North-dipping, slightly tuffaceous rock in the Lower Lake Formation. View is to west. Exposure is of uppermost 15 m of type section.

Canyon, Cache Creek, and Redbank Gorge (fig. 2), and in various roadcuts and gullies.

In the type section, a thickness of approximately 130 m of strata was measured. This is a minimum thickness for the formation, as the top of the section is not exposed. In Wildcat Canyon and north of Seigler Canyon Creek, the Lower Lake Formation is as thick as 90 m.

LITHOLOGY

The Lower Lake Formation is composed of pebbly sandstone and sandstone at its base and grades upward into siltstone with sandstone and tuff interbeds. Above this material are local beds of calcareous siltstone, limestone, tuff, sandstone, diatomite, and pebble conglomerate (fig. 10).

The predominant lithology is feldspathic to lithic, locally pebbly wacke that is light gray (*N*7) to yellowish gray (5*Y*8/1). The rocks are poorly sorted and generally poorly stratified. The strata commonly are thin bedded. About half of the measured section is composed of poorly consolidated sandstone, which is most common at the base of the formation from Wildcat Canyon to Lower Lake.

Calcareous siltstone and limestone are common in the Lower Lake–Anderson Flat area (fig. 2), and are present, but less common, in the Clearlake Highlands area. Near Lower Lake and Anderson Flat, limestone is present as resistant beds about 1 m thick. In this area the limestone ranges from micrite to diatomaceous biomicrite and packed, algal biomicrite, and it ranges in color from white to very pale orange (*N*9 to 10*YR*8/2). In the same area, the calcareous siltstone has a wide range in color, from orangish white to yellowish gray (10*YR*9/2 to 5*Y*8/1), and contains as much as 30 percent carbonate cement. The limestone-calcareous siltstone boundary used in this report is at 50 percent carbonate, as used by Folk (1974, p. 168). Both the limestone and calcareous siltstone commonly contain one or more of the following fossils, in order of decreasing abundance: diatoms, gastropods, ostracodes, siliceous sponge spicules, tule roots, pelecypods, algae, and fish bones, teeth, or scales.

In the Clearlake Highlands area, and along or east of State Highway 53, limestone and calcareous siltstone are generally similar in color but much less fossiliferous than in the Lower Lake–Anderson Flat area. Limestone in this area is micrite and sandy micrite, and contains as much as 20 percent angular to subrounded, sand- to granule-sized red and green chert, quartz, greenstone, and metagraywacke. Limestone in this area is in patches that are possibly part of a thin bed that unconformably overlies the more steeply dipping Cache Formation.

Diatoms are common in the clastic and calcareous rock in the Lower Lake Formation and are locally abundant enough to form diatomite.

Exposures of diatomite are best in road and construction cuts because the material is easily eroded.

Tuff beds represent approximately 3 percent of the Lower Lake Formation in its type section. The beds, which are 1 cm to 1.1 m thick, are present throughout the upper part of the formation. The tuff has a wide range in color. The pumiceous and vitric deposits range from white (*N*9) and pale yellowish gray (5*Y*8/2) to moderate orange pink (5*YR*8/4) and very pale orange (10*YR*8/2), and the lithic tuffs are medium to light gray (*N*5 to *N*7). Most of the tuff was probably deposited by air fall into standing water, because it is associated with calcareous rock and aquatic organisms and because it contains no evidence of reworking. In general, the tuffs and lapilli tuffs are devoid or nearly devoid of nonvolcanic clastic grains. This fact, along with the generally coarser grain size of the tuffs relative to the enclosing epiclastic material, suggests that deposition was rapid and that little reworking occurred. The lithic tuff units commonly contain a few percent clinopyroxene and are common in the Lower Lake–Clearlake Highlands area. The pumiceous tuff is generally restricted to the Wildcat Canyon–Lower Lake area.

All tuff in the Lower Lake Formation probably came from vents in the Clear Lake volcanic field. Material in the Lower Lake–Clearlake Highlands area is possibly from the partly coeval flows of the dacite of Cache Creek of Hearn, Donnelly, and Goff (1976) or from one or more of the many basaltic, andesitic, or dacitic flows on the west side of the nearby arm of Clear Lake. Hearn, Donnelly, and Goff (1976) listed the names of coeval flows whose vents could have contributed pyroclastic material to the Lower Lake Formation. A concealed basaltic vent in the nearby arm of Clear Lake was proposed as the source of basaltic tuff beds in the Lower Lake Formation by Donnelly (1977).

AGE AND STRATIGRAPHIC RELATIONS

The age of the Lower Lake Formation is Pleistocene as indicated by radiometrically dated underlying, interbedded, and overlying volcanic units (fig. 6). The numerous fossils in the formation are of little use in determining its age.

