Radioelement and Trace-Element Content of the Ione Formation, Central California

GEOLOGICAL SURVEY BULLETIN 1382-B

Prepared in cooperation with the Lawrence Berkeley Laboratory, University of California, Berkeley

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By H. A. WOLLENBERG *and* F. C. W. DODGE

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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CONTENTS

ILLUSTRATIONS

TABLES

RADIOELEMENT AND TRACE-ELEMENT CONTENT OF THE IONE FORMATION, CENTRAL CALIFORNIA

By H. A. WOLLENBERG[1] and F. C. W. DODGE

ABSTRACT

Radioactivity and content of uranium plus thorium in 77 samples of sandstones and clays from the Eocene Ione Formation of central California correlate with abundance of titanium, zirconium, and lanthanum, suggesting a general correspondence between the radioelements and heavy minerals. There is no apparent correlation between the content of gold and radioelements. Of 77 samples of Eocene rocks, gold was detected in less than one-third; there is little probability that the element exists in exploitable amounts in the Ione Formation.

Sandstones of the Ione Formation in the Ione-Buena Vista area are characterized by low potassium content as compared with their northern counterparts and with samples from the Eocene Tesla and Domengine Formations of the west side of the Great Valley. Sandstones from all areas sampled are similar in uranium and thorium contents. Processes associated with transportation and deposition rather than composition of source materials alone may have significantly affected radioelement concentrations in the Ione.

INTRODUCTION

The Ione Formation consists of interbedded anauxitic clays and quartz sands deposited in Eocene deltas and shallow water on the weathered surface of Jurassic metavolcanic and metasedimentary rocks of the Sierra Nevada foothills. The formation crops out in a narrow belt extending about 200 miles along the western margin of the Sierra Nevada. The presence in the Ione sands of zircon and ilmenite in appreciable amounts suggested to Allen (1929) a predominantly granitic source, probably the Sierra Nevada batholith to the east, even though other granitic derivatives such as hornblende, sphene, and biotite are scarce. Allen attributed this scarcity, together with low contents of Na, K, Ca, Mg, and Fe, to

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strong chemical weathering. Lignite is interbedded with sands and clays, particularly in the lower strata of the formation (Pask and Turner, 1952).

The purpose of our investigation of the Ione Formation was twofold: (1) to investigate a possible correlation between uranium and thorium and heavy-mineral contents, principally zircon and ilmenite (characterized by abundances of Zr and Ti, respectively), which might in turn be indicative of gold concentrations, and (2) to compare regional differences in K, U, and Th with contents observed in granitic and pregranitic rocks of the Sierra Nevada (Wollenberg and Smith, 1968, 1970).

Gold in minable amounts was discovered in and was recovered from Tertiary river channel gravels in the Sierra Nevada (Lindgren, 1911; Peterson and others, 1968; Whitney, 1880). Allen (1929, p. 402) noted that the gravels were deposited at least in part by the same streams that laid down the delta deposits of the Ione Formation. With these aspects in mind, we sampled various exposures of the formation from the Ione-Buena Vista area on the south through the Folsom-Rocklin, Lincoln, and Marysville Buttes areas to the north. (See fig. 1.)

In addition to samples from the Ione Formation, we collected and analyzed samples of middle Eocene sandstones (Domengine and Tesla Formations) from the Nortonville and Corral Hollow areas of the California Coast Ranges. Allen (1941) noted the general similarity in mineralogy between the Ione Formation and upper Eocene rocks of the Coast Ranges and proposed that these formations all had a common source, the Sierra Nevada. He observed that andalusite and anauxite, prevalent in the Ione, are present in the Tesla and other Coast Range Eocene sandstones. Andalusite commonly occurs in metamorphic rocks of the Sierra Nevada (Dodge, 1971) but has not been reported from pre-Tertiary rocks of the Coast Ranges. Allen's observations were confirmed by Huey (1948) in his report on the Tesla Formation and by Todd and Monroe (1968) in their study of the petrology of the Domengine Formation.

Uranium and thorium in granitic rocks are most concentrated in the nonmagnetic accessory minerals, monazite, zircon, allanite, and sphene. Of these, sphene is generally the most ubiquitous in granitic rocks of the Sierra Nevada batholith (Lee and Dodge, 1964, table 2). The magnetic accessories, chromite, ilmenite, and magnetite, are comparatively devoid of uranium and thorium. Neither magnetic nor nonmagnetic accessory minerals contain appreciable amounts of gold in solid solution. Lindgren's (1911)

