Geologic Studies in White Pine County, Nevada

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Rubidium and Strontium in Hybrid Granitoid Rocks, Southern Snake Range, Nevada

By DONALD E. LEE *and* WILLIS P. DOERING

Composition of Calcium-Poor Quartzites of Late Precambrian and Early Cambrian Age from Eastern White Pine County, Nevada

By DONALD E. LEE, R. E. VAN LOENEN, E. L. MUNSON BRANDT, *and* WILLIS P. DOERING

A Radiometric Age Study of Mesozoic-Cenozoic Metamorphism in Eastern White Pine County, Nevada, and Nearby Utah

By DONALD E. LEE, RICHARD F. MARVIN, *and* HARALD H. MEHNERT

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RUBIDIUM AND STRONTIUM IN HYBRID GRANITOID ROCKS, SOUTHERN SNAKE RANGE, NEVADA

By DONALD E. LEE and WILLIS P. DOERING

ABSTRACT

In the southern Snake Range, Nevada, the equivalent of a large part (from 63 to 76 percent SiO_2) of the classic differentiation sequence has resulted mainly from assimilation of chemically distinct host rocks. The curves for rubidium and strontium in these hybrid rocks resemble those expected in normally differentiated rocks, and the potassium-rubidium ratios tend to decline from the mafic to the felsic parts of the outcrop area. However, the K:Rb curve is discontinuous where the rock contains 2.5 percent CaO (about 70 percent SiO_2), indicating the complexity of the igneous processes that resulted in the formation of this hybrid pluton.

INTRODUCTION

This paper describes the distribution of rubidium and strontium in hybrid granitoid rocks (Jurassic) of the southern Snake Range, Nevada. These intrusive rocks are of petrologic interest for two main reasons:

1. In the Snake Creek–Williams Canyon area the equivalent of a large part (from 63 to 76 percent SiO_2) of the classic differentiation sequence has developed mainly from assimilation of chemically distinct host rocks, which are Prospect Mountain Quartzite (Precambrian Z and lower Cambrian), Pioche Shale (Lower and Middle Cambrian), and Pole Canyon Limestone (Middle Cambrian).
2. The Pole Canyon–Can Young Canyon area intrusive body is an unusual muscovite-bearing hybrid rock that has developed through assimilation of the upper Precambrian Osceola Argillite of Misch and Hazzard (1962). The distinctive nature of this intrusive is especially striking inasmuch as it is separated from the Snake Creek–Williams Canyon area intrusive by a septum of sedimentary rocks 1.6 km long and only about 300 m wide.

The Jurassic rocks studied crop out a few kilometers north of the Mount Wheeler mine in the southern part of the Snake Range, about 80 km southeast of Ely, Nev. These same rocks are the subject of a comprehensive field and laboratory study (Lee and Van Loenen, 1971) that includes both a geologic map that shows sample localities and tables of extensive chemical data for all the specimens discussed in the present report. The sample numbers used here are the same as in the comprehensive study, where rocks are numbered in order of increasing CaO content; that is, from most felsic to most mafic. The field numbers used in earlier papers cited in this report are keyed to these sample numbers by Lee and Van Loenen (1971, p. 11).

The samples were analyzed for rubidium and strontium on an X-ray emission spectrometer. Net counts of the unknown samples were compared to those of standard samples having similar major-element and rubidium and strontium concentrations, and values were corrected for mass absorption by measuring the Compton scattering peak. The standard samples were measured for rubidium and strontium on a mass spectrometer using the stable isotope dilution method.

Muscovite, feldspar, and whole-rock analyses listed are correct within 3 percent of the reported values for rubidium and strontium, but the Rb:Sr ratios are correct within 2.3 percent of the reported values because mass absorption effects are canceled. Biotite analyses listed are correct only within 4 percent of the values reported for rubidium and within 6 percent of the values reported for strontium and Rb:Sr ratios because these biotites are iron-rich and so have large mass absorption coefficients.

Results of semiquantitative spectrographic analyses are based on their identity with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, and so forth, and are reported arbitrarily as midpoints of these brackets: 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1, respectively. The precision of a reported value is approximately plus or minus one bracket at the 68-percent confidence level, or two brackets at the 95-percent confidence level.

SNAKE CREEK–WILLIAMS CANYON AREA

The influence of host rocks on the chemistry and mineralogy of intrusive rocks of the southern Snake Range is most clearly shown in the Snake Creek–

Williams Canyon area. There the intrusive is undeformed, probably has not been eroded to a depth of much more than 300 m, and is well exposed in contact with quartzite, shale, and limestone. Within a horizontal distance of 5 km, the intrusive grades from a quartz monzonite (76 percent SiO_2, 0.5 percent CaO) where the host rock is quartzite, to a granodiorite (63 percent SiO_2, 4.5 percent CaO), where the host rock is limestone. Other major elements vary as one would expect in a normal differentiation sequence (Lee and Van Loenen, 1971, fig. 4).

Most minor elements show a similar variation, the exceptions being the rare earths (Lee and Bastron, 1967; Cain, 1974), zirconium (Lee and others, 1968; Lee and Van Loenen, 1971, fig. 6), fluorine (Lee and Van Loenen, 1971, fig. 7), and, most notably, barium (Lee and Doering, 1974).

Quantitative rubidium and strontium analyses and Rb:Sr ratios of the rocks are listed in table 1. In figure 1, rubidium is plotted against CaO rather than K_2O for a better point spread, and the equivalent ranges of K_2O and SiO_2 are indicated. The increase of rubidium contents from the mafic to the felsic parts of the pluton is, of course, what one would expect in a normally differentiated granitoid mass; because of the similarity of the two ions, Rb^+ always substitutes for K^+ in crystallizing silicates.

