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Contact relations of the Ione and Valley Springs Formations in the east-central Great Valley, California

by

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CONTACT RELATIONS OF THE IONE AND VALLEY SPRINGS FORMATIONS IN THE EAST-CENTRAL GREAT VALLEY, CALIFORNIA

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ABSTRACT

The Eocene Ione Formation and the overlying Oligocene Valley Springs Formation are the lowest two units of the almost entirely nonmarine Tertiary section of the east-central Great Valley. The strata now assigned to the Valley Springs Formation were originally included in the Ione Formation as the "clay rock or tuff," the highest of three subdivisions of the Ione. Although most workers have recognized the fundamental lithologic difference between the Ione proper and the "clay rock and tuff," and noted that the two units are separated by a disconformity, some of the more recent workers have emphasized the compositional similarities between the two units near the contact and have suggested that the contact is locally gradational. The nature of the contact, whether it is a major unconformity or is basically conformable with only minor local erosion, has important implications for the geologic history of the region.

Short detailed sections were measured across the Ione-Valley Springs contact at three localities where the rocks are well exposed. Samples collected from the sections were analysed by X-ray diffraction for clay minerals and selected thin sections were pointed-counted for sandstone modes. The rocks in the measured sections reflect the quartzose sandstone and kaolinitic clay lithology characterizing the Ione Formation, and the tuffaceous mudrock and sandstone lithology characterizing the Valley Springs Formation. Compositional differences between the two formations were noted in conglomerate clast composition, sandstone mineralogy and, to a lesser degree, in clay mineralogy.

The age of the Ione Formation is poorly controlled, but on the basis of its relations to other formations, it is considered to be middle Eocene in age and could be as young as late Eocene. The age of the Valley Springs Formation is tied to K-Ar dates of included rhyolitic or rhyodacitic tephra which indicate an age of late Oligocene and early Miocene. The best age estimates for the two formations suggests that the Ione is no younger than about 37-40 Ma and the Valley Springs is no older than about 30 Ma, which leaves a hiatus of *at least* 7-10 m.y. Lithologic and compositional contrasts between the two units, together with widespread evidence of erosion and weathering at the contact, provide evidence of disconformity. Both the Ione and Valley Springs consist mostly of fluvial facies, however, the presence of marine facies near the top of the Ione indicates that the coastline was near the east side of the valley during Ione deposition, whereas the Valley Springs piedmont alluvial system apparently extended completely across the valley indicating a large westward shift in the coastline at the contact. There is also evidence of a significant climatic change at the contact. It is concluded that the Ione and Valley Springs Formations are separated by a regional disconformity and that compositional similarities near the contact are due to reworking of Ione detritus into the lower part of the Valley Springs.

INTRODUCTION

The Ione and Valley Springs Formations are the lowest two of the four units, the Ione, Valley Springs, Mehrten, and Laguna Formations, that make up the almost entirely nonmarine Tertiary section of the east-central Great Valley (Bartow, 1991). The Eocene Ione Formation, characterized by quartzose sandstone and kaolinitic clay, is overlain by the late Oligocene and early Miocene Valley Springs Formation, characterized by tuffaceous mudrock and sandstone, and rhyolitic or rhyodacitic tuff. These two formations are exposed discontinuously along the northeastern edge of the Great Valley in central California (Fig. 1). The Ione is probably at least partly equivalent to the prevolcanic auriferous gravels of the Sierra Nevada which occur as isolated paleochannel deposits in the lower to middle elevations of the range (Allen, 1929; Bateman and Wahrhaftig, 1966). The Ione seems to mostly represent deltaic or paralic deposits that might be considered a distal facies of the auriferous gravels. The Valley Springs represents a large fluvial depositional system that extended westward from paleovalleys in the high Sierra Nevada to a piedmont alluvial plain under the present Great Valley.

The name "Ione Formation" was first used by Lindgren (1894) for the beds of clay and sand containing layers of lignite that crop out along the foothills of the Sierra Nevada; the name derives from the town of Ione in Amador County. The strata now assigned to the Valley Springs Formation were originally included in the Ione Formation as the "clay rock or tuff," the highest of three subdivisions of the Ione (Turner, 1894, p 464). Allen (1929) recognized the fundamental lithologic difference between the Ione proper and the "clay rock and tuff," and noted that the two units are separated by a disconformity. The Valley Springs Formation was formally defined by Gale and others (1939) from a type section near the town of Valley Springs in Calaveras County. They showed that it was deposited on an eroded surface of low to moderate relief. Pask and Turner (1952) and Slemmons (1966) also considered the two formations to be separated by an unconformity. Some more recent workers have emphasized the compositional similarities between the two units near the contact and have suggested that the contact is locally gradational (Gillam, 1974; Ely and others, 1977; Dickinson and others, 1979).