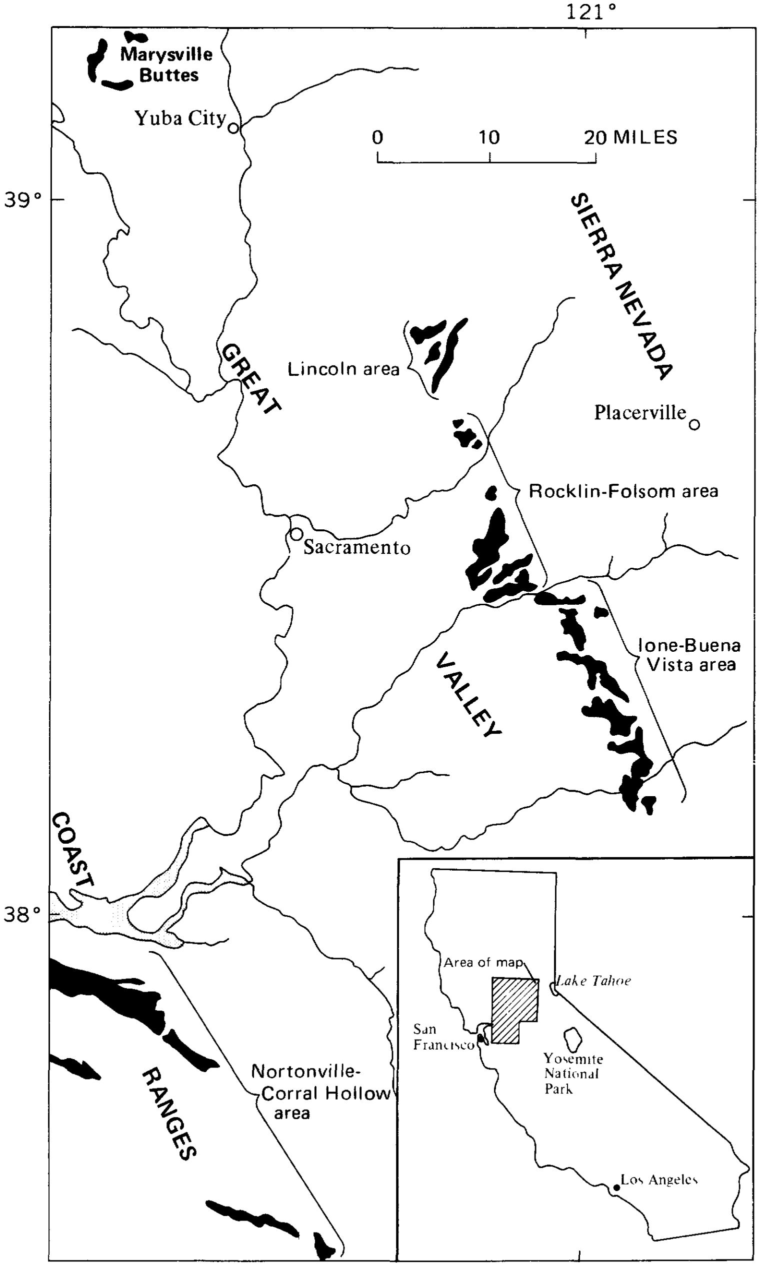

FIGURE 1.—Map of central California showing outcrop areas of Eocene rocks.

description of the heavy minerals accompanying gold in Sierran deposits includes radioactive (predominantly zircon) and nonradioactive accessories. Therefore, gold may or may not correlate with the radioactivity of the host sands of Sierran placers. Potassium, which generally contributes one-quarter to one-third of the observed field radioactivity, does not correlate with heavy mineral assemblages but rather with the abundance of K-feldspar in parent rocks and associated clay minerals in sand deposits.

ACKNOWLEDGMENTS

The authors thank W. P. Craven of the International Pipe and Ceramics Corporation for guidance in the sampling of the Ione clay and sand pits and personnel of the Calaveras Cement Company for providing samples and descriptions of the Gerberding drill core. The work was done partly under the auspices of the U.S. Atomic Energy Commission.

ANALYTICAL METHODS

At about half of the sampled locations, field gamma radioactivity was measured with a sensitive portable scintillation counter having a 3- by 3-inch NaI(Tl) detector. Thus field radioactivity could be directly compared with trace-element concentrations. Samples of 1.5 to 2 kg (kilograms) were collected in polyethylene bags. Moist samples were dried, then all were packaged in tight polyethylene containers, holding 0.8 to 1 kg, for gamma-ray spectrometry for K, U, and Th at the gamma-counting facility at Lawrence Berkeley Laboratory. Counting, pulse-height analysis, and data reduction have been described by Wollenberg, Smith, and Bailey (1967). After gamma counting, splits of the same materials were analyzed at the U.S. Geological Survey laboratories for gold by atomic absorption (Thompson and others, 1968) and for several other elements by semiquantitative spectrometric methods using techniques described by Grimes and Marranzino (1968). Analytical data, sample locations, and sample descriptions are given in table 2.

RESULTS AND DISCUSSION

Radioelement contents of Eocene rocks are summarized by lithologic type and geographic location in table 1. Data on the Ione Formation are arranged in groups according to areas, from north to south. The Ione sandstones sampled in the Ione-Buena Vista area are characterized by a low potassium content (average 0.25 percent) as compared with sandstone from other areas.

Pask and Turner (1952) recognized an upper predominantly sandy facies and a lower predominantly clayey facies in the Ione Formation in the Buena Vista area. Closely spaced samples were

TABLE 1.—*Summary of radioelement contents of Eocene sedimentary rocks, arithmetic mean values, and ranges*

[Samples are from rocks of the Ione Formation except in the Nortonville-Corral Hollow area where they are from rocks of the Tesla and Domengine Formations. Ss=dominantly sandstones and conglomerates; Cl=clays and lignites. U and Th content in parts per million; K content in percent; range given in parentheses beneath mean values]

Location	Sample type	Number of samples	U	Th	K	Th/U
Marysville Buttes	Ss	2	2.25 (2.06–2.45)	7.30 (6.25–8.35)	2.38 (1.93–2.82)	3.2
Lincoln area	Ss	1	1.50	4.06	0.43	2.7
	Cl	6	4.87 (1.50–7.98)	12.8 (4.00–17.7)	1.24 (0.42–1.68)	3.0
Rocklin-Folsom area	Ss	4	2.52 (2.40–3.78)	8.25 (2.81–12.4)	1.30 (0.59–2.21)	3.3
Ione-Buena vista area	Ss	19	4.87 (0.59–17.6)	18.5 (1.62–73.4)	0.24 (0.07–1.09)	4.0
	Cl	7	1.75 (1.39–3.09)	7.08 (3.19–10.1)	0.52 (<0.01–2.00)	4.4
Ione roadcut	Ss	16	8.16 (1.31–38.5)	35.9 (7.13–227)	0.14 (<0.01–0.60)	4.6
Gerberding borehole	Cl	13	4.90 (1.85–62.2)	8.40 (3.72–14.8)	0.43 (0.04–1.78)	2.1
Nortonville-Corrall Hollow area	Ss	5	1.51 (1.23–2.21)	5.66 (4.56–9.01)	1.37 (0.21–2.77)	3.7

taken from a roadcut in the upper sandstones near Ione and from drill core from the clays of the lower Ione Formation near Buena Vista. The sandstones of the roadcut (samples 14–3′ to 14–49′) showed a broad range of U and Th contents, roughly following variations in Zr, Ti, and La. This suggests a correlation of radioelements with zircon, ilmenite or sphene, and perhaps monazite. It is interesting to note that generally the highest U contents were not associated with lignitic sandstones, but rather with the gray sandstones (samples 14–30′ through 14–49′) indicative, by their dark color and their generally high Zr and Ti contents, of high heavy-mineral contents. Generally, Ione sandstones and clayey sandstones have a broader range in Th and Th/U ratio than do the predominantly clayey sediments, although average U content is similar for the two rock types.