In the Wildcat Canyon–Lower Lake area the Lower Lake Formation is underlain by Cretaceous rocks (units Ib and IIIa, b, and c of Swe and Dickinson, 1970) of the Great Valley sequence. About 200 m north of the intersection of State Highways 29 and 53 (fig. 8) is an exposure of basal beds of the Lower Lake Formation lying on these Cretaceous rocks with marked angular unconformity. East of Clearlake Highlands, in sec. 27, T. 13 N., R. 7 W., the Lower Lake Formation unconformably laps over the Cache Formation with an angular discordance of approximately 5° to 20°. In the upper reaches of Wildcat Canyon the formation is underlain by pyroxene dacite of Diener Drive that has yielded a K-Ar date of 0.92±0.03 m.y. (Donnelly-Nolan and others, 1980). North of Cache Creek the formation is interbedded with and underlain by hypersthene dacite of Clearlake Highlands (Hearn and others, 1976). This dacite is dated at 0.52±0.06 m.y. (Donnelly-Nolan and others, 1980). In the same area dacite of Cache Creek, dated at 0.40±0.21 m.y. (Donnelly-Nolan and others, 1980), is interbedded with the formation. This relation is best exposed in a roadcut on the east side of State Highway 53 about 3.2 km north of Lower Lake. Also underlying the Lower Lake Formation is dacite of Peacock Point, which is undated but is probably between 0.6 and 0.35 m.y. old (Hearn and others, 1976). Exposures of this dacite are present in Clearlake Highlands.

Overlying the Lower Lake Formation are three units from the Clear Lake volcanic field, one of which has been dated radiometrically. On the north side of Wildcat Canyon, and along the west side of Seigler Canyon, the Lower Lake Formation is overlain by dacite of Pinkeye Lake, dated at 0.48±0.03 m.y. (Donnelly-Nolan and others, 1980). Farther west the Lower Lake Formation and the dacite of Pinkeye Lake are overlain by dacite of Thurston Lake. West of the town of Lower Lake the formation is conformably overlain by olivine basalt of Roundtop Mountain, estimated to be between 0.10 and 0.15 m.y. old (Hearn and others, 1976; Donnelly, 1977). One kilometer northeast of Lower Lake the contact between the Lower Lake Formation and the Martinez Formation of Paleocene age is concealed, but it is thought to be a fault (fig. 3).

Fossils found in the Lower Lake Formation include fresh-water pelecypods and gastropods, siliceous sponge spicules, smooth-shelled ostracodes, diatoms, and casts or molds of tule roots. Fish remains are reported from three localities in the Lower Lake Formation (Casteel and Rymer, 1975, 1980). All fossils found in the Lower Lake Formation have a stratigraphic range from Pliocene(?) to Holocene.

KELSEYVILLE FORMATION

NAME AND TYPE SECTION

The Kelseyville Formation is here named for lacustrine and less abundant fluvial beds exposed near Kelseyville (fig. 2). Geologists of the California Department of Water Resources (1957) were the first to include these beds in the unrestricted Cache Formation. These beds were included in the unrestricted Cache Formation by McNitt (1968b) because he believed them to be stratigraphically below flows of the Clear Lake volcanic field. Hearn, Donnelly, and Goff (1976) referred to strata comprising the Kelseyville Formation as "lake deposits of Kelseyville" (fig. 5).

The type section of the Kelseyville Formation is along Kelsey Creek, and along a ravine south of Kelseyville and west of State Highway 29, in the SE¼NE¼ sec. 27, the NW¼NW¼ sec. 26, and the SW¼SW¼ sec. 23, all in T. 13 N., R. 9 W. (fig. 8). The section was measured in two parts in order that the section be as complete as possible. The break in the section is at the Kelsey Tuff Member (described under "Lithology"), which is a widespread marker bed in the Kelseyville Formation.

DISTRIBUTION AND THICKNESS

The Kelseyville Formation crops out in the southern half of Big Valley and in surrounding hills. The best exposures of the formation are in Kelsey and Cole Creeks and in the intervening low hills. Other good exposures are in roadcuts along State Highway 29 and in the low hills north of Sweetwater Creek. The Kelseyville Formation is also present, but concealed, west and north of the Adobe Creek and Big Valley faults, respectively, below alluvial cover that ranges widely in thickness.

The total thickness of the Kelseyville Formation is unknown because of poor exposures and a lack of subsurface data. In the type section, approximately 140 m of strata was measured, but this figure does not include approximately half of the unit exposed farther south. A reasonable minimum thickness for the formation is approximately 500 m. Along the southern and eastern margins of Big Valley the Kelseyville Formation thins to a few meters.

LITHOLOGY

The type section of the Kelseyville Formation consists of approximately 96 percent sandstone interbedded with about 3 percent conglomerate and 1 percent tuff. The sandstone ranges from lithic wacke to lithic arenite, and generally it has a dusky yellow (5*Y*5/4) to yellowish-gray (5*Y*8/1) color. In the upper 30 m of the Kelseyville Formation, the sandstone is locally slightly oxidized and has a yellowish-brown (10*YR*6/4) to grayish-orange (10*YR*7/4) color. Poor consolidation and poor to moderate sorting are common in the sandstone. The sandstone is typically poorly to moderately stratified in beds that are commonly continuous through the limited exposures (fig. 11).

South of the Wight Way fault, and lower in the Kelseyville Formation, silty wacke and sandy siltstone are typical. Bedding in the rocks of this area is generally poorly to moderately developed, and most commonly beds are less than a few centimeters thick. The beds are continuous through the exposures, similar to the sandstone beds north of the Wight Way fault.