The four Tertiary formations of the east-central Great Valley, despite representing similar nonmarine environments, are lithologically distinct (Table 1). Some uncertainity now seems to exist, however, about the nature of the contact between the Ione and Valley Springs Formations, that is, whether the contact is everywhere a major unconformity, or whether it merely represents minor local erosion and is even locally gradational. This uncertainty has implications for the geologic history of the region. Is there a large hiatus between the two units, comprising most of the Oligocene as has been commonly supposed (see Bartow, 1991), or is the sedimentary record complete or nearly complete from the Eocene through the early Miocene? This uncertainty is perhaps heightened by (1) the sparsity of age information from these two units, (2) the very low dip of the units (generally less than 2 degrees) which, in combination with the moderate topographic relief, obscures the nature of the contact, (3) the compositional similarities between the units at some localities, and (4) by the tendency for material from one unit to be reworked into the overlying unit, as has been observed for other Tertiary units in the area. The purpose of this report is to present data collected from the Ione and Valley Springs near their contact which may serve to clarify the relations between the two formations, and thereby to clarify the geologic history of the region.

Acknowledgements

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METHODS

Short detailed sections were measured across the Ione-Valley Springs contact at three localities where the rocks are well exposed (Fig. 1, Plate 1). Two of these localities (A and B) are from roadcuts near Camanche Reservoir on the Ione 7.5' quadrangle (Fig. 2), and the third (C) is along Rydberg Creek, a tributary to Dry Creek, on the Cooperstown 7.5' quadrangle (Fig. 3). Localities A and B are in the area where some uncertainty exists about the contact; locality C is in an area where a well-developed laterite has formed at the top of the Ione Formation (Ely and others, 1977) and there is, therefore, little doubt about the nature of the contact.

Samples were collected about two to three meters apart through each of the measured sections (Plate 1). Samples of clay were analysed by conventional X-ray diffraction methods using the suction-on-porcelain method of sample prepartion. Relative amounts of kaolinite, smectite, mixed-layer clay, and chlorite were estimated using the methods outlined by Schultz (1960, 1964, 1978). Sandstone and other rocks were studied by modal analyses of thin sections and by X-ray diffraction analyses of bulk sample material. The sandstone samples were point-counted by the Gazzi-Dickinson method (Dickinson, 1970; Ingersoll and others, 1984); the primary parameters are plotted on Figure 4. Clay mineralogy and selected secondary parameters determined from modal analysis of sandstones are plotted on Plate 1.

DESCRIPTION OF THE ROCKS

Lithology

The rocks in the three measured sections (Plate 1) reflect the most common lithologies in the Ione and Valley Springs Formations. The Ione in the sections is composed mostly of quartzose sandstone, clayey sandstone, and claystone, and includes a few small pebbly sandstone lenses. A well indurated and strongly mottled (red and light gray) zone about 1 m thick at the top of the Ione at locality C is interpreted as a remnant of a lateritic paleosol (Ely and others, 1977). The Valley Springs includes tuffaceous mudstone (wavy bedded in part) and claystone or mudstone. Matrix-rich conglomerate lenses characterize the Valley Springs at locality A. The Valley Springs at locality C contains reworked clasts of laterite material in its lower part and a thick (>10 m) vitric tuff in the upper part of the section.

The Ione and Valley Springs Formations are most similar in the area of locality B where a series of clayey sandstone and claystone beds (Ione) is overlain by tuffaceous claystone and mudstone (Valley Springs). Colors are mostly yellowish gray or light gray in both formations, and the clayey, fine-grained sandstone in the Ione can superficially look much like sandy tuffaceous mudstone in the Valley Springs.

For the most part, however, the lithologies of the two formations are distinct. Massive to laminated, clayey sandstone, light gray to white or locally brick red, is common in the Ione, but does not occur in the Valley Springs. Ione claystone is commonly dense and homogeneous and may have a conchoidal fracture. The distinctive tuffaceous mudstone or claystone with crude wavy bedding and clay-lined partings, fissures, and minute tubules and vugs that characterizes the Valley Springs, on the other hand, does not occur in the Ione.

Composition

Conglomerate clasts.—The conglomerate beds in the Ione and Valley Springs are usually distinct in composition. Ione conglomerate clasts are almost entirely white vein quartz or quartzite and contain very minor amounts of highly weathered Sierran basement rock types locally. The Valley Springs conglomerate contains abundant quartzose clasts, but it also contains a more diverse assemblage of less weathered Sierran basement rock types. Tertiary rhyolitic or rhyodacitic clasts may also be present in the Valley Springs, but are usually not abundant. Both units contain metavolcanic clasts from the Sierran foothills metamorphic belt.

Sandstone.—Pask and Turner (1952) divided the Ione in the Buena Vista area (including locality B of this report) (Fig. 1) into two informal members with different mineralogy. The lower unit, which makes up most of the formation, has the typical Ione mineralogy characterized by high quartz/feldspar ratio, very low plagioclase/total feldspar ratio, common anauxite, and little or no mica or lithic grains. The upper unit has lower quartz/feldspar ratio, contains more plagioclase, and contains minor amounts of mica and lithic grains (Gillam, 1974). The internal stratigraphy of the Ione, however, is complex, as would be expected for a fluvial-deltaic unit, and the validity of Pask and Turner's (1952) stratigraphy is questionable. Nevertheless, there does seem to be a general trend of an upward increase in less stable minerals. Allen (1929) also noted an upward increase in feldspar.