Analyses of 34 samples of sedimentary rocks that are in contact with (and were assimilated by) the hybrid granitoid rocks were listed by Lee and Van Loenen (1971, tables 1 and 2). For the present study, splits of the shales, quartzites, and argillites were analyzed for rubidium and strontium. The quantitative results are listed in table 2, and the quartzite and shale averages are indicated on those parts of figure 1 that presumably represent assimilation of the respective rocks by the Snake Creek-Williams Canyon area intrusive. The Pole Canyon Limestone average (20 parts per million rubidium) assumed (fig. 1) is based on the fact that the soluble portions of carbonate sediments contain only very minor amounts of rubidium (Heier and Billings, 1970, p. 37-K-1), and nine samples of the Pole Canyon Limestone average about 95 percent $CaCO_3$ (Lee and Van Loenen, 1971, table 2).

TABLE 1.—*Quantitative rubidium and strontium analyses, in parts per million, and rubidium-strontium ratios of granitoid rocks of the Snake Creek-Williams Canyon area, Nevada*

[W. P. Doering, analyst. Method of analysis explained in text. Complete analyses of rocks listed by Lee and Van Loenen (1971, Table 5). Samples 71, 72, 77, 81, and 85 are xenoliths]

Sample No.	Rb	Sr	Rb/Sr
1	263	99	2.66
2	231	106	2.18
3	353	119	2.12
4	253	119	2.12
5	219	119	1.84
6	177	140	1.23
7	269	104	2.59
8	244	100	2.44
9	179	205	.88
10	240	162	1.48
11	187	166	1.13
12	153	224	.68
13	191	212	.90
14	164	325	.50
15	148	329	.45
16	152	339	.45
17	156	356	.44
18	133	366	.36
19	131	363	.36
20	146	362	.40
21	139	368	.38
22	109	368	.30
23	155	393	.39
24	180	440	.41
25	123	373	.33
26	130	418	.31
27	136	421	.32
28	144	415	.35
29	123	470	.26
30	114	451	.25
31	121	491	.25
32	116	453	.25
33	111	457	.24
34	92.2	498	.19
35	104	507	.21
36	111	471	.24
37	95.6	498	.19
38	106	500	.21
39	113	515	.22
40	89.3	537	.17
41	96.7	538	.18
42	136	440	.31
43	102	496	.21
44	105	465	0.23
45	91.6	502	.18
46	109	498	.22
47	89.4	547	.16
48	102	512	.20
49	105	582	.18
50	93.8	541	.17
51	109	486	.23
52	93.0	528	.18
53	109	471	.23
54	118	472	.25
55	111	492	.23
56	97.9	551	.18
57	101	511	.20
58	98.6	553	.18
59	151	420	.36
60	97.0	606	.16
61	83.8	713	.12
62	94.1	569	.17
63	97.2	645	.15
64	99.9	636	.16
65	89.0	701	.13
66	86.2	676	.13
67	72.6	631	.12
68	101	653	.16
69	174	471	.37
70	95.3	671	.14
71	92.6	474	.20
72	191	190	1.01
73	85.5	707	.12
74	79.0	729	.11
75	77.7	726	.11
76	77.9	742	.11
77	137	476	.29
78	67.8	854	.08
79	82.3	716	.12
80	74.4	744	.10
81	83.1	603	.14
82	87.0	725	.12
83	100	678	.15
84	76.3	763	.10
85	166	353	.47
86	70.5	822	.09

Thus, the increase in rubidium from the mafic to the felsic parts of the Snake Creek-Williams Canyon intrusive appears to reflect some process of differentiation, being largely unrelated to the rubidium contents of the assimilated country rocks. However, barium shows the opposite trend (Lee and Doering, 1974, fig. 1), tending to decrease from the mafic to the felsic parts of the igneous exposure, even though Ba^{2+}, like Rb^+, substitutes for K^+ in crystallizing silicates. In a general way, the barium contents of these rocks appear to relate to the average barium contents of the quartzite, shale, and limestone assimilated.

We speculate that the opposite trends noted for rubidium and barium in this igneous sequence may have resulted from the interplay of the following two factors:

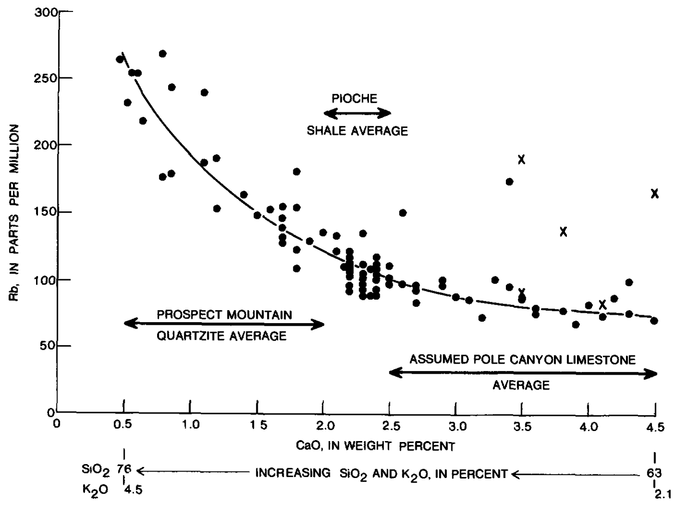

FIGURE 1.—Relation between CaO and rubidium contents in granitoid rocks of the Snake Creek-Williams Canyon area, Nevada. Equivalent ranges of contents of SiO_2 and K_2O, in weight percent, are indicated. Average rubidium contents of sedimentary rocks are indicated on parts of diagram representing assimilation of those rocks. Based on tables 1 and 2 and on data listed by Lee and Van Loenen (1971, table 5). Dot, main intrusive phase; X, xenolith.