Conglomerate is sparse in the type section of the Kelseyville Formation. Lenses or thin beds of conglomerate are in sandstone and are generally composed of granules and pebbles derived from the Fran-

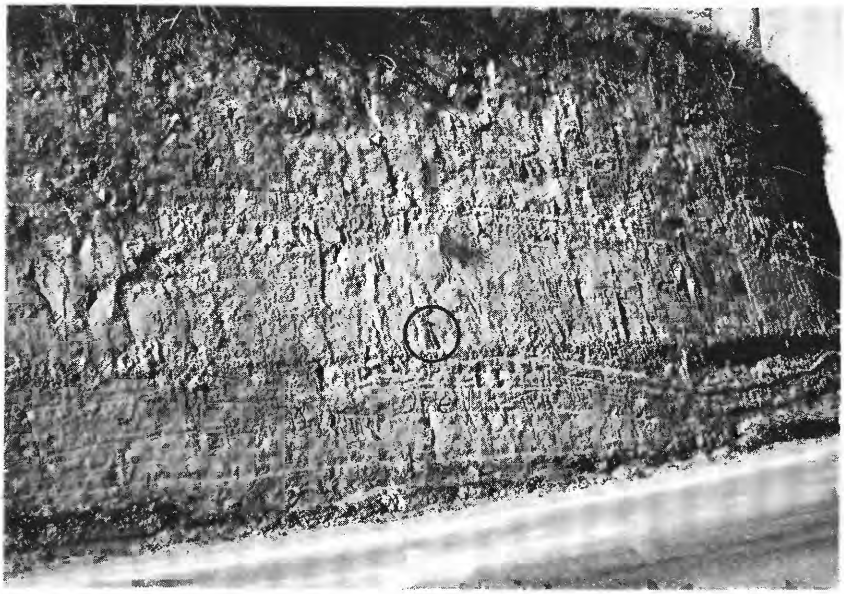


FIGURE 11.—Lacustrine sandstone and siltstone in the Kelseyville Formation. View is northwest along Kelsey Creek Drive in sec. 23, T. 13 N., R. 9 W. Note encircled hammer for scale.

ciscan assemblage. However, conglomerate is well represented to the southeast, in the Carlsbad Spring area, near the top of the Kelseyville Formation, and it is also present along the extreme southwestern boundaries of the Kelseyville Formation, near its base, along Adobe and Sweetwater Creeks.

West of Highland Springs Reservoir is an isolated exposure of very pale orange (10*YR*8/2) to yellowish-gray (5*Y*8/1) diatomite that is included in the Kelseyville Formation. The exposure is approximately 5 m thick and overlies Franciscan greenstone.

Within the Kelseyville Formation is a 1.0- to 1.7-m-thick bed of lapilli tuff of basaltic andesite composition (57.9 and 58.7 percent SiO_2, dry weight; B. C. Hearn, Jr., written commun., 1978). Because of its distinctive character and its presence throughout much of Big Valley, the tuff is useful as a marker bed. The tuff is here named the Kelsey Tuff Member of the Kelseyville Formation for exposures in Kelsey Creek and along State Highway 29. The type section of the tuff is exposed in a roadcut along State Highway 29 3.4 km SSE of Kelseyville in the SE¼NE¼ sec. 26, T. 13 N., R. 9 W. (fig 12). Because the tuff is the only reliable marker bed in the formation it is described in detail.

The presence of the tuff southeast of Kelseyville was noted by Anderson (1936) and Hodges (1966). In the report of the Lake County Flood Control and Water Conservation District (1967) the tuff is refer-

FIGURE 12.—Type section of Kelsey Tuff Member of Kelseyville Formation in roadcut of State Highway 29 in sec. 26, T. 13 N., R. 9 W. Note fine-grained lower unit and coarser, poorly sorted upper unit.

red to as "volcanic-ash aquifer" and "aquifer ash" and is described as a dactic to andesitic lithic tuff. The bed contains ground water under artesian pressure, and supplies water to wells in the area south of the Big Valley fault.

Exposures of the Kelsey Tuff Member south and southeast of Kelseyville are 140–170 cm thick. The best exposures of the tuff are in Kelsey Creek and in roadcuts and gullies in the hills on the east side of Big Valley. In this area the tuff is easily traced beneath the thin soil cover because of its relative resistance to erosion and its marked difference in grain size from the enclosing sandstone. Another good exposure of the tuff is in a creek tributary to Kelsey Creek, in sec. 27, T. 13 N., R. 9 W.

The distribution of the Kelsey Tuff Member (fig. 13) is known from surface exposures and by numerous water wells drilled for water contained in the "aquifer ash." The tuff occurs 16–45 m below the ground surface west of the Adobe Creek fault. North of the Big Valley fault, the tuff occurs approximately 160 m below the ground surface in one well, but its extent and attitude are not known.

The Kelsey Tuff Member consists of two units. The lower unit, 20–30 cm thick, is composed of several thin beds (fig. 12) that range from light gray (*N*7) to yellowish gray (5*Y*8/1) and from fine-grained vitric tuff to coarser, lithic tuff. The upper unit, commonly 120–170 cm thick (fig.