The Valley Springs sandstone contains more feldspar, lithic grains and biotite than the Ione. Despite the increase in less stable minerals in the uppermost part of the Ione, the Ione and Valley Springs sandstones are distinct, with the exception of one sample from locality C (Fig. 4). The Valley Springs, morever, contains common to abundant glass shards and pumice grains in its mudrock facies and also locally in the sandstone. This type of material is nowhere present in the Ione. The Ione sandstone contains very rare weathered volcanic lithic grains which are probably metavolcanic rocks from the foothills metamorphic belt. Volcanic lithic grains are generally more abundant in the sandstone of the Valley Springs, but the abundance varies and this constituent may be absent in some samples. Volcanic (beta) quartz has been reported from Ione sandstone (Gillam, 1974), but this, also, could have been derived from older metavolcanic rocks.

Clays.—Kaolinite is the dominant clay mineral in both the Ione and Valley Springs Formations in the samples studied (Plate 1). There is an increase in smectite, locally marked, above the contact, but the kaolinite content is locally high in the Valley Springs and it is the dominant clay throughout the section at locality C. The mixed-layer clay content is generally small but variable and it is included with the smectite on Plate 1. The illite content is negligible.

Evidence of disconformity

The apparent local absence of evidence for a disconformity is the crux of the problem. Previous workers have observed that the Valley Springs was deposited on a surface of low to moderate erosional relief (Allen, 1929; Gale and others, 1939). Despite clear evidence for a disconformity at many localities (the area of locality C for example), in a few areas it is not clear. The Buena Vista area north of Camanche Reservoir studied by Gillam (1974) is an example of such an area.

As described by Gillam (1974), the Ione Formation locally grades up into the Valley Springs, primarily by a marked increase in the volcanic component, implying that there is not a clearly recognizable contact horizon. In the area in question, represented by locality B, I found a definite and reasonably clear contact on the basis of field inspection. There is a superficial lithologic similarity between the two formations at this locality, but rocks below the contact were all recognizable as Ione, with a slight degree of reddening of the uppermost few centimeters, and rocks above this horizon were readily identifiable as Valley Springs. At locality A, a little over 2 km to the south, the contact is an erosional surface with about 5 m of relief. About 4 km to the north, a well-developed, exumed, lateritic paleosol caps the Ione Formation (Singer and Nkedi-Kizza, 1980) and a lateritic paleosol separates the two formations in the vicinity of locality C to the south. The laterite locally found at the top of the Ione is the only laterite directly associated with the formation, although a second laterite has been recognized locally on the basement rocks below the Ione.

FACIES

The depositional facies of the Ione Formation have never been subjected to a thorough and comprehensive study. Allen (1929) interpreted the Ione as a deltaic deposit. This is probably partly true. Marine fossils have been found in the unit locally, but are very rare (Dickerson, 1916; Allen, 1929). Much of the unit, on the other hand, shows the fining-upward sequences with large-scale crossbedding characteristic of fluvial deposits. The clay matrix common to much of the sandstone has misled earlier workers who believed that it was original sediment that was deposited with the sand. The vast majority of the matrix clay is authigenic kaolinite that clearly formed after deposition, partly by alteration of framework grains, so it is unnecessary to appeal to flocculation of clays by marine waters to explain the mixing of clay with sand. At present, the best interpretation seems to be that the Ione is largely fluvial, but it does contain the deposits of marginal marine or coastal (lagoonal or deltaic?) environments locally. There has not yet been demonstrated any generally applicable vertical facies trend for the formation as a whole, although Gillam (1974) showed a trend in the Ione-Buena Vista area from lagoonal in the lower part to fluvial higher up, and a return to shallow marine in the uppermost part. It is difficult to say, with any certainty, what facies is represented at the upper contact at each locality.

The predominant tuffaceous mudrock lithofacies of the Valley Springs, interpreted in the context of the middle to lower regions of a piedmont alluvial system, represents a complex of ephemeral-lake and marsh environments on a low-gradient alluvial plain (Bartow, 1986). As with the Ione Formation, an overall vertical trend is not apparent in the Valley Springs, but the tuffaceous mudrock lithofacies is present near the base in the region in question.

AGE

The age of the Ione Formation is poorly controlled. Marine fossils of "Capay" (early Eocene) age that were described by Dickerson (1916) from strata alleged to belong to the Ione at Sutter Buttes and Oroville Table Mountain areas were collected from marine units below the Ione Formation (Allen, 1929). The few marine fossils from the restricted Ione Formation do little more than suggest an early or middle Eocene age (Gillam, 1974). Plant fossils, principally from the Chalk Bluff locality near Grass Valley about 100 km north of Ione (MacGinitie, 1941), also suggest only an Eocene age. Consequently, the age of the Ione is based principally on its relations to other units and correlations to marine units in the subsurface under the Central Valley (Redwine, 1972; Bartow, 1985). It is generally correlated with the Domengine Formation of early middle Eocene age. Bartow (1991) considered the Ione to be equivalent to the entire middle to late Eocene marine sequence (comprising the Domengine Sandstone, Kreyenhagen Shale, and Poverty Flat Sandstone) of the northern San Joaquin Valley, in which case the Ione could be as young as late Eocene.