Clays of the lower Ione Formation in the Valley Springs area near Buena Vista are typified by the samples from the Gerberding borehole (samples G–22′ to G–238′). The hole was drilled 254 feet and bottomed in the strongly weathered surface of Jurassic metamorphic rocks at the base of the Ione Formation. Highest uranium contents in the core were in an interval of gray lignitic sand (sample G–162′) where U predominates over Th by a factor of 5.5. As this is the only specific indication in our samplings of strong preferential concentration of U by carbonaceous material, this lignitic sandstone has been excluded from the averages of table 1. Other lignitic samples from the cores and from surface exposures

TABLE 2.—*Analyses of Eocene rocks from central California*

[General area of sample locality designated by the following letters: M=Marysville Buttes, I=Ione-Buena Vista area. R=Rocklin-Folsom area, L=Lincoln area, N=Nortonville-Corral Hollow area; range and township lines are referred to Mount Diablo base and meridian. Source: rcut=roadcut, pit=clay or sand pit, mill c=mill concentrate, drill c=drill core or cutting or cuttings, n oc=natural outcrop. Sample description: cl=clay, ss=sandstone, cgl=conglomerate, sh=shale, yl=yellow, brn=brown. Semiquantitative spectrographic analytical results are reported as approximate geometric midpoints of ranges whose boundaries are 1.2, 0.83, 0.56, 0.38, and 0.18 (or multiples of these numbers); results are reported as 1, 0.7, 0.5, 0.3, 0.2, and 0.15 (or appropriate multiples). Other analytical results are reported to the nearest figure cited. Spectrographic analyses by D. J. Grimes, E. L. Mosier, and J. M. Motooka. Chemical analyses (atomic absorption) by W. L. Campbell, M. S. Rickard, T. A. Roemer, and Z. C. Stephenson. Gamma-ray analyses by A R. Smith and H. A. Wollenberg. Undetected elements present in amounts below spectrographic detectibility levels and respective detectibility levels (ppm): Ag (0.5), As (200), Bi (10), Cd (20), Sb (100), Sn (10), W (50)]

	Semiquantitative spectrographic analyses														
	Percent				Parts per million										
Sample	Fe	Mg	Ca	Ti	B	Ba	Be	Co	Cr	Cu	La	Mo	Mn	Db	Ni
Ione Formation															
1	5	1	2	0.5	70	1,500	1	10	70	50	30	<5	1,500	<10	20
2	2	.3	.5	.2	<10	1,000	1	10	30	5	20	<5	300	<10	10
3	.5	.03	<.05	1	50	100	<1	<5	30	5	50	<5	300	20	30
4	.5	.05	<.05	.5	10	70	<1	<5	10	10	20	<5	20	<10	5
5	15	.05	<.05	>1	30	50	<1	<5	70	20	30	<5	500	<10	5
6	.7	.07	<.05	.7	20	100	<1	<5	500	15	50	<5	50	<10	7
7	5	.3	<.05	1	30	300	<1	<5	300	30	50	<5	20	<10	50
8	1.5	.3	<.05	1	50	300	<1	<5	300	7	70	<5	30	<10	50
9	1.5	.05	<.05	.1	<10	100	<1	<5	150	30	20	<5	20	<10	10
10	2	.1	<.05	1	50	150	<1	<5	200	20	30	<5	300	<10	20
11	3	.5	<.05	1	70	150	<1	<5	300	50	20	<5	100	<10	50
12	1.5	.05	.07	>1	70	300	<1	<5	200	5	70	5	500	100	20
13	2	.05	<.05	1	50	100	<1	<5	70	10	20	<5	300	30	20
14- 3′	3	.03	<.05	.5	20	100	<1	<5	50	20	20	<5	70	<10	5
14- 6′	3	.02	<.05	.3	10	30	<1	<5	30	20	20	<5	30	<10	5
14- 9′	5	.02	<.05	1	30	70	<1	<5	30	20	<20	<5	200	<10	5
14-12′	5	.03	<.05	.7	20	500	<1	<5	30	50	<20	<5	100	<10	5
14-15′	3	.03	<.05	.5	30	50	<1	<5	50	10	<20	<5	100	<10	5
14-18′	.7	.02	<.05	.5	10	70	<1	<5	15	5	<20	<5	30	<10	5
14-21′	1	.03	<.05	.5	20	30	<1	<5	20	20	20	<5	50	<10	5
14-24′	.3	.03	<.05	.5	10	70	<1	<5	20	20	20	<5	30	<10	5
14-27′	.3	.03	<.05	.5	20	30	<1	<5	10	20	20	<5	100	<10	5
14-30′	1	.05	<.05	>1	70	100	<1	<5	100	10	70	<5	500	50	5
14-33′	3	.07	<.05	>1	300	150	<1	<5	500	10	150	5	1,500	200	<5
14-36′	1	.05	<.05	>1	100	100	<1	<5	200	10	200	<5	700	70	<5
14-39′	3	.1	<.05	1	70	200	<1	<5	150	20	300	10	200	20	10
14-42′	2	.05	<.05	>1	50	150	<1	<5	70	20	100	5	500	30	5
14-45′	1	.07	<.05	1	50	150	<1	<5	150	30	100	5	150	20	5
14-49′	.7	.05	<.05	1	70	150	<1	<5	70	20	100	<5	200	20	<5
15	3	.5	.1	>1	150	150	<1	5	200	50	20	5	30	<10	100
16	1.5	.3	.05	1	70	700	<1	<5	300	30	20	<5	30	<10	70
17	1	.3	.05	1	100	1,500	1	<5	150	30	20	<5	20	<10	30