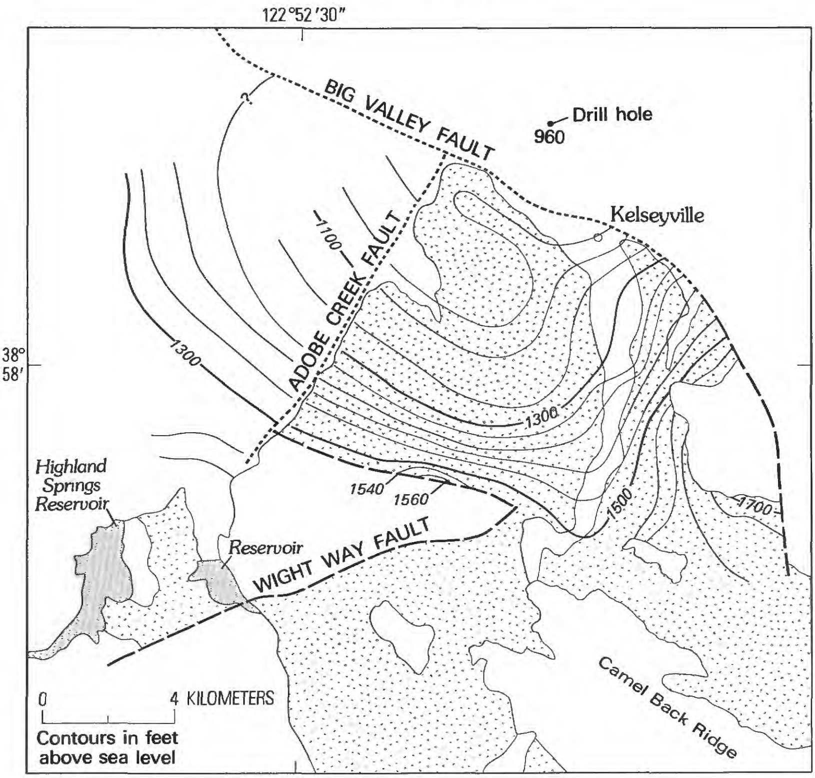


FIGURE 13.—Structure-contour map of top of Kelsey Tuff Member of Kelseyville Formation. Note presence of tuff west of Adobe Creek fault. Tuff is present below alluvial cover and upper part of Kelseyville Formation at drill hole northwest of Kelseyville. Exposure pattern of Kelseyville Formation is shown by stipple pattern. Kelseyville Formation is covered by Quaternary alluvium west and north of Adobe Creek and Big Valley faults, respectively. (Data from this study and well logs.)

12), is an unsorted bed of pumiceous, basaltic andesite lapilli tuff that is gray (*N*6) to yellowish gray (5*Y*8/1).

The Kelsey Tuff Member shows chemical affinity to flows of the Clear Lake volcanic field and is possibly from one of the vents that erupted pyroclastic material and small flows high on the flanks of Mount Konocti to the east (B. C. Hearn, Jr., oral commun., 1976). The tuff was deposited primarily in a lacustrine environment, and around the margins of this lake basin it was deposited in a fluvial environment.

Seven other beds of tuff were seen in the Kelseyville Formation, but because of limited extent and exposure none of these has proved to be of use as a marker bed. These beds range from crystal-rich dacitic tuff to vitric lapilli tuff, and generally range in thickness from about 3 to 17 cm. However, one of these beds, present near the base of the Kelseyville

Formation near Sweetwater Creek, is of importance in the determination of the age of the formation (see below). This locally lithic, pumiceous, lapilli tuff is interbedded with lithic wacke of the formation and is approximately 5 m thick. The tuff contains as much as 5 percent lithic inclusions of metagraywacke and other older rocks and is very pale orange (10*YR*8/2).

AGE AND STRATIGRAPHIC RELATIONS

The Kelseyville Formation in Big Valley is of Pleistocene age, ranging from approximately 0.64 m.y. at the exposed base to approximately 0.13 m.y. at the exposed top. The age of the exposed top of the formation is an estimate of the end of oxygen-isotope stage 6 (Shackleton and Opdyke, 1973), which is probably correlative with deposits that represent cold climatic conditions in the Kelseyville Formation and with the Illinoian Glaciation of the mid-North American continent.

Rocks of the Franciscan assemblage underlie most of the Kelseyville Formation. The contact between the Kelseyville Formation and the Franciscan assemblage (fig. 4) is exposed to the south and west of Big Valley. Other indicators of Franciscan rocks as underlying the Kelseyville are a small exposure of Franciscan greenstone in the NW¼ sec. 33, T. 13 N., R. 9 W., and reports of water wells that penetrate Franciscan rock in the Adobe Creek drainage, west of the Adobe Creek fault.

Serpentinite also underlies the Kelseyville Formation locally. Exposures of serpentinite in the Big Valley area are in sec. 33, T. 13 N., R. 9 W., and to the southeast, near Sweetwater Creek and Camel Back Ridge (fig. 4).