The age of the Valley Springs Formation is tied to K-Ar dates of included rhyolitic or rhyodacitic tephra. The key dates in the type section are 20.4 Ma (sanidine) and 22.5 Ma (biotite) from the tuff at the top of the section and 23.4 Ma (sanidine) from a lower tuff near the middle of the section (Dalrymple, 1964, corrected from old to new constants); all fall within the early Miocene. Other rhyolite or rhyodacite tuffs in the Sierra Nevada that can be reasonably correlated with the Valley Springs Formation are as old as 30.3 Ma (late Oligocene) (Dalrymple, 1964). The Valley Springs, therefore, is late Oligocene and early Miocene in age. The best age estimates for the two formations suggest that the Ione is no younger than about 37-40 Ma and the Valley Springs is no older than about 30 Ma, which leaves a hiatus of at least 7-10 m.y.

DISCUSSION

A clear distinction can almost always be made between the Ione and Valley Springs Formations using field criteria. The contact is sharp and generally shows evidence of weathering—locally a laterite is developed at the top of the Ione.

There is generally a clear compositional difference between the two formations that is locally complicated by reworking of Ione detritus into the lower part of the Valley Springs. Evidence of reworking is seen at locality C where the composition of the Valley Springs mimics the composition of the unconformably underlying Ione. The clay mineralogy is not much help in determining the location and nature of the contact. Smectite shows some increase across the contact, at least locally. Much of the kaolinite in the lower part of the Valley Springs is probably reworked from the Ione.

Both the Ione and Valley Springs consist mostly of fluvial facies that could plausibly be interpreted as representing a conformable sequence. However, marine or lagoonal facies in the Ione, including marine deposits near the top, indicate that the coastline was near the east side of the valley during Ione deposition, whereas the deposits of the Valley Springs piedmont alluvial system, including ephemeral-lake and marsh facies, apparently extend completely across the valley. Therefore, a large (>80 km) westward shift in the coastline took place at the Ione-Valley Springs contact.

Certain features of the Ione Formation, that is, the laterite locally developed on top of the unit, the included lignite, and the quartz-kaolinite mineralogy, indicate a warm, wet climate—probably tropical or subtropical. There is nothing in the Valley Springs to suggest such a climate. Weathering is not as severe; more feldspar, biotite, and even volcanic glass is preserved. There is some evidence of a climate shift near the top of the Ione, notably an increase in feldspars, but there is evidence of an abrupt climate change across the contact.

Finally, and perhaps most importantly, there is an hiatus of *at least* 7-10 m.y. at the contact. This is certainly a minimum. Post-Eocene erosion has most probably removed some of the Ione resulting in an hiatus of more than 10 m.y. in the Sierra Nevada foothill region.

In conclusion, the evidence supports the hypothesis that the Ione and Valley Springs Formations are separated by a disconformity of regional extent. The compositional similarities observed locally are the result of reworking of Ione detritus into the lower part of the Valley Springs and do not indicate a conformable and gradational contact.

REFERENCES

Allen, V.T., 1929, The Ione Formation of California: University of California, Publications in Geological Sciences, v. 18, no. 14, p. 347-448.

Bartow, J.A., 1985, Map and cross sections showing Tertiary stratigraphy and structure of the northern San Joaquin Valley, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1761, scale 1:250,000.

Bartow, J.A., 1986, An unusual lacustrine(?) claystone from the middle Tertiary of central California, U.S.A., [abs.]: Abstracts, 12th International Sedimentological Congress, 24-30 August 1986, Canberra, Australia, p. 22.

Bartow, J.A., 1991, The Cenozoic evolution of the San Joaquin Valley, California: U.S. Geological Survey Professional Paper 1501, 40 p.

Bartow, J.A., and Marchand, D.E., 1979, Preliminary geologic maps of Cenozoic deposits of the Sutter Creek and Valley Springs quadrangles, California: U.S. Geological Survey Open-File Report 79-436, scale 1:62,500.

Bateman, P.C. and Wahrhaftig, Clyde, 1966, Geology of the Sierra Nevada, *in* Bailey, E.H., ed., Geology of northern California: California Division of Mines and Geology Bulletin 190, p.107-172.

Dalrymple, G.B., 1964, Cenozoic chronology of the Sierra Nevada, California: University of California Publications, Geological Sciences, v. 47, 41 p.

Dickerson, R.E., 1916, Stratigraphy and fauna of the Tejon Eocene of California: University of California Publications in Geological Sciences, v. 9, no. 17, p. 363-524.

Dickinson, W.R., 1970, Interpreting detrital modes of graywacke and arkose: Journal of Sedimentary Petrology, v.40, p. 695-707.

Dickinson, W.R., Ingersoll, R.V., and Graham, S.A., 1979, Paleogene sediment dispersal and paleotectonics in northern California: Geological Society of America Bulletin, Pt.II, v. 90, p. 1458-1528.

Ely, R.W., Grant, T.A., and McCleary, J.R., 1977, Exhumed early Tertiary paleotopographic surfaces on the Ione Formation, northern San Joaquin Valley, California [abs.]: Geological Society of America Abstracts with Programs, v. , p. 417.

Gale, H.S., Piper, A.M., and Thomas, H.E., 1939, Geology [of the Mokelumne area], *in* Piper, A.M., Gale, H.S., Thomas, H.E., and Robinson, T.W., Geology and ground-water hydrology of the Mokelumne area, California: U.S. Geological Survey Water-Supply Paper 780, p. 14-101.