1. Distribution coefficients for barium in biotite and K-feldspar are greater than 1, and those for rubidium tend to be less than 1 (Nagasawa and Schnetzler, 1971). We might, therefore, expect barium to be preferentially incorporated into the early-formed potassium minerals and rubidium to stay in the melt as long as possible.
2. Perhaps for some reason the Ba^{2+} ion was relatively immobile in the magnetic environment and thus the barium content of the granitoid rock reflects the barium content of the sedimentary rock assimilated.

A number of authors (for example, Taubeneck, 1965; the workers cited by Heier and Billings, 1970, p. 37-E-8) have noted that the K:Rb ratio changes progressively with concentration of felsic constituents over mafic constituents; that is, "differentiation." When a rock system undergoes some sort of differentiation, rubidium is expected to increase relative to potassium in the felsic fractions and the K:Rb ratio will decrease in a sequence from mafic to felsic rocks. In figure 2, K:Rb is plotted against CaO for the Snake Creek-Williams Canyon area intrusive. The K:Rb ratio for the Pole Canyon Limestone is not indicated on figure 2, but it is clear that this ratio involves only minor amounts of both elements because the average potassium content of nine samples of this limestone is only about 0.18 percent (Lee and Van Loenen, 1971, table 2), and, as argued earlier, the average rubidium content of this limestone (about 95 percent $CaCO_3$) probably also is very low. The K:Rb ratios of the pluton do indeed tend to decrease toward the felsic part of the exposure, but there is a break in the curve near 2.5 percent CaO. A secondary trend for barium also branches from the main trend where the rock contains from 2.0 to 2.5 percent CaO (Lee and Doering, 1974). Thus, although both Rb^+ and Ba^{2+} substitute for K^+ in crystallizing silicates, the equivalent of a large part of the classic differentiation sequence (from 63 to 76 percent SiO_2) that has resulted from assimilation of

TABLE 2.—*Quantitative rubidium and strontium analyses, in parts per million, and rubidium-strontium ratios of Pioche Shale, Prospect Mountain Quartzite, and Osceola Argillite of Misch and Hazzard (1962), southern Snake Range, Nevada*

[W. P. Doering, analyst. Method of analysis explained in text. Complete analyses of rocks listed by Lee and Van Loenen (1971, Table 1)]

Sample No.	Rb	Sr	Rb/Sr
	Pioche Shale		
S1	147	41.1	3.58
S2	78.6	104	.76
S3	396	359	1.10
S4	141	79.1	1.79
S5	273	33.2	8.27
S6	338	28.4	11.90
S7	217	45.9	4.72
S8	333	125	2.67
S9	105	82.7	1.27
Average---	225.4	99.8	2.25
	Prospect Mountain Quartzite		
Q1	88.3	24.8	3.56
Q2	113	28.9	3.92
Q3	53.2	14.4	3.70
Q4	15.8	4.5	3.49
Average---	67.6	18.2	3.72
	Osceola Argillite		
Ar1	121	215	0.57
Ar2	19.3	178	.11
Ar3	148	51.9	2.85
Ar4	220	28.7	7.67
Ar5	18.3	117	.16
Ar6	143	44.8	3.20
Average---	111.6	105.9	1.05

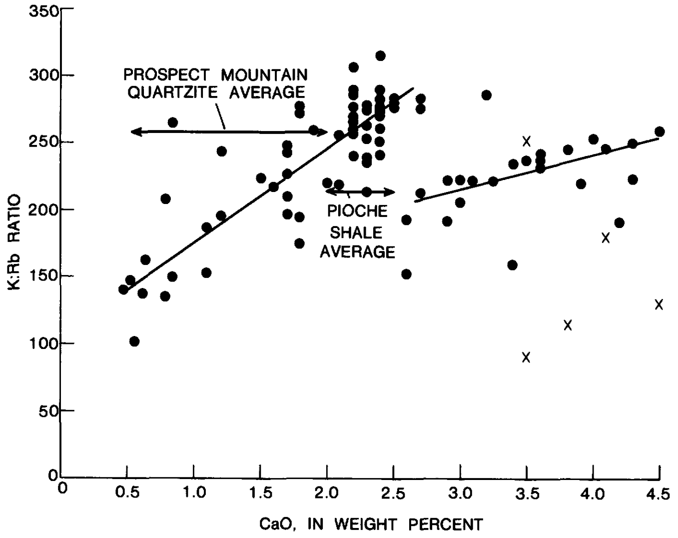

FIGURE 2.—Relation between K:Rb ratios and CaO contents of granitoid rocks of the Snake Creek-Williams Canyon area, Nevada. Equivalent ranges of contents of SiO_2 and K_2O are shown in figure 1. Average K:Rb ratios of sedimentary rocks indicated on parts of diagram representing assimilation of those rocks are based on tables 1 and 2 and on data listed by Lee and Van Loenen (1971, tables 5 and 9). Dot, main intrusive phase; X, xenolith.

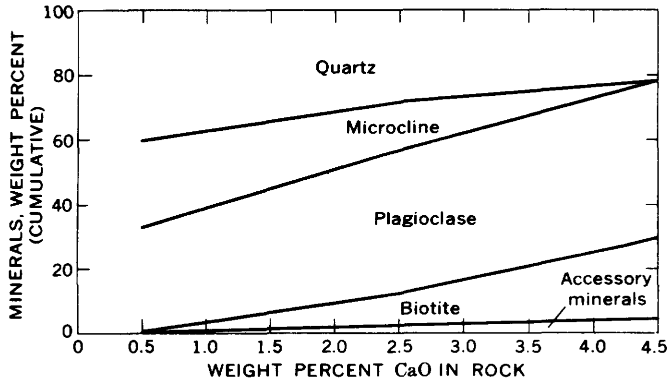

FIGURE 3.—General relations between CaO content and mineralogy for granitoid rocks of the Snake Creek-Williams Canyon area, Nevada. From Lee and Van Loenen (1971, fig. 11).