TABLE 2.—*Analyses of Eocene rocks from central California*—Continued

Sample	Semiquantitative spectrographic analyses—Continued						Chemical analysis (ppm)	Gamma-ray analyses			Locality	Source	Sample description
	Parts per million							Ppm		Percent			
	Pb	Sc	Sr	V	Y	Zr	Au	Th	U	K			
Ione Formation—Continued													
1	10	15	300	150	20	200	0.03	8.35	2.45	1.93	M; sec. 29, T. 16 N., R. 2 E.	N oc	Conglomeritic ss.
2	10	5	200	30	10	150	.02	6.25	2.06	2.82	do	do	Clayey ss.
3	30	5	<100	50	20	>1,000	<.02	15.7	7.06	.07	I; sec. 5, T. 5 N., R. 10 E.	Pit	Ss wash.
4	<10	10	<100	100	20	300	<.02	10.7	1.75	.16	do	do	Quartz ss.
5	<10	20	<100	150	50	>1,000	<.02	26.8	5.10	.10	do	do	Ironstone.
6	<10	5	<100	70	<10	>1,000	.02	5.42	1.62	.25	I; sec. 31, T. 6 N., R. 10 E.	do	Anauxitic ss.
7	<10	15	100	200	10	200	<.02	8.39	2.22	.90	do	do	Bedded cl.
8	<10	15	100	150	10	200	<.02	10.1	1.70	1.01	do	do	Massive cl.
9	<10	5	<100	50	<10	70	.04	1.86	0.35	.07	do	do	Quartz cgl.
10	<10	20	<100	150	15	>1.000	.03	12.7	3.24	.21	I; sec. 17, T. 5 N., R. 10 E.	do	Buff quartz ss.
11	<10	50	<100	200	15	200	.02	7.10	1.62	.46	do	do	Mottled gray cl.
12	<10	20	<100	200	30	>1,000	.03	73.4	17.6	.35	I; sec. 6, T. 5 N., R. 10 E.	Rcut	Clayey ss.
13	<10	15	<100	150	15	>1,000	.03	23.3	7.60	.21	do	do	Quartz ss.
14- 3′	<10	5	<100	70	<10	100	<.02	13.4	2.47	.09	do	do	Clayey ss.
14- 6′	<10	5	<100	50	<10	100	<.02	1.6	2.16	.08	do	do	Do.
14- 9′	<10	10	<100	100	<10	1,000	<.02	25.7	3.70	.13	do	do	Fe-stained ss.
14-12′	<10	10	<100	70	15	500	<.02	21.2	6.19	.13	do	do	Do.
14-15′	<10	10	<100	100	15	200	<.02	14.4	2.86	.08	do	do	Clayey ss.
14-18′	<10	7	<100	30	10	200	.02	7.13	1.31	.07	do	do	Massive ss.
14-21′	<10	5	<100	30	10	200	<.02	9.58	1.92	.09	do	do	Do.
14-24′	<10	5	<100	50	<10	100	<.02	8.83	1.87	.07	do	do	Gray ss.
14-27′	<10	5	<100	30	<10	200	<.02	8.01	1.55	.11	do	do	Do.
14-30′	10	15	<100	200	30	>1,000	.04	66.5	9.92	.34	do	do	Fossiliferous ss.
14-33′	70	50	<100	500	100	>1,000	<.02	227	38.5	<.01	do	do	Do.
14-36′	10	20	<100	200	70	>1.000	<.02	70.5	15.3	.23	do	do	Do.
14-39′	50	20	<100	150	100	1,000	.04	22.7	19.7	.60	do	do	Cl and ss.
14-42′	30	20	<100	150	100	>1,000	.07	22.1	9.81	.19	do	do	Lignitic ss.
14-45′	10	15	<100	200	50	1,000	.07	16.5	6.20	.24	do	do	Do.
14-49′	15	15	<100	150	20	300	.04	29.5	7.17	.19	do	do	Do.
15	<10	50	<100	300	10	200	.03	8.89	3.09	.30	I; sec. 15, T. 6 N., R. 9 E.	Pit	Massive cl.
16	<10	15	<100	200	10	200	.03	5.59	1.54	1.09	R; sec. 30, T. 9 N., R. 8 E.	do	Quartz ss.
17	<10	20	100	300	30	200	.03	8.89	1.76	2.00	do	do	Kaolinized slate.

TABLE 2.—*Analyses of Eocene rocks from central California*—Continued

Sample	Fe	Mg	Ca	Ti	B	Ba	Be	Co	Cr	Cu	La	Mo	Mn	Db	Ni
	Semiquantitative spectrographic analyses														
	Percent				Parts per million										
	Ione Formation—Continued														
18	5	1.5	1.5	0.7	10	1,500	<1	20	100	50	30	<5	500	<10	30
19	7	.7	.1	.5	20	1,500	1	10	30	50	50	<5	700	<10	20
20	5	1	10	3	15	2,000	<1	5	70	15	20	<5	500	<10	5
21	7	3	3	1	10	500	<1	30	700	15	20	<5	1,500	<10	70
22	7	.2	.1	.7	20	150	<1	7	100	70	20	<5	150	<10	30
23	5	1	.5	.5	20	700	<1	10	100	30	20	<5	500	<10	30
24	7	.5	.05	.7	70	500	1	10	200	50	30	<5	200	<10	100
25	5	.7	.05	.7	100	3,000	1	15	300	50	20	<5	100	<10	100
26	3	.5	.07	1	70	500	<1	5	200	70	20	<5	30	<10	100
27	3	.7	.2	.5	30	700	<1	10	70	30	20	<5	300	<10	30
29	5	.05	.1	.5	20	150	<1	5	70	10	30	<5	300	<10	10
30	1	.05	<.05	.7	15	150	<1	<5	70	20	20	<5	300	<10	<5
31	1.5	.02	<.05	.3	30	70	<1	<5	15	10	30	<5	30	<10	5
32	0.5	0.2	<.05	0.5	100	700	<1	<5	100	15	30	<5	100	<10	20
33	1.5	.5	<.05	.7	70	700	1	10	200	50	30	<5	300	<10	70
34	1.5	.15	<.05	.3	20	300	<1	<5	1,000	30	<20	<5	500	<10	20
35	.3	.2	.05	.7	30	500	<1	<5	700	7	<20	<5	200	<10	30
36	1	.02	<.05	.7	20	300	2	<5	30	100	30	<5	10	10	20
37	.1	.07	1.5	.3	50	2,000	10	10	7	15	50	<5	300	<10	30
38	5	.05	<.05	>1	300	300	<1	<5	700	20	50	<5	1,000	30	<5
39	.15	.2	<.05	1	50	100	<1	<5	150	30	<20	<5	300	20	<5
40	.3	.03	<.05	>1	70	150	<1	<5	150	20	<20	<5	150	20	<5
41	>20	.07	<.05	.7	50	70	<1	10	500	100	<20	<5	300	<10	30
42	10	.5	1	.3	500	300	1	<5	10	30	<20	<5	70	15	7
43	5	.3	.15	1	100	500	<1	<5	200	30	<20	<5	200	10	30
C-6	.5	.1	.05	1	20	30	<1	<5	10	5	100	<5	20	20	5
G-22′	15	.7	.15	.7	30	100	<1	20	300	70	<20	<5	300	<10	300
G-36′	1.5	.5	.07	.7	20	300	1	30	300	200	30	5	15	<10	200
G-51′	7	.5	.05	1	30	150	<1	<5	700	50	<20	<5	20	<10	70
G-79′	.5	.2	.2	.3	15	30	<1	5	100	70	<20	<5	<10	<10	30
G-88′	5	.15	.05	1	30	70	<1	7	1,500	30	<20	<5	100	10	50
G-106′	5	.7	.15	1	30	200	<1	70	300	70	70	<5	100	15	200
G-127′	7	.7	.2	1	70	300	<1	15	1,000	100	20	<5	150	15	150
G-147′	10	.7	.2	1	70	200	<1	5	700	100	<20	<5	700	10	100
G-162′	1.5	.5	.3	1	30	200	<1	150	2,000	100	<20	<5	500	10	700
G-164′	5	.7	.3	>1	70	200	<1	10	700	50	<20	<5	70	10	150
G-195′	7	.5	.15	1	70	200	<1	5	1,500	70	<20	<5	700	10	100
G-213′	15	.5	.15	.7	70	300	1	30	500	70	<20	<5	1,000	<10	150
G-223′	10	.7	.2	1	70	300	<1	30	500	100	<20	<5	2,000	10	100
G-238′	10	.5	.1	.7	100	1,500	<1	<5	150	30	<20	<5	70	<10	30