Gillam, M.L., 1974, Contact relations of the Ione and Valley Springs Formations in the Buena Vista area, Amador County, California: Stanford, Calif., Stanford University, M.S. report, 180 p.

Ingersoll, R.V., Bullard, T.F., Ford, R.L., Grimm, J.P. Pickle, J.D., and Sares, S.W., 1984, The effect of grain size on detrital modes: a test of the Gazzi-Dickinson point-counting method: Journal of Sedimentary Petrology, v. 54, p. 103-116.

Lindgren, Waldemar, 1894, Description of the Sacramento quadrangle [California]: U.S. Geological Survey Geologic Atlas, Folio 5, 3 p.

MacGinitie, H.D., 1941, A middle Eocene flora from the central Sierra Nevada: Carnegie Institution Washington, Publication 534, 178 p.

Pask, J.A., and Turner, M.D., 1952, Geology and ceramic properties of the Ione Formation, Buena Vista area, Amador County, California: California Division of Mines and Geology Special Report 19, 39 p.

Redwine, L.E., 1972, The Tertiary Princeton submarine valley system beneath the Sacramento Valley, California: Los Angeles, Calif., University of California, Ph.D. thesis, 480 p.

Schultz, L.G., 1960, Quantitative X-ray determinations of some aluminous clay minerals in rocks: Seventh National Conference on Clays and Clay Minerals, p. 216-224.

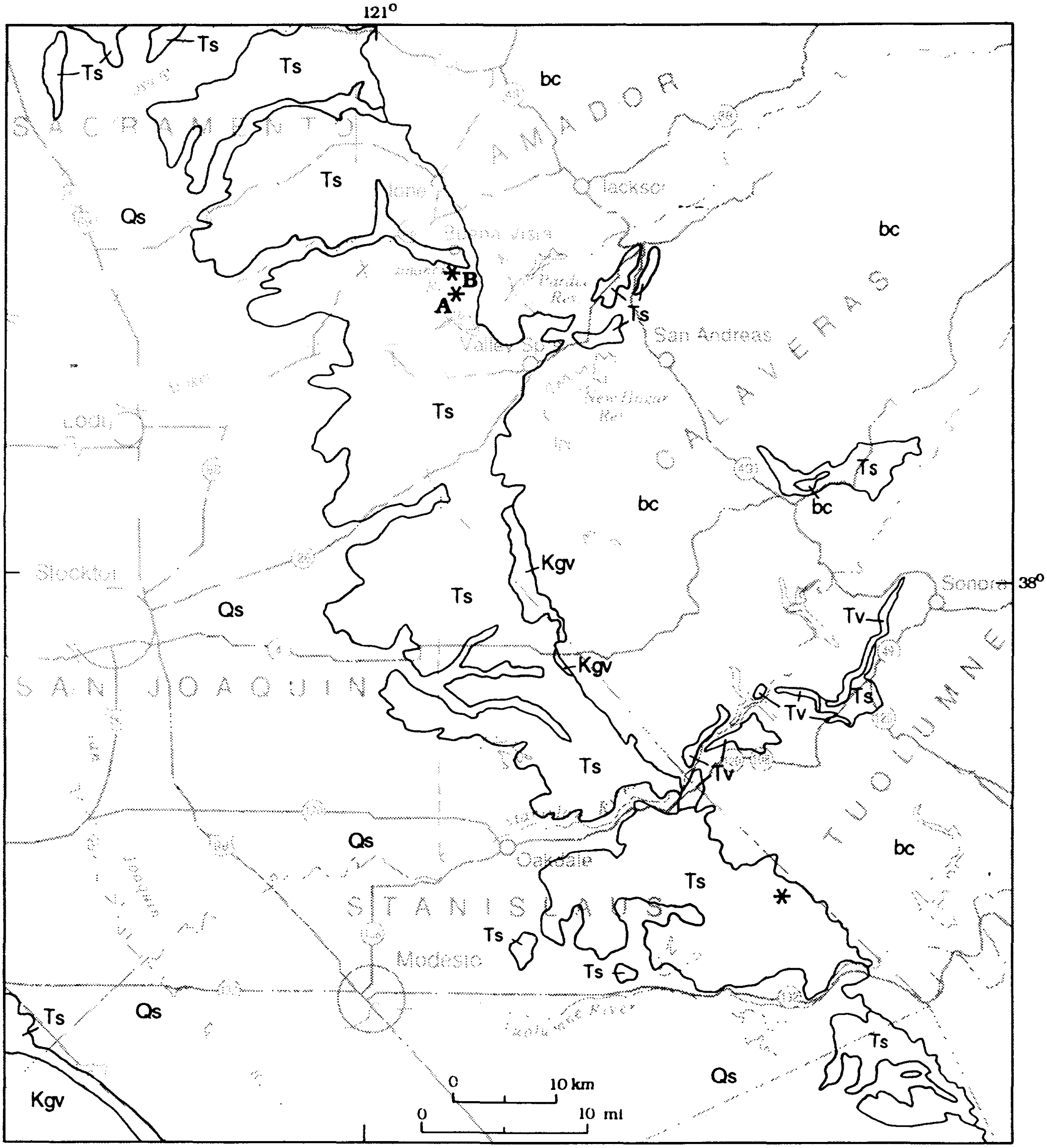
Schultz, L.G., 1964, Quantitative interpretation of mineralogical composition from X-ray and chemical data for the Pierre Shale: U.S. Geological Survey Professional Paper 391-C, p. C1-C31.