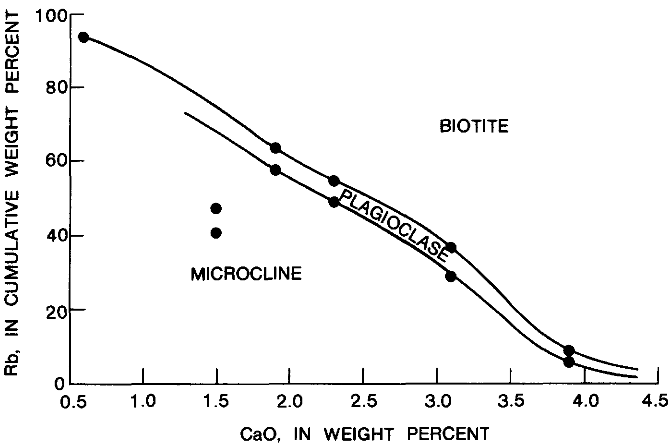

FIGURE 4.—Distribution of rubidium among minerals in granitoid rocks of the Snake Creek-Williams Canyon area, Nevada. Based on data in table 3.

chemically distinct host rocks in the Snake Creek-Williams Canyon area displays the following relations:

1. Rubidium increases toward the felsic part of the sequence (fig. 1).
2. Barium decreases toward the felsic part of the sequence (Lee and Doering, 1974, fig. 1).
3. K:Rb ratios tend to decrease toward the felsic part of the sequence (fig. 2).
4. The curves for both barium and K:Rb versus CaO are discontinuous in that part of the sequence (from 2.0 to 2.5 percent CaO) representing assimilation of Pioche Shale.

The distribution of potassium in these hybrid granitoid rocks is apparent from the opposite trends for biotite (∿9.5 percent K_2O) and microcline (∿14–15 percent K_2O) summarized in figure 3 and described in detail by Lee and Van Loenen (1970, p. D198; 1971, p. 27). On the basis of data in table 3, the distribution of rubidium is approximated in figure 4, which resembles a diagram showing the distribution of barium in these same rocks (Lee and Doering, 1974, fig. 3).

The plot (fig. 5) of strontium (table 1) versus CaO for the Snake Creek-Williams Canyon intrusive agrees with the results of a comprehensive study by Turekian and Kulp (1956), who found that, for granitic rocks, there is an increase in strontium content with increase in calcium, not only for samples from a single pluton, but also for universal sampling. A plot of Rb:Sr ratios listed in table 1 is not included here, but the ratio increases systematically from the most mafic to the most felsic parts of the exposure, as one would expect in a series of normal differentiates.

On the basis of the data in table 4, the distribution of strontium in the granitoid rocks is approximated in figure 6. Epidote is by far the most strontium-rich mineral present in these rocks (Lee and others, 1971), and, in the most mafic parts of the exposure, where it comprises about 2 percent of the rock, it contains more than 9 percent of the strontium present in the rock. In this regard, it is interesting to note that the allanite (cerium-epidote) present in the mafic parts of the exposure (Lee and Bastron, 1967) does not concentrate strontium. X-ray fluorescence analyses by Robena Brown showed that the constituent allanites from samples 22, 66, 67, 72, and 78 (table 1) each contain less than 100 ppm strontium. The amounts of strontium contained in apatite (table 4) are too small to be

TABLE 3.—*Distribution of rubidium among minerals in granitoid rocks of the Snake Creek-Williams Canyon area and the Pole Canyon-Can Young Canyon area, Nevada*

[W. P. Doering, analyst. Method of analysis explained in text. Leaders (---) indicate no data. All analyses in weight percent]

Sample No.	CaO in rock	Mineral in rock				Rb in pure mineral				Contribution to Rb content of the rock					Total Rb in rock				
		Biotite	Microcline	Muscovite	Plagioclase	Biotite	Microcline[1]	Muscovite	Plagioclase	Biotite	Microcline	Muscovite	Plagioclase	Total[2]	Biotite	Microcline	Muscovite	Plagioclase	Total
										Snake Creek-Williams Canyon Area									
3	0.55	2	20	---	34	0.1082	---	---	---	0.0022	---	---	---	0.0353	6.2	---	---	---	100.0
15	1.5	10	18	---	38	.0781	0.0338	---	0.0024	.0078	0.0061	---	0.0009	.0148	52.7	41.2	---	6.1	100.0
22	1.8	7	17	---	40	.0569	.0354	---	.0014	.0040	.0063	---	.0006	.0109	36.7	57.8	---	5.5	100.0
39	2.3	8	14	---	43	.0648	.0393	---	.0013	.0052	.0055	---	.0006	.0113	46.0	48.7	---	5.3	100.0
66	3.1	10	10	---	45	.0442	.0201	---	.0011	.0044	.0020	---	.0005	.0069	63.8	29.0	---	7.2	100.0
78	3.9	19	2	---	49	.0356	.0213	---	.0004	.0068	.0004	---	.0002	.0074	91.9	5.4	---	2.7	100.0
										Pole Canyon-Can Young Canyon Area									
89	0.98	6	19	6	35	0.0740	0.0453	0.0435	0.0020	0.0040	0.0086	0.0026	0.0007	0.0159	27.0	52.8	16.0	4.2	100.0
90	1.1	5	17	9	36	.0888	.0335	.0465	.0012	.0044	.0057	.0042	.0004	.0147	29.9	38.8	28.6	2.7	100.0
93	1.3	4	19	5	40	.0950	.0456	.0579	.0010	.0038	.0087	.0029	.0004	.0158	24.1	55.1	18.3	2.5	100.0

[1] Rubidium contents of microclines determined directly only for samples 66 and 78; rubidium content of other microclines calculated, based on data for coexisting minerals and rubidium content of whole rocks.