Of the rocks that underlie the Kelseyville Formation, flows of the Clear Lake volcanic field are the most useful for determining the age of the formation. Seven such units locally underlie and may be interbedded with the Kelseyville Formation in the Cole Creek–Camel Back Ridge area, and six have been dated by the K-Ar method (dates given here are from Donnelly-Nolan and others, 1980). Biotite-hornblende dacite of Mount Olive (0.53±0.02 m.y.) underlies the Kelseyville Formation in the vicinity of Mount Olive (Hearn and others, 1976). Also underlying the Kelseyville Formation in the vicinity of Mount Olive is basalt of McIntire Creek. Biotite rhyolite of Milky Creek (0.60±0.02 m.y.) of Hearn, Donnelly, and Goff (1976) underlies the Kelseyville Formation near the junction of Milky and Kelsey Creeks, and in the Kelsey Creek gorge area. In the same general area Hearn, Donnelly, and Goff (1976) reported the presence of biotite-hornblende dacite of Camel's Hump (0.59±0.02 m.y.) and biotite dacite of Kelsey Creek (0.53±0.03 and 0.58±0.02 m.y.). Also underlying the formation, but farther north, is biotite rhyolite of Cole Creek (0.54±0.02 m.y.). The contact between the biotite rhyolite and the Kelseyville Formation is visible in roadcuts along State Highway 29 near the center of sec. 23, T. 13 N., R. 9 W.; in the Wilkinson Road area; and in the large ravine in the N½ sec. 26, T. 13 N., R. 9 W. (fig. 3). Logs of water wells to the west of these exposures indicate that the rhyolite is present at depth below the northeastern part of the Kelseyville Formation. Obsidian flows composing Camel Back Ridge (the rhyolite of Thurston Creek) and dated at 0.64±0.03 and 0.53±0.016 m.y. (Donnelly-Nolan and others, 1980) are lithologically similar to an unnamed pumiceous lapilli tuff exposed near the base of the Kelseyville Formation. The resemblance suggests that the exposed Kelseyville Formation is mainly younger than 0.64 m.y. old.

Quaternary terrace deposits overlie most of the Kelseyville Formation, except in the area south of the Wight Way fault and in the hills south of Kelseyville, east of Kelsey Creek. Isolated exposures of terrace gravel are present on hilltops in the Cole Creek drainage. There, terrace gravel is differentiated from underlying fluvial conglomerate of the formation by the presence of obsidian (rhyolite of Thurston Creek) in the gravel. The large expanse of the Kelseyville Formation west of Kelsey Creek and north of the Wight Way fault is covered by a thin veneer of obsidian-bearing terrace gravel. Much of this veneer has been obscured or removed by intense agricultural activity in Big Valley. Quaternary alluvium locally conceals the Kelseyville Formation along Kelsey and Cole Creeks, north of the Big Valley fault, and west of the Adobe Creek fault. In these areas the Kelseyville Formation was detected in water-well logs (fig. 13). The thickness of alluvium in these areas is variable and little known, owing to the difficulty of determining formational units from water-well logs.

On the basis of stratigraphic relations with different dated units of the Clear Lake volcanic field, the Kelseyville Formation is believed to be partly equivalent in age to the Lower Lake Formation (fig. 6). Also, the upper part of the Kelseyville appears to be correlative with lacustrine sediment of Clear Lake (Sims and others, 1980).

FOSSILS

Numerous fossils have been found in the Kelseyville Formation, including gastropods, ostracodes, diatoms, fishes, siliceous sponge spicules, and plants. However, the fossils are of little use in determining the age of the formation, except for megafossil plants.

Plants remains collected by me and by J. A. Wolfe represent growth and deposition during two distinct climatic periods: a warm (interglacial) period, represented low in the section, and a cold (glacial) period, represented higher in the section (J. A. Wolfe, written communs., 1976, 1977). In essence, fossil leaves from sample sites located approximately 200 m below the Kelsey Tuff Member, and that represent growth during an interglaciation, are, according to Wolfe:

Platanus racemosa Nutt. (California sycamore)
Quercus douglasii Hook. and Arn. (blue oak)
Quercus wislizenii A. DC. (interior live oak)
Populus trichocarpa Torr. and Gray (black cottonwood)
Salix spp. (willows; at least three species present).

Megafossil plants lying stratigraphically above the previously listed fossils, determined by Wolfe as representing growth during a glacial interval, are

Abies cf. *A. procera* Rehd. (noble fir)
Abies concolor (Gord. and Glend.) Lindl. (white fir)
Alnus rhombifolia Nutt. (white alder)
Arctostaphylos manzanita (common manzanita)
Ceanothus cordulatus Kell. (mountain whitethorn)
Cercocarpus betuloides Nutt. (birch, leaf mountain mahogany)
Picea breweriana S. Wats. (Brewer or weeping spruce)
Pinus balfouriana Grev. and Galf. (foxtail pine)
Populus trichocarpa Torr. and Gray (black cottonwood)
Pseudotsuga menziesii (Mirb.) Franco (Douglas-fir)
Quercus chrysolepis Liebm. (canyon live oak)
Salix spp. (willow)
Thuja cf. *T. plicata* Donn (western redcedar)
Extinct and undescribed *Pinus* species, apparently a formation of Subsect. Ponderosae.