TABLE 2.—*Analyses of Eocene rocks from central California*—Continued

Sample	Semiquantitative spectrographic analyses—Continued						Chemical analysis (ppm)	Gamma-ray analyses			Locality	Source	Sample description
	Parts per million							Ppm		Percent			
	Pb	Sc	Sr	V	Y	Zr	Au	Tb	U	K			
Ione Formation—Continued													
18	10	15	300	150	30	150	<.02	12.4	2.40	1.32	R; sec. 20, T. 10 N., R. 7 E.	Rcut	Sandy st.
19	<10	10	<100	100	50	1,000	.10	4.06	1.74	.42	R; sec. 17, T 10 N., R. 7 E.	do	Anauxitic ss.
20	<10	10	700	150	<10	100	<.02	2.81	2.38	.59	R; sec. 25, T. 11 N., R. 6 E.	do	Cl and ss.
21	<10	50	300	500	50	>1,000	.10	4.06	1.50	.43	L; sec. 23, T. 12 N., R. 6 E.	do	Fossiliferous ss.
22	<10	20	<100	300	20	150	<.02	4.00	1.74	.42	L; sec. 10, T. 12 N., R. 6 E.	Pit	Sandy cl.
23	<10	15	200	150	20	200	<.02	17.7	4.98	1.44	do	do	Lignitic cl.
24	10	20	<100	300	20	200	<.02	17.0	6.67	1.16	do	do	Massive cl.
25	10	30	<100	300	10	200	<.02	14.7	6.38	1.45	do	do	Do.
26	10	30	<100	300	15	200	<.02	14.2	4.75	1.29	do	do	Do.
27	<10	10	100	150	10	300	<.02	9.41	1.74	1.68	do	do	Sandy cl.
29	<10	15	<100	150	15	300	<.02	18.1	3.88	.30	I; sec. 28, T. 5 N., R. 10 E.	N oc	Fe-stained ss.
30	<10	15	<100	100	10	300	<.02	30.5	4.07	.24	do	do	Massive ss.
31	<10	5	<100	20	<10	100	<.02	10.3	1.80	.15	do	Rcut	Clayey ss.
32	<10	10	<100	70	<10	100	<.02	1.97	1.09	.58	I; sec. 21, T. 5 N., R. 10 E.	Rcut	Clayey ss.
33	<10	30	<100	200	15	150	<.02	8.16	1.68	.82	do	do	Sandy cl.
34	<10	5	<100	70	10	70	.12	1.62	.59	.21	I; sec., 3, T. 4 N., R. 10 E.	do	Cgl and ss.
35	<10	10	<100	70	10	100	<.02	1.83	.61	.27	do	do	Sandy cgl.
36	15	15	<100	70	30	150	.02	24.4	6.52	.20	I; sec. 20, T. 5 N., R. 10 E.	Pit	Lignitic ss.
37	<10	15	<100	100	70	150	<.02	3.19	1.39	<.01	I; sec. 36, T. 6 N., R. 9 E.	do	Lignite.
38	20	>100	<100	200	50	>1,000	<.02	171	33	<.01	I; sec. 6, T. 5 N., R. 10 E.	Mill c	Heavy minerals.
39	15	30	<100	100	<10	1,000	<.02	22.2	10.0	.16	do	Pit	Massive ss.
40	70	30	<100	150	10	1,000	.02	38.0	12.6	.32	do	do	Clayey ss.
41	15	70	<100	700	10	150	<.02	3.72	.55	.14	I; sec. 15, T. 6 N., R. 9 E.	do	Laterite.
42	20	15	<100	100	15	200	<.02	26.6	4.85	.12	I; sec. 5, T. 6 N., R. 9 E.	Drill c	Silty ss.
43	<10	15	<100	200	10	700	<.02	6.42	2.04	.42	do	Pit	Fine ss.
C-6	15	15	<100	150	<10	300	.10	16.0	2.76	.14	I; sec. 5, T. 5 N., R. 10 E.	do	Do.
G-22′	20	70	<100	500	20	150	<.02	7.20	4.52	.04	I; sec. 12, T. 4 N., R. 10 E.	Drill c	Yl-brn cl.
G-36′	30	50	<100	300	70	150	<.02	14.8	11.1	.59	do	do	Gray cl.
G-51′	<10	70	<100	300	15	500	<.02	9.93	2.19	.22	do	do	Do.
G-79′	15	15	<100	100	15	70	<.02	11.8	2.92	.06	do	do	Lignite
G-88′	<10	15	<100	100	10	300	<.02	8.47	4.62	.14	do	do	Sandy cl.
G-106′	<10	30	<100	200	70	300	<.02	4.75	4.40	.28	do	do	Gray cl.
G-127′	<10	70	150	500	30	300	.08	7.62	8.50	.43	do	do	Do.
G-147′	<10	50	<100	300	20	300	<.02	7.36	2.41	.31	do	do	Do.
G-162′	10	30	<100	700	20	300	<.02	11.1	62.2	.27	do	do	Lignitic ss.
G-164′	10	70	200	300	15	300	<.02	6.33	16.0	.34	do	do	Gray cl.
G-195′	<10	50	<100	500	15	300	<.02	11.4	1.87	.36	do	do	Brn cl.
G-213′	<10	70	<100	500	20	150	<.02	3.72	2.05	.43	do	do	Gray cl.
G-223′	<10	70	<100	300	30	150	<.02	4.95	1.85	.63	do	do	Conglomeritic cl.
G-238′	15	30	100	200	30	200	<.02	10.9	2.33	1.78	do	do	Gray cl.