Schultz, L.G., 1978, Mixed-layer clay in the Pierre Shale and equivalent rocks, northern Great Plains region: U.S. Geological Survey Professional Paper 1064-A, p. A1-A28.

Singer, M.J., and Nkedi-Kizza, Peter, 1980, Properties and history of an exhumed Tertiary oxisol in California: Soil Science Society of America Journal, v. 44, p. 587-590.

Slemmons, D.B., 1966, Cenozoic volcanism of the central Sierra Nevada, California, *in* Bailey, E.H., ed., Geology of northern California: California Division of Mines and Geology Bulletin 190, p.199-208.

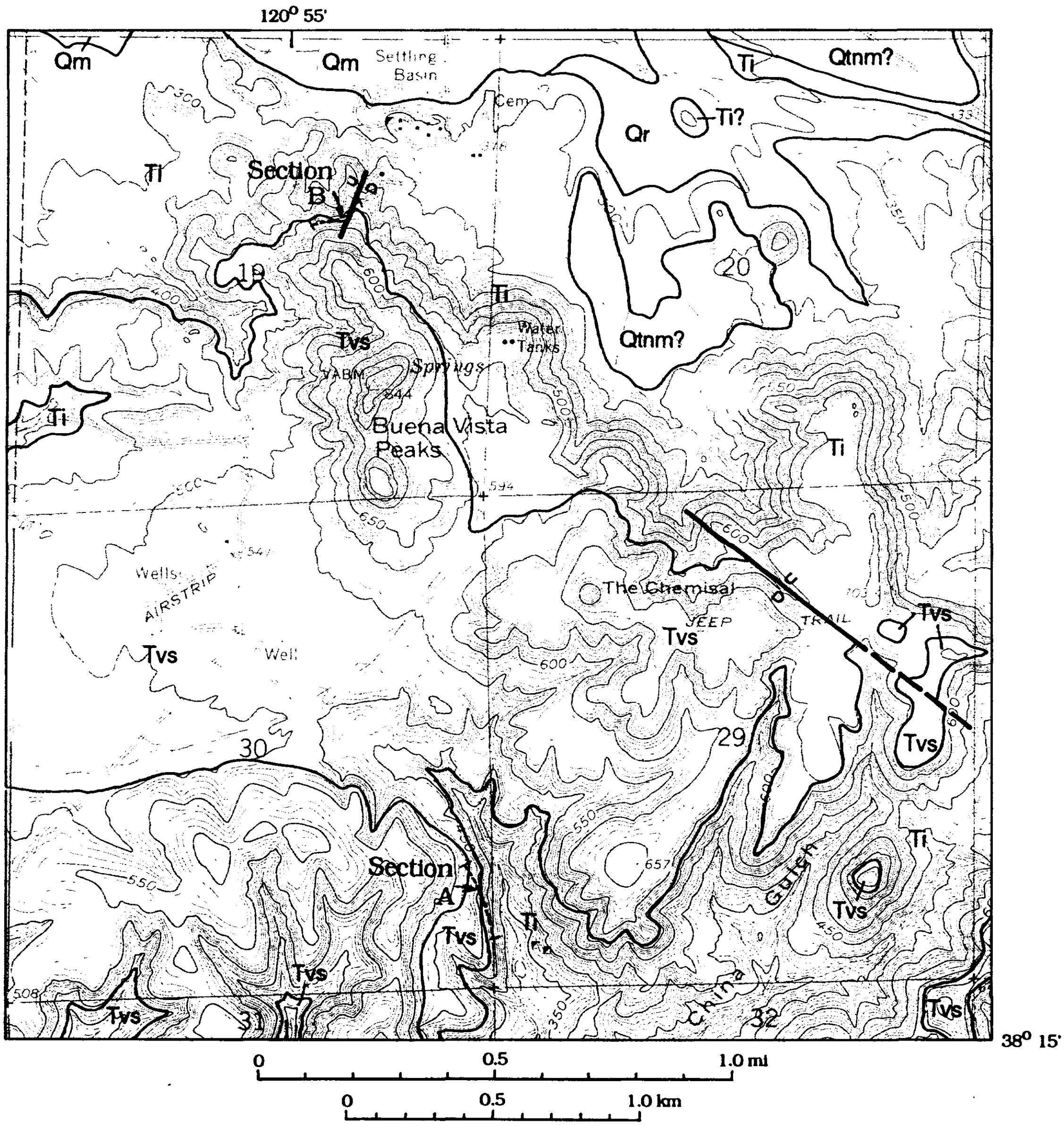
Turner, H.W., 1894, The rocks of the Sierra Nevada: U.S. Geological Survey, 14th Annual Report, pt.2, p. 441-495.