The beds that contain these plant fossils lie above the unnamed tuff that is inferred to be 0.64 m.y. old. The presence of fossil spruce cones and pollen in the upper part of the Kelseyville and which represents a glaciation are in contrast to the glacial pollen spectra from a long core from Clear Lake of Sims, Adam, and Rymer (1980), which contains virtually no spruce pollen, and which is inferred to represent deposition during oxygen-isotope stages 5 through 2. The upper part of the Kelseyville is thus inferred to represent deposition during oxygen-isotope stage 6. The stratigraphically lower interglacial flora of the Kelseyville then represents deposition during stage 7. This all suggests a minimum age of approximately 0.13 m.y. for the top of the exposed part of the Kelseyville Formation, as correlated with age assignments of Shackleton and Opdyke (1973).

MEASURED SECTIONS

REFERENCE SECTION OF CACHE FORMATION

[Along Blackeye Canyon in the N½N½ sec. 13, T. 13 N., R. 7 W., Lower Lake 7.5-minute quadrangle. Measured by M. J. Rymer using Abney level and tape, June 13, 1977]

	Thickness (meters)
Covered by vegetation	1.0+
Cache Formation (incomplete):	
Sandstone, pebbly, yellowish-gray (5*Y*7/2), poorly consolidated; contains local yellowish-gray (5*Y*7/2), poorly consolidated pebble conglomerate; higher beds not exposed	2.0+
Tuff, lapilli, basaltic, light-yellowish-gray (5*Y*9/2); continuous bedding 0.5–5 cm thick, resistant; contains two beds of dusky-red (5*R*3/4) to grayish-black (*N*2), basaltic, pyroclastic breccia, blocks of breccia as much as 62 cm in maximum dimension, average block size 6–10 cm; tuff beds below blocks are plastically deformed	1.6
Covered interval	49.6
Sandstone, yellowish-gray (5*Y*8/1), moderately cemented, medium-grained	0.3
Covered interval	12.8
Tuff, lithic, light-gray (*N*7), friable, thin-bedded; top not exposed	0.9
Sandstone, pebbly, light-brown (5*YR*7/6) to light-gray (*N*7), poorly consolidated; contains light-brown (5*YR*7/6) pebble conglomerate; contains local light-gray (*N*7) to light-brown (5*YR*7/6) friable sandstone; contains local limonite-cemented beds as thick as 7 cm	25.5
Sandstone, light-gray (*N*7), fine-grained, poorly bedded, well-sorted, poorly consolidated	8.0
Pebble conglomerate, tuffaceous, light-gray (*N*7); contains light-gray (*N*7), friable, tuffaceous sandstone	1.6
Siltstone, clayey, light-gray (*N*7), thin-bedded; contains plant fragments	1.2
Tuff, medium-gray (*N*5), lithic, basaltic, friable; has local wavy lamination	2.7
Sandstone, light-gray (*N*7), moderately sorted, poorly consolidated, cross-stratified; contains pebble conglomerate, pebbly sandstone, and limonite-cemented beds	14.2
Pebble conglomerate, light-gray (*N*7) to yellowish-gray (5*Y*8/1), moderately sorted, poorly consolidated, cross-stratified, contains local boulders, 37 cm maximum dimension; contains abundant light-gray (*N*7) to yellowish-gray (5*Y*8/1), moderately to poorly sorted, poorly consolidated sandstone and pebbly sandstone in lower 20.8 m sandstone and pebbly sandstone are dominant; entire section contains resistant limonite-cemented beds	27.2
Pebble conglomerate, tuffaceous, light-gray (*N*7) to yellowish-gray (5*Y*8/1), poorly sorted, poorly consolidated; contains sparse cobbles; pebbles and cobbles are subrounded; in upper 10 cm contains tuff, lithic, light-gray (*N*7), poorly bedded, poorly consolidated	21.6
Covered interval	2.4
Tuff, vitric, light-gray (*N*7), moderately resistant, massive	3.5
Pebble, conglomerate, yellowish-gray (5*Y*7/2) to reddish-brown (10*R*5/6), poorly sorted, poorly consolidated; clasts are subrounded to subangular and as large as 25 cm in maximum dimension, average clast size is approximately 2 cm; contains yellowish-gray (5*Y*8/1) fine- to medium-grained moderately sorted sandstone	1.0
Covered interval	4.8