TABLE 2.—*Analyses of Eocene rocks from central California*—Continued

Sample	Semiquantitative spectrographic analyses														
	Percent				Parts per million										
	Fe	Mg	Ca	Ti	B	Ba	Be	Co	Cr	Cu	La	Mo	Mn	Db	Ni
Tesla Formation															
CH1	0.5	0.2	0.5	0.3	30	300	<1	<5	20	10	30	<5	70	<10	5
CH2	1	.07	.05	.5	50	50	<1	<5	70	15	<20	<5	50	20	10
CH3	.5	.1	.05	.15	20	300	<1	<5	30	20	20	<5	30	<10	5
CH5	1.5	.2	.5	.15	20	1,000	1	<5	20	15	20	<5	100	<10	5
Domengine Formation															
1274C	0.2	0.1	0.1	0.15	10	700	<1	<5	70	5	20	<5	20	<10	5

Sample	Semiquantitative spectrographic analyses—Continued						Chemical analysis (ppm)	Gamma-ray analyses			Locality	Source	Sample description
	Parts per million							Ppm		Percent			
	Pb	Sc	Sr	V	Y	Zr	Au	Th	U	K			
Tesla Formation—Continued													
CH1	<10	<5	<100	50	<10	200	<0.02	6.84	1.44	1.02	N; sec. 25, T. 3 S., R. 3 E.	N oc	Clayey ss.
CH2	30	5	<100	100	<10	150	<.21	9.01	2.21	.21	N; sec. 26, T. 3 S., R. 3 E.	do	Do.
CH3	<10	5	<100	50	<10	100	<.02	5.16	1.33	1.24	N; sec. 32, T. 3 S., R. 4 E.	do	Buff ss.
CH5	10	<5	150	70	<10	150	<.02	4.56	1.23	2.77	do	do	Do.
Domengine Formation—Continued													
1274C	<10	<5	100	15	<10	150	<0.02	2.75	1.34	1.60	N; sec. 4, T. 1 N., R. 1 E.	N oc	Buff ss.

in sandstones and clays show Th/U ratios of the order of those in the nonlignitic sandstones and clays, but the mean Th/U ratio of clays and lignites is somewhat lower than that of sandstones. From a regional standpoint, clays of the Ione-Buena Vista area contain appreciably less potassium than clays at Lincoln.

REGIONAL DIFFERENCES IN U, Th, AND K

The relations between contents of U, Th, and K in different regions are illustrated in the ternary diagram of radioelement fraction (normalized to U(ppm)+Th(ppm)+K(percent)=100), figure 2. The generally low-K field of the samples from the Ione-Buena Vista area covers a broad range of Th/U, as does the relatively higher K field of the Nortonville-Corral Hollow samples.

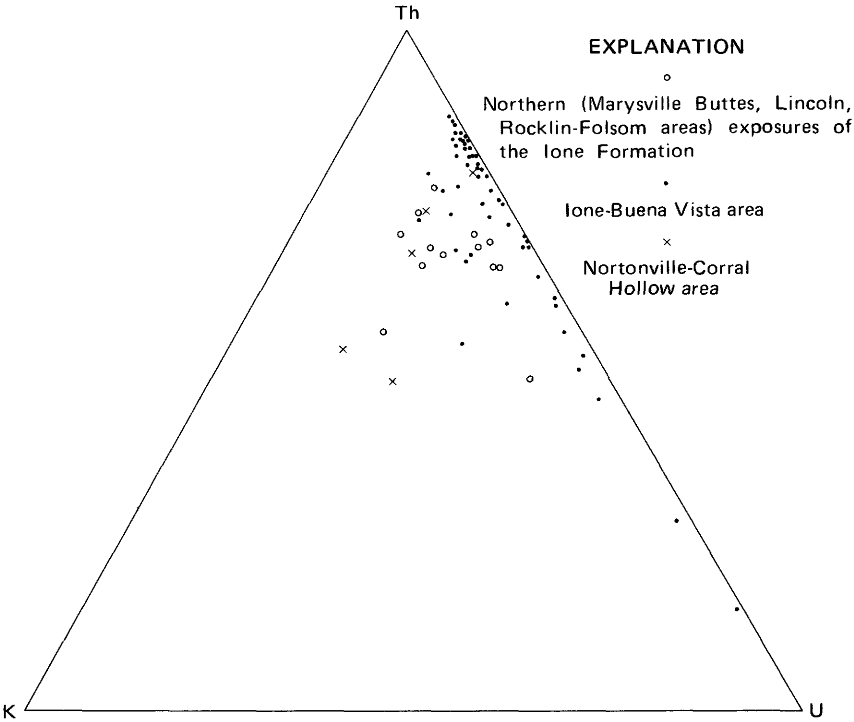

FIGURE 2.—Relation of radioelement contents of Th, U, and K in Eocene rocks, normalized to U(ppm)+Th(ppm)+K(percent)=100.