EXPLANATION

Qs	Alluvium (Quaternary)
Ts	Sedimentary rocks (Pliocene to Eocene)
Tv	Volcanic rocks (Miocene)
Kgv	Great Valley sequence (Late Cretaceous)
bc	Basement complex (Mesozoic and Paleozoic)

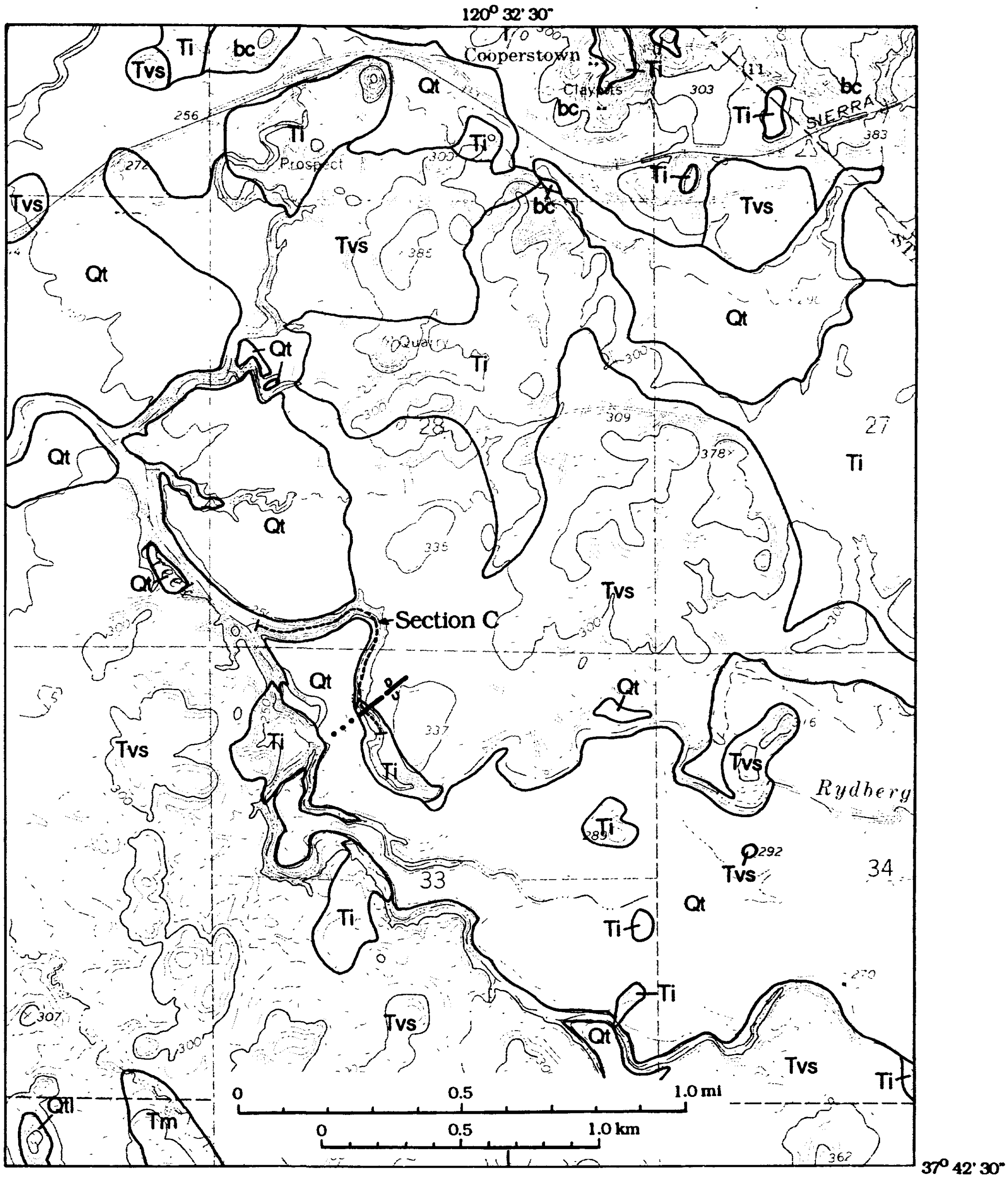
Figure 1. Index map of the east-central Great Valley showing distribution of Tertiary strata and locations of measured sections A, B, and C.



EXPLANATION

Qm	Modesto Formation (Pleistocene)
Qr	Riverbank Formation (Pleistocene)
QTnm	North Merced Gravel (Pleistocene and Pliocene)
Tm	Mehrten Formation (Pliocene and Miocene)
Tvs	Valley Springs Formation (Miocene and Oligocene)
Ti	Ione Formation (Eocene)
———	Contact
—U/D—	Fault

Figure 2. Geologic map of part of the Ione 7.5' quadrangle showing locations of measured sections A and B. See Figure 1 for location. Geology modified from Bartow and Marchand (1979).



EXPLANATION

Qt	Terrace deposits (Pleistocene)
Qtl	Turlock Lake Formation (Pleistocene)
Tm	Mehrten Formation (Pliocene and Miocene)
Tvs	Valley Springs Formation (Miocene and Oligocene)
Ti	Ione Formation (Eocene)
bc	Basement complex (Mesozoic and Paleozoic)
———	Contact
•••——	Fault

Figure 3. Geologic map of part of the Cooperstown 7.5' quadrangle showing location of measured section C. See Figure 1 for location. Modified from "Preliminary areal geology and outcrop map of the Stanislaus Nuclear Project" by Woodward-Clyde Consultants for Pacific Gas and Electric Co. (unpublished).