[2] Direct analyses of whole rocks gave 0.00862 and 0.00678 weight percent rubidium for samples 66 and 78, respectively.

TABLE 4.—*Distribution of strontium among minerals in granitoid rocks of the Snake Creek-Williams Canyon area and the Pole Canyon-Can Young Canyon area, Nevada*

[Quantitative Sr analyses (microclines in samples 66 and 78; plagioclases in samples 15, 22, 55, 66, 78, and 89; rocks) by W. P. Doering. Semiquantitative analyses (apatites, epidotes, and microclines in samples 15, 22, 55, 88, 89, and 90; plagioclases in samples 90 and 93) by R. E. Mays. Methods of analysis explained in text. Leaders (---) indicate no data. All analyses in weight percent]

Sample No.	CaO in rock	Mineral in rock				Sr in pure mineral				Contribution to Sr content of the rock					Total Sr in rock				
		Apatite	Epidote	Microcline	Plagioclase	Apatite	Epidote	Microcline	Plagioclase	Apatite	Epidote	Microcline	Plagioclase	Total[1]	Apatite	Epidote	Microcline	Plagioclase	Total
										Snake Creek-Williams Canyon Area									
15	1.5	0.1	0.1	18	38	0.05	0.3	0.03	0.0600	0.0001	0.0003	0.0054	0.0228	0.0286 (0.0329)	0.3	1.0	19.0	79.7	100.0
22	1.8	.15	.2	17	40	.05	.3	.03	.0644	.0001	.0006	.0051	.0258	.0316 (.0368)	.3	1.9	16.2	81.6	100.0
55	2.5	.15	.6	16	41	.07	.3	.03	.0904	.0001	.0018	.0048	.0371	.0438 (.0492)	.2	4.1	11.0	84.7	100.0
66	3.1	.2	1.0	10	45	.07	.3	.0325	.1383	.0001	.003	.0033	.0622	.0686 (.0676)	.1	4.4	4.8	90.7	100.0
78	3.9	.2	2.0	2	49	.05	.3	.0301	.1180	.0001	.006	.0006	.0578	.0645 (.0854)	.2	9.3	.9	89.6	100.0
										Pole Canyon-Can Young Canyon Area									
89	0.98	0.1	---	19	35	0.05	---	0.07	0.0660	0.0001	---	0.0133	0.0231	0.0365 (0.0325)	0.3	---	36.4	63.3	100.0
90	1.1	.1	---	17	36	.05	---	.05	.07	.0001	---	.0051	.0252	.0304 (.0350)	.3	---	16.8	82.9	100.0
93	1.3	.1	---	19	40	.05	---	.05	.07	.0001	---	.0095	.0280	.0376 (.0352)	.3	---	25.3	74.4	100.0

[1] Totals in parentheses are by rock analysis.

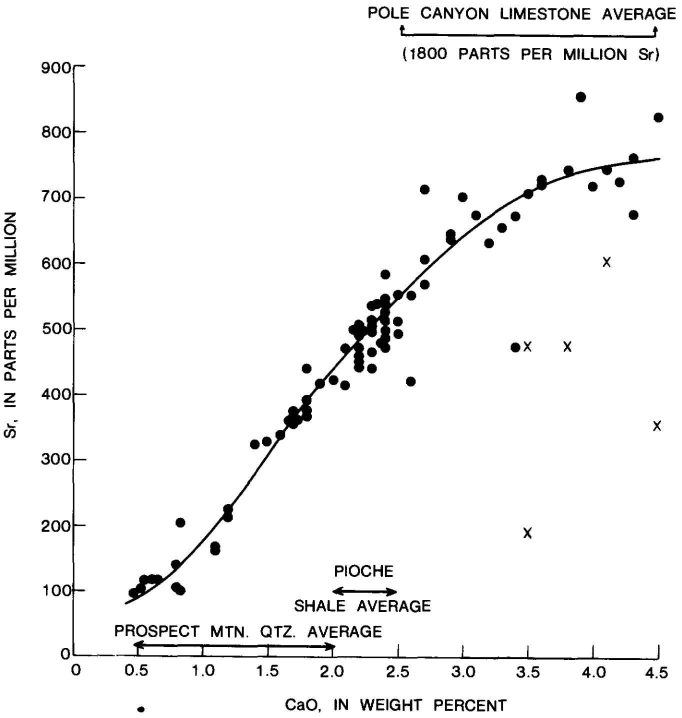

FIGURE 5.—Relation between CaO and strontium in granitoid rocks of the Snake Creek-Williams Canyon area, Nevada. Equivalent ranges of contents of SiO_2 and K_2O are as shown on figure 1. Average strontium contents of sedimentary rocks are indicated on parts of diagram representing assimilation of those rocks. Based on tables 1 and 2 and on data by Lee and Van Loenen (1971, tables 1 and 5). Dot, main intrusive phase; X, xenolith.