RELATION OF RADIOELEMENTS TO HEAVY MINERALS

The apparent correlation between radioelements and heavy minerals on a formation-wide basis was tested by plotting Th+U against semiquantitative spectrographic values of Zr, Ti, and La (fig. 3). Absolute values of Zr greater than 1,000 ppm (parts per million) and Ti greater than 1 percent are not reported; nevertheless, the plot shows generally positive trends and indicates, in turn, the general correspondence of Th and U and heavy minerals. The relatively high concentration of La (≧70 ppm) in highly radioactive gray sandstones (samples 14–30′ to 14–49′, table 2) suggests the presence of rare-earth minerals, perhaps allan-

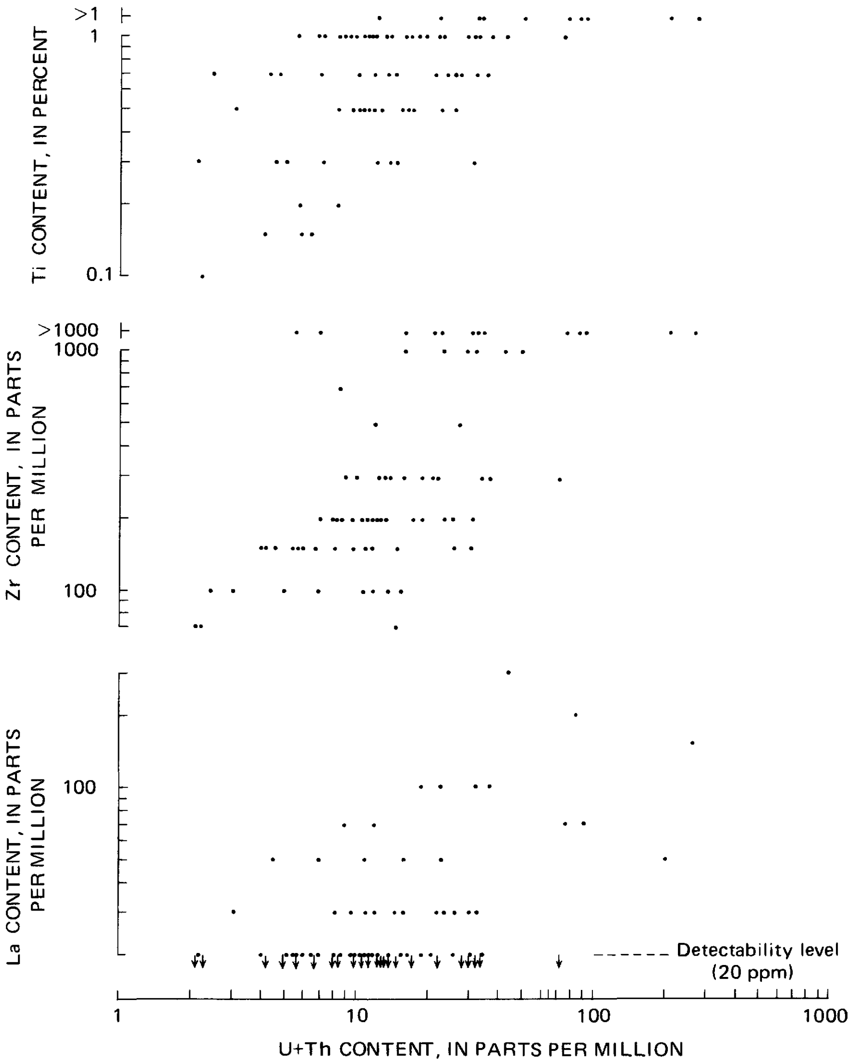

FIGURE 3.—Relation between Th plus U and Ti, Zr, and La contents in Eocene rocks.

ite and (or) monazite, although these minerals were not reported by Allen (1929), and Lindgren (1911) noted the conspicuous absence of monazite in the Tertiary gravels (also see Lee and Dodge, 1964). The positive correlation between Th and U and heavy-mineral concentrations in present-day Gulf and Atlantic coast beach sands was described by Mahdavi (1964).

In some localities, sandstones with high Th and U contents have relatively high Mn contents, as shown in table 2. With one marked exception, the lignitic sandstone near Buena Vista with abundant U (sample G–162′), highly radioactive sandstones are low in Ni and Mg, components most likely derived from ultramafic source rocks; the highly radioactive sandstones are generally high in Cr, however. Quartz-pebble conglomerates near the base of the Ione Formation have the lowest U and Th contents, attesting to the abundance of quartz.

GOLD CONTENT

There is no apparent correlation between Th, U, or whole-rock radioactivity (counts per minute per gram of sample) and gold content. Of the 77 analyzed samples, 24 had values exceeding the atomic-absorption analyses detection limit of 0.02 ppm Au. The highest Au content measured in the Eocene sandstones, 0.21 ppm, was in a sample of Tesla Formation from Corral Hollow; radioelement contents were 2.21 ppm U and 9.01 ppm Th. This sample contained intermediate amounts of Ti and Zr (0.5 percent and 100 ppm, respectively). Gold was below the detection limit in the richest Th-U Zr-Ti samples of dark sandstones from the roadcut near Ione (samples 14–30′ and 14–36′). A sample of brownish sandstone from the Lincoln area (No. 21) contained 0.10 ppm Au, greater than 1,000 ppm Zr, and 1 percent Ti. However, radioelement contents of the sample were relatively low: 1.50 ppm U and 4.06 ppm Th. There appears to be little or no correlation between gold and heavy-mineral contents in the Eocene sandstones.

RELATION OF FIELD COUNTING RATES TO Ti AND Zr

From the plot of radioelements relative to Ti and Zr in figure 3, one may surmise that there are similar relations between field counting rates and Ti and Zr, representatives of heavy-mineral concentrations. The plot shown in figure 4 indicates that the gamma-ray counting rates measured on the outcrop vary roughly with zircon and ilmenite contents in the sands (field counting rates were measured at only about one-half of the sample localities).