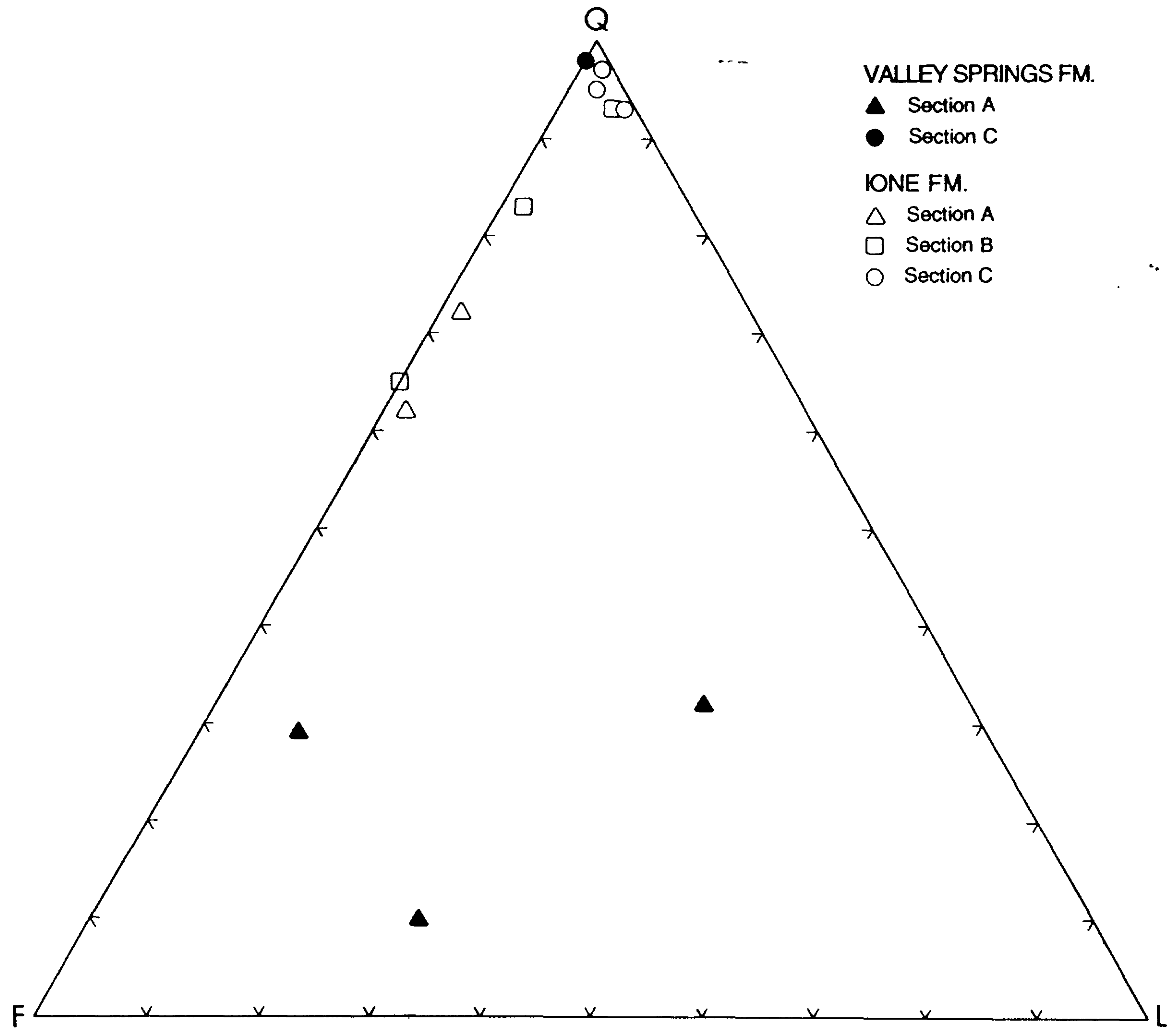


Figure 4. Triangular QFL (quartz, feldspar, lithic grain) plot of selected sandstone samples from the Ione and Valley Springs Formations.

Table I. Physical characteristics of the Tertiary formations of the east-central Great Valley, California, useful in discrimination of outcrops

Character/FM.	IONE	VALLEY SPRINGS	MEHRTEN	LAGUNA
Color	usually white or yellow; may be red or mottled (red/white)	pale greenish or tan or gray	gray, blue, sometimes brown	light gray, tan, brown
Bedding	massive or large scale crossbedding	finer facies—crude irregular or wavy bedding; sandstone—massive or crossbedded	lenticular sandstone and conglomerate—common crossbedding	lenticular sand, silt, gravel
Composition	sand—quartz, kaolinite, minor feldspar; pebbles—quartz, quartzite, minor weathered local basement rocks	sand—quartz, feldspar, shards and pumice; pebbles—basement rocks, volcanic rocks	variable; sand—usually amphiboles, pyroxene; pebbles—mostly volcanic rocks, *always* andesite	sand—quartz, feldspar; pebbles—basement rocks; may have minor reworked andesite
Matrix	dense white clay *filling* pores	pale greenish clay *coating* grains and *lining* cavities	sandstone usually well sorted, but may be minor interstitial mud	variable—common clay skins