Cache Formation—Continued	Thickness (meters)
Pebble conglomerate, yellowish-gray (5*Y*8/1) to reddish-brown (10*R*5/6), poorly sorted, poorly consolidated; clasts are as large as 25 cm in maximum dimension, average clast size is approximately 2 cm; contains yellowish-gray (5*Y*8/1), fine- to medium-grained, moderately sorted sandstone	3.2
Tuff, vitric, very light gray (*N*8), poorly bedded, moderately sorted	0.8
Covered interval	6.4
Siltstone, yellowish-gray (5*Y*7/2), poorly bedded, poorly exposed	3.2
Covered interval	2.4
Siltstone, yellowish-gray (5*Y*8/1), poorly bedded, poorly exposed	0.7
Covered interval	16.0
Sandstone, yellowish-gray (5*Y*8/1), moderately bedded, poorly to moderately sorted, poorly to moderately consolidated; also contains siltstone, pebbly sandstone, and pebble conglomerate; local lensing of conglomerate	4.2
Covered interval	2.4
Siltstone, clayey, yellowish-gray (5*Y*7/2) to pale-olive (10*Y*6/2), poorly to moderately bedded, moderately sorted, poorly exposed, weathers to light-gray (*N*7) to yellowish-gray (5*Y*7/2) chips; contains local pebble conglomerate, lenses as thick as 10 cm; has local iron-stained and limonite-cemented beds; limonite-cemented beds are as much as 20 cm thick	0.8
Covered interval	3.2
Siltstone, clayey, yellowish-gray (5*Y*8/1) to pale-olive (10*Y*6/2), poorly to moderately bedded, moderately sorted, poorly exposed, weathers to light-gray (*N*7) chips; contains local pebble conglomerate, lenses as thick as 10 cm; has local iron-stained and limonite-cemented beds; limonite cemented beds are as much as 20 cm thick and appear in intervals of approximately 70 cm	6.1
Covered interval	16.0
Siltstone, clayey, yellowish-gray (5*Y*8/1) to pale-olive (10*Y*6/2), poorly to moderately bedded, moderately sorted, poorly exposed, weathers to light-gray (*N*7) chips; contains local pebble conglomerate, lenses as thick as 10 cm; has local iron-stained and limonite-cemented beds, limonite-cemented beds are as much as 20 cm thick and appear in intervals of approximately 70 cm	3.2
Covered interval	13.2
Sandstone and pebble conglomerate, yellowish-gray (5*Y*8/1) to pale-olive (10*Y*6/2), locally reddish-brown (10*R*4/4), horizontally bedded, locally cross-stratified, moderately sorted, poorly consolidated; has local lensing of conglomerate beds; in lower 100 cm contains very light gray (*N*8), massive vitric tuff; lower beds not exposed	3.2+
Partial thickness of Cache Formation	265.9+

TYPE SECTION OF LOWER LAKE FORMATION

[Along west side of State Highway 53 in the town of Lower Lake in the W½SW¼SW¼ sec. 2, T. 12 N., R. 7 W., Lower Lake 7.5-minute quadrangle. Measured by M. J. Rymer using Abney level and tape, June 13, 1977]

	Thickness (meters)
Covered by vegetation	1.0+
Lower Lake Formation (incomplete):	
Diatomite, diatomaceous siltstone, and silty diatomite, white (*N*9) to very pale-orange (10*YR*8/2), horizontally bedded; beds 1 to 8 cm thick; higher beds not exposed	0.2

Lower Lake Formation—Continued	Thickness (meters)
Tuff, lapilli, lithic, medium-gray (N5)	0.1
Siltstone, greenish-gray (5GY7/1), poorly consolidated	0.7
Diatomite, diatomaceous siltstone, and silty diatomite, white (N9) to very pale orange (10YR8/2), horizontally bedded; beds 1 to 8 cm thick	2.9
Sandstone, yellowish-gray (5Y7/2), fine-grained, very poorly consolidated, composed of angular grains	0.2
Sandstone, siltstone, yellowish-gray (5Y7/2), friable; contains local pebbles (approximately 1 percent of total); has local limonite stains	0.1
Sandstone, pebbly, yellowish-gray (5Y7/2) to dusky-yellow (5Y6/4), poorly consolidated; contains some pebbly siltstone beds	0.3
Pebble conglomerate, and lithic lapilli tuff, medium-light-gray (N6), poorly consolidated; contains clasts as long as 8 cm, average pebble size approximately 2 cm; has an undulatory, unconformable contact at base	2.4
Siltstone, clayey, yellowish-gray (5Y8/1), friable, horizontally bedded	7.3
Tuff, lapilli, lithic, medium-gray (N5), friable; has an unconformable contact at base	0.1
Siltstone, clayey, yellowish-gray (5Y7/2), friable, horizontally bedded; contains local sandstone beds	0.3
Sandstone, pebbly and pebble conglomerate, light-brown (5YR6/4) to dark-yellowish-orange (10YR6/6); lower part covered (section offset)	1.0+
Sandstone, pebbly, light-brown (5YR6/4) to dark-yellowish-orange (10YR6/6), and light-brown (5YR6/4) pebble conglomerate; composed of sub-rounded to rounded pebbles; locally contains cobbles (5 percent), poorly consolidated	13.0+
Siltstone, calcareous, white (N9), resistant; contains local, discontinuous limestone beds	1.0
Tuff, lapilli, lithic, light-gray (N7), resistant, horizontally bedded, well-sorted; locally graded	1.1
Siltstone, calcareous, white (N9), resistant; contains local, discontinuous limestone beds	3.6
Siltstone, calcareous, white (N9), friable; contains ostracodes, pelecypods, gastropods, and fishes	12.4
Siltstone, yellowish-gray (5Y7/2) to very pale orange (10YR8/2), friable, fossiliferous (ostracods and pelecypods), locally calcareous; contains interbeds of mudstone and sandstone	10.5
Sandstone, yellowish-gray (5Y8/1), fine-grained, friable; with interbedded white (N9), resistant vitric and lithic tuffs; beds from 2 to 75 cm thick	1.3
Siltstone, yellowish-gray (5Y8/1), friable; locally calcareous, resistant, fossiliferous (fishes and gastropods); contains local yellowish-gray (5Y8/1), friable sandstone; all poorly exposed; beds as thick as 100 cm; at 11.4-m depth contains a very light gray (N8), 20-cm-thick vitric tuff	12.7
Covered interval	33.4
Sandstone, pebbly, grayish-orange (10YR7/4) to yellowish-gray (5Y7/2), friable, poorly bedded; has local small-scale lensing; contains local grayish-orange (10YR7/4) to yellowish-gray (5Y7/2) medium-grained sandstone; local graded bedding; beds from 10 to 40 cm thick; unconformable contact at base	23.3
Partial thickness of Lower Lake Formation	127.9+