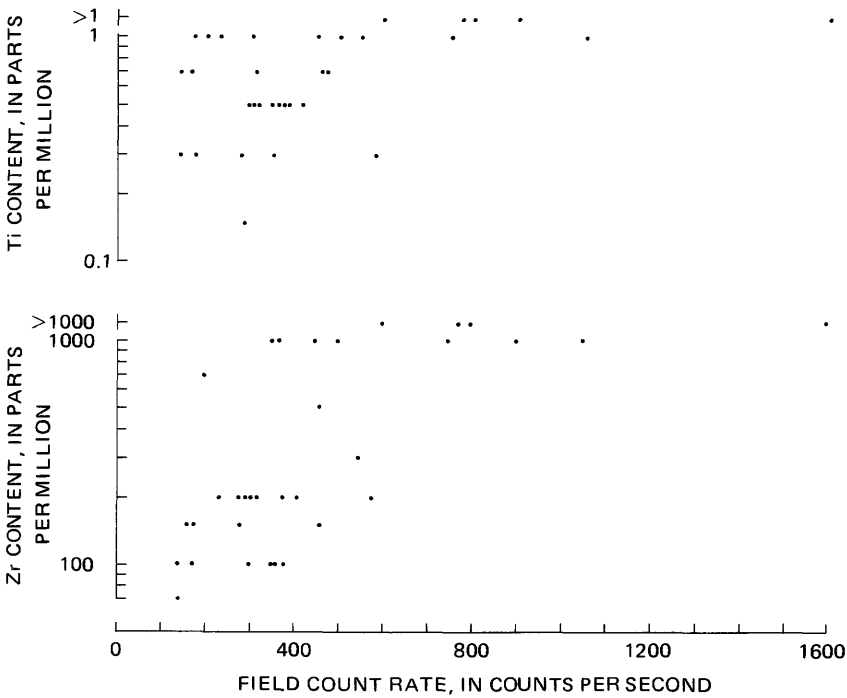

FIGURE 4.—Relations between field counting rate and Ti and Zr contents.

COMPARISON OF IONE FORMATION AND ITS SOURCE ROCKS, RADIOELEMENT CONTENTS AND RATIOS

Radioelement contents and Th/U ratios of the Ione Formation sandstones and clays, summarized in table 1, can be compared with mean radioelement contents of possible source rocks of the Ione (table 3). Units sampled previously, which are probably repre-

TABLE 3.—*Mean and standard deviation of the mean radioelement content of possible source rocks of the Ione Formation*

Unit sampled	U (ppm) Mean	U (ppm) Standard deviation	Th (ppm) Mean	Th (ppm) Standard deviation	K (percent) Mean	K (percent) Standard deviation	Th/U Mean	Th/U Standard deviation
Granitic rocks of the Yosemite-San Joaquin region (from Wollenberg and Smith, 1968)	3.95	2.33	12.5	8.0	2.37	1.01	3.7	1.4
Rocklin pluton (Wollenberg, unpub. data) and Bucks Granodiorite of Whitfield and others (1969, p. 267–277)	2.2	.8	4.0	.6	1.3	.3	2.0	1.1
Prebatholithic rocks of the central Sierra Nevada (from Wollenberg and Smith, 1970)	2.31	1.05	5.71	1.6	1.34	.55	2.7	1.0
Overall values	2.8	----	5.7	----	1.7	----	2.8	----

sentative of the Ione's source materials, are granitic rocks of the Yosemite-San Joaquin region, the Rocklin and Bucks plutons, and pregranitic Paleozoic and Mesozoic rocks of the western slope of the Sierra Nevada. Although the Yosemite-San Joaquin granitic rocks are well to the south of the Ione-Buena Vista area, analyses of various samples of granitic rocks collected between Yosemite and Lake Tahoe indicate similar Th, U, and K contents. The Th and U contents of the sandstones and clays in the Ione-Buena Vista area are similar to, or somewhat higher than, those in granitic rocks of the Yosemite-San Joaquin region. Radioelement contents of the northerly exposures of Ione sandstones are more nearly like those of the pregranitic rocks and the Bucks and Rocklin plutons. However, clays at Lincoln are similar in K, U, and Th contents to the more radioactive granitic rocks. These comparisons suggest that the Eocene sandstones and clays in the Ione-Buena Vista area were derived from a region of predominantly granitic rocks. The relatively high Th and U contents of the Lincoln clays as compared with considerably lower values of some of the northerly sandstones make it difficult to associate possible source rocks to the sediments of the northern areas. Low K contents of the samples from the Ione-Buena Vista area relative to the more potassic northerly samples suggest that processes associated with transport and deposition, rather than composition of source materials alone, may have played a key role in the distribution of radioelements in the Eocene sedimentary rocks.

The overall mean Th/U ratio in the Eocene sandstones and clays is 3.65, similar to the ratios in Sierran rocks listed in table 3. However, Th/U ratios are different in the two litholoic categories used in table 1, being higher in sandstones and conglomerates (mean 4.05) than in clays and lignites (mean 2.93). This suggests some fractionation of U and Th, most likely after deposition of the sediments, as U, more mobile as the uranyl ion than Th, would associate readily with the clays, especially in the reducing environment afforded by lignitic material.

CONCLUSIONS

There is little probability that gold exists in exploitable concentrations in the Ione Formation, nor is there any apparent correlation between radioelements and gold content. Gold content of samples of the formation was found not to exceed 0.10 ppm, and generally was less than 0.02 ppm. Apparently most of the available gold carried down by streams was deposited in the river channels, and only small amounts reached the depositional basin of the Ione Formation.

The formation in the vicinity of Ione-Buena Vista is characterized by relatively high Th/U ratios and scarce K. High radioactivity is associated with dark streaks in sandy members where spectrographic analyses indicate an abundance of Ti, Zr, and La. North of the Ione-Buena Vista area the formation contains generally lower Th and U and considerably more K, as do samples of the Tesla and Domengine Formations from the west side of the Great Valley.

High radioactivity and Th/U ratios in the formation near Ione and Buena Vista suggest a predominantly granitic source. Lower radioelement contents and ratios in the more northerly exposures may indicate that their source region was underlain mainly by prebatholithic rocks, but compositions most likely have been modified by processes of transport and deposition.

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