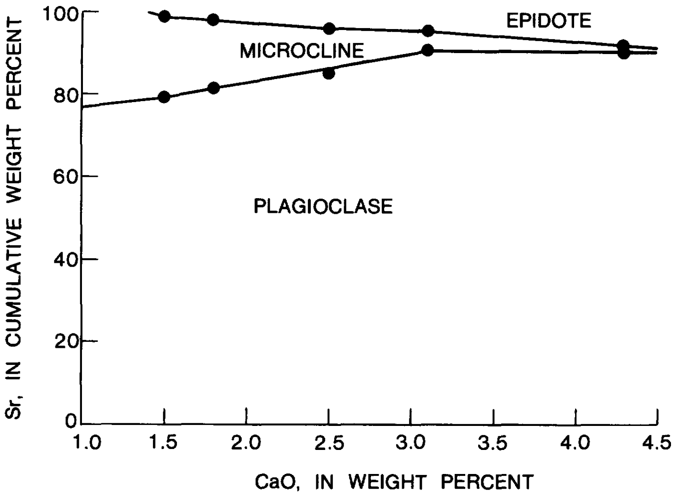

FIGURE 6.—Distribution of strontium among minerals in granitoid rocks of the Snake Creek-Williams Canyon area, Nevada (based on data in table 4).

represented in figure 6, and the very minor amounts of strontium present in the constituent sphenes (Lee and others, 1969) are not considered here.

POLE CANYON-CAN YOUNG CANYON AREA

The unusual two-mica hybrid rock developed in the Pole Canyon-Can Young Canyon area through assimilation of the Osceola Argillite has been described in detail by Lee and Van Loenen (1971, p. 5, 38-39). Chemical differences in the rock from place to place are relatively small with no systematic spatial distribution of values for either major or minor elements.

The distribution of rubidium in three samples (Nos. 89, 90, and 93) of this intrusive is outlined in table 3, which shows that a significant portion of the rubidium present is contained in muscovite. However, in each case, rubidium preferentially enters the coexisting biotite, which is in agreement with Heier and Billings (1970, p. 37-D-1). The rubidium contents of the rocks themselves are somewhat higher than the average rubidium content of six samples of the argillite assimilated (table 2).

The distribution of strontium in the same three samples of this intrusive is outlined in table 4. These two-mica rocks are devoid of epidote, and practically all of the strontium present is contained in plagioclase and microcline. The strontium contents of the rocks themselves are appreciably greater than the average strontium content of six samples of the argillite assimilated.

SUMMARY

The Snake Creek-Williams Canyon area intrusive is an ideal subject for a study of igneous processes. The chemistry and mineralogy of this intrusive are highly variable over a horizontal distance of 5 km; these variations involving major elements are those expected in a series of differentiates. However, from references already cited, it is apparent that the trends for the rare earths, fluorine, zirconium, and barium, are the opposite of those expected in normally differentiated rocks. Moreover, the breaks in the curves for barium and K:Rb versus CaO near the part of the intrusive outcrop that presumably represents assimilation of shale indicate a discontinuity in the transition between the mafic and felsic parts of the Snake Creek-Williams Canyon igneous sequence not apparent from our previous work on these rocks.

Puchelt (1972, p. 56-D-15) stated, "A useful index of fractionation is the ratio Ba/Rb." In this connection, we present figure 7, in which rubidium is plotted against barium for granitoid rocks of the Snake Creek-Williams Canyon area, and the course of crystalliza-

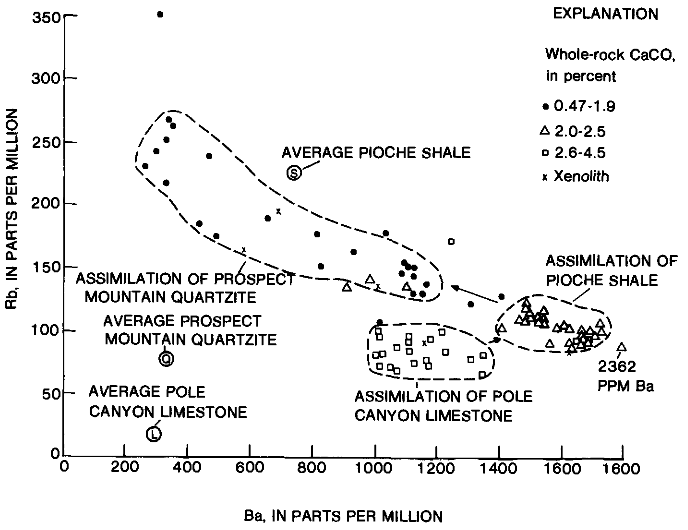

FIGURE 7.—Relation between rubidium and barium contents in granitoid rocks of the Snake Creek-Williams Canyon area, Nevada (based on tables 1 and 2 of this report, on tables 1 and 2 of Lee and Doering, 1974, and on data listed by Lee and Van Loenen, 1971).

tion from the mafic (assimilation of limestone) to the felsic (assimilation of quartzite) parts of the igneous sequence is indicated. The concentration of points in rather well-defined fields presumably representing assimilation of limestone, shale, and quartzite shows little relation to the averages indicated for the sedimentary rock types themselves.

Any attempt to explain the behavior of both rubidium (figs. 1, 4, 7) and barium (Lee and Doering, 1974, fig. 1) during crystallization of these contaminated rocks becomes contrived. Thus, it is clear that we have much to learn about the distribution coefficients of both elements under various conditions such as those discussed by Puchelt (1972, p. 56-D-15). We note, finally, that a mineralogical study of the igneous biotites recovered from these rocks (Lee and Van Loenen, 1970) shows a number of regular chemical changes from the mafic to the felsic parts of the exposure, indicating complete reworking of the detrital mica present in the assimilated Pioche Shale.

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Composition of Calcium-Poor Quartzites of Late Precambrian and Early Cambrian Age from Eastern White Pine County, Nevada

By DONALD E. LEE, R. E. VAN LOENEN, E. L. MUNSON BRANDT,
and WILLIS P. DOERING

GEOLOGIC STUDIES IN WHITE PINE COUNTY, NEVADA

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COMPOSITION OF CALCIUM-POOR QUARTZITES OF LATE PRECAMBRIAN AND EARLY CAMBRIAN AGE FROM EASTERN WHITE PINE COUNTY, NEVADA

By DONALD E. LEE, R. E. VAN LOENEN, E. L. MUNSON BRANDT,
and WILLIS P. DOERING

ABSTRACT

The 18 samples of quartzites of late Precambrian and Early Cambrian age described are remarkable for their very minor contents of CaO, especially in relation to the amounts of SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, K_2O, and TiO_2 present. The Na_2O contents of these quartzites are also low, and the average K_2O:Na_2O ratio is 20:1. The original miogeosynclinal shelf sediments were mixtures of (1) sand with a fair degree of mineralogical maturity and a low degree of textural maturity, and (2) argillaceous material. In most rocks described, the bulk chemistry of the argillaceous material apparently was appropriate for the crystallization of metamorphic mica(s) under conditions of metamorphism that were essentially isochemical, except for depletion of pore fluids. There is no evidence of metasomatism either in the field or in thin section. It is concluded that the sediments were derived from a deeply weathered crystalline terrane. This type of Precambrian source rock probably was present on the craton to the east at the time the original shelf sediments were transported westward and deposited.

INTRODUCTION

During study of age relations in eastern White Pine County, Nev., samples of Precambrian and Cambrian quartzite selected for their contents of metamorphic mica were analyzed chemically and found to be almost devoid of CaO, even though their average SiO_2 content is less than 90 percent. The Na_2O contents of these quartzites also are low, and the average K_2O:Na_2O ratio is 20:1. The purpose of this report is to describe the chemistry and mineralogy of 2 samples of Precambrian quartzite and 16 samples of Precambrian and Cambrian Prospect Mountain Quartzite and to comment on the provenance of the original sediments.

Barium values were determined according to the X-ray fluorescence method described by Lee and Doering (1974, p. 671). An X-ray emission spectrometer was used to measure rubidium and strontium values. The unknown sample net counts were compared to those of standard samples having similar rubidium, strontium, and major-element concentrations. Mass absorption effects were corrected by measuring the Compton scattering peak. The standard samples were analyzed for rubidium and strontium on a mass spectrometer using the stable isotope dilution method, which has an uncertainty of 1.5 percent at the 95-percent confidence level. The values reported for rubidium and strontium (table 1) have an uncertainty of 3.0 percent at the 95-percent confidence level. The Rb:Sr ratios reported are correct to 2.3 percent with 95-percent confidence, because mass absorption effects are canceled.

Semiquantitative spectrographic results are based on their identity with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12 percent, and so forth; and the results are reported arbitrarily as midpoints of these brackets, 1.0, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1 percent, respectively. The precision of a reported value is approximately one bracket at 68-percent or two brackets at 95-percent confidence.

CHEMISTRY AND MINERALOGY OF THE QUARTZITES

The quartzites described were derived from Precambrian crystalline and sedimentary rocks exposed on the craton to the east (Stewart and Poole, 1974), and deposited as shelf sediments in the Cordilleran miogeosyncline during late Precambrian and Early Cambrian time. By early Triassic time a total of from 10,000 to 13,000 m of strata was deposited in the Cordilleran miogeosyncline (Hose and Blake, 1976, p. 3), resulting in deep burial and some static metamorphism of the Cambrian and older sediments. During Mesozoic and (or) Tertiary time some of the clastic sediments of late Precambrian and Early Cambrian age were also subjected to a dynamic metamorphism, resulting from tectonic overpressures related to movement along the regional thrust faults. Finally, some of these quartzites may have been subjected to thermal metamorphism related to the intrusion of the Mesozoic and Tertiary rocks exposed in the area of the sample sites (fig. 8). (See the map of Hose and Blake, 1976.)

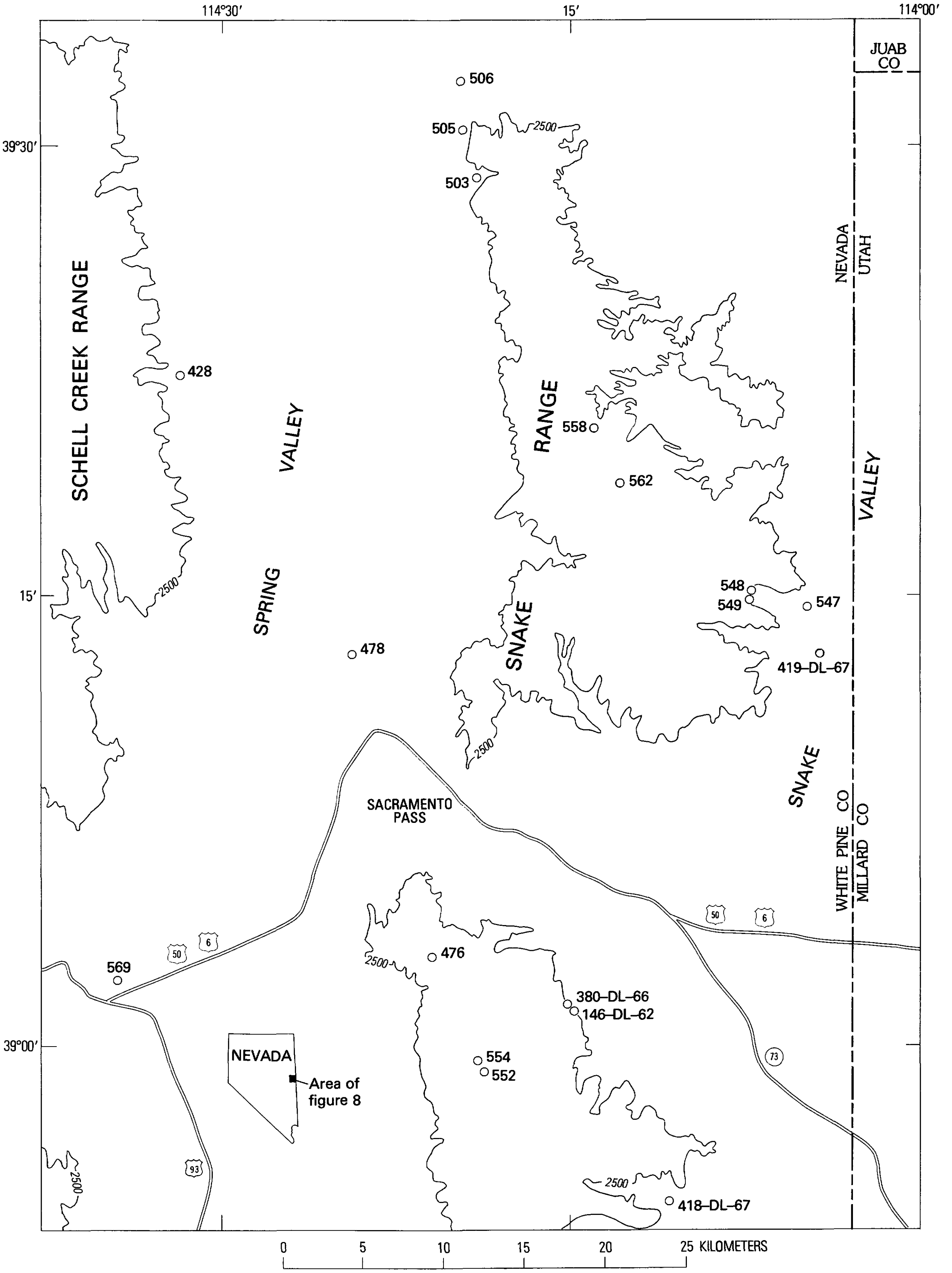

FIGURE 8.—Localities of quartzite samples analyzed. Precise latitudes and longitudes of localities listed in table 5. Base from U.S. Geological Survey 1:250,000 Ely, Nevada, Utah (1956, rev. 1971).

The nature of the metamorphism affecting each of these quartzites still is being studied, but apparently the metamorphism was essentially isochemical, except for depletion of pore fluids, for no evidence of metasomatism exists either in the field or in thin section. Thus the analyses (table 5) probably are representative of the chemistry of the original sediments. Petrographic data are summarized in table 6.

As a group these quartzites are remarkable for their very minor contents of CaO, especially when viewed in relation to the amounts of SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, K_2O, and TiO_2 present. The difficulties encountered in determining very small amounts of CaO by means by gravimetric analysis were discussed by Peck (1964, p. 34, 35), and he stated: "A better alternative, if calcium must be determined, is to make a spectrographic analysis on a portion of the sample." We have therefore included in table 5 the spectrographically determined values of Ca. These (semiquantitative) results confirm the dearth of CaO in these quartzites. Spectrographic values for Ca range from 0.015 to 0.05 percent ($\cong$0.02–0.07 percent CaO) for the 12 quartzites that were shown to be devoid of CaO by gravimetric analysis.

The literature contains other examples of quartzites with such low contents of CaO (for example, Pettijohn, 1963, table 2; Ketner, 1966, table 3), but they are orthoquartzites, very mature sands consisting almost entirely of detrital quartz cemented with silica and containing only minor amounts of all oxides other than silica.

The quartzites in table 5 also contain only minor amounts of Na_2O, and their average K_2O:Na_2O ratio exceeds 20:1. Such a high K_2O:Na_2O ratio is unusual in clastic sedimentary rocks, except for some arkoses and argillites. (See Pettijohn, 1963, figs. 2, 3.)

Considering the minor amounts of CaO and large amounts of K_2O present in these quartzites, analytical results for Sr, Rb, and Ba (table 5) are about what would be expected. Sr^{2+} substitutes for Ca^{2+} in rock-forming minerals, and these quartzites contain only about 4–84 ppm Sr. On the other hand Rb^+ and Ba^{2+} substitute for K^+, and these quartzites contain about 16–258 ppm Rb and 133–1757 ppm Ba. Excepting the two samples of Precambrian quartzite (428 and 476), the Rb and Ba values (table 5) plot (not shown) near a line representing a Ba:Rb ratio of about 5; comparative data are rare in the literature. The semiquantitative values for the various trace elements (table 5) generally conform to the ranges reported for sandstones by Pettijohn (1963, table 10).

The modal analyses listed in table 5 and the data summarized in table 6 show that the original sediments were sands with various amounts of admixed argillaceous materials. The degree of mineralogical maturity of the detrital grains varies, but plagioclase is either absent or present in only minor amounts, as shown by both the chemical and modal analyses listed in table 5. Some of these assemblages contain appreciable amounts of potassium feldspar, whereas others are composed almost entirely of quartz. The detrital grains generally show a low degree of textural maturity. Samples in which size and shape are still apparent are composed of poorly sorted and poorly rounded grains that have suffered relatively little attrition during transport and deposition.

The mineralogy of the argillaceous materials present in the original sediments is a matter of conjecture, for these materials have crystallized to metamorphic micas. Stewart (1970, p. 24, 25) reported the presence of muscovite, chlorite, "mica clay