Base of section; unit unconformably overlies Great Valley sequence:

Great Valley sequence:	
Sandstone, wacke, feldspathic, slightly friable, light-olive-gray (5Y6/1); lower beds not measured	10.0+

TYPE SECTION OF KELSEYVILLE FORMATION

[Exposures along Kelsey Creek in the SE¼NE¼ sec. 27, to NW¼NW¼ sec. 26, and in the SW¼SE¼ sec. 23, in T. 13 N., R. 9 W., Kelseyville 7.5-minute quadrangle. Measured by M. J. Rymer using Abney level and tape, June 12, 1977]

	Thickness (meters)
Covered by vegetation and terrace gravel, pebbly	0.1+
Kelseyville Formation (incomplete):	
Sandstone, yellowish-gray (5*Y*7/2) to dusky-yellow (5*Y*6/4), fine- to medium-grained; horizontally bedded, friable; local wavy parallel lamination; contains small carbonaceous plant fragments; contains local pebble conglomerate to pebbly sandstone beds of variable thickness	13.2
Pebble conglomerate, pale-brown (5*YR*5/2), irregularly bedded	0.3
Sandstone, yellowish-gray (5*Y*7/2) to dusky-yellow (5*Y*6/4), fine- to medium-grained, horizontally bedded, friable; local limonite stains and concretions; contains small carbonaceous plant fragments and fossil leaves	20.4
Tuff (Kelsey Tuff Member), lapilli, basaltic andesite, medium- light-gray (*N*6) to yellowish-gray (5*Y*7/2), unsorted, in part pumiceous, very poorly bedded; forms resistant ledge; at base are several thin beds of light-gray (*N*7) to yellowish-gray (5*Y*8/1), fine-grained, vitric basaltic andesite tuff; lower beds are commonly well sorted, some are graded	1.4
Sandstone, yellowish-gray (5*Y*7/2) to dusky-yellow (5*Y*6/4)), fine- to medium grained, silty, massive, friable; locally sandy siltstone; local horizontal bedding; contains small carbonaceous plant fragments and fossil leaves and cones	24.2
Covered interval	3.5
Sandstone, yellowish-gray (5*Y*7/2) to dusky-yellow (5*Y*6/4), fine- to medium-grained, silty, massive, friable; local sandy siltstone; contains small carbonaceous plant fragments and fossil leaves and cones	36.3
Sandstone, as above, pebbly sandstone, and local pebble conglomerate (as thick as 2.6 m), horizontally bedded; conglomerate and locally pebbly sandstone are well cemented, olive gray (5*Y*5/1); tree stumps in their growth position in the lower 2 m	29.7
Sandstone, olive-gray (5*Y*5/1) to dusky-yellow (5*Y*6/4), medium- to coarse-grained, massive and locally bedded, friable; contains a few local pebble conglomerate lenses approximately 20 cm thick, consolidated; contains abundant plant fragments and fossil leaves; lower beds not measured	12.0+
Partial thickness of Kelseyville Formation	141.0+

TYPE SECTION OF KELSEY TUFF MEMBER OF KELSEYVILLE FORMATION

[Roadcut along State Highway 29, 3.4 km SSE of Kelseyville in the SE¼NE¼ sec. 26, T. 13 N., R. 9 W., Kelseyville 7.5-minute quadrangle. Measured by M. J. Rymer using tape, April 29, 1974]

	Thickness (meters)
Kelseyville Formation (incomplete):	
Sandstone, yellowish-gray (5*Y*7/2) to dusky-yellow (5*Y*6/4), fine- to medium-grained, silty, massive, friable; local wavy parallel lamination; contains small carbonaceous plant fragments	1.0+
Kelsey Tuff Member:	
Tuff, lapilli, basaltic andesite, light-gray (*N*7) to yellowish-gray (5*Y*7/2), unsorted, in part to pumiceous, very poorly bedded, resistant	1.4

Kelsey Tuff Member—Continued	*Thickness (meters)*
Tuff, basaltic andesite, very light gray (*N*8) to dusky-yellow (5*Y*6/4), moderately to well sorted, friable; beds 3–13 cm thick	0.3
Kelseyville Formation:	
Sandstone, yellowish-gray (5*Y*7/2) to dusky-yellow (5*Y*6/4), fine- to medium-grained, silty, massive, friable; local wavy parallel lamination, contains carbonaceous plant fragments	3.0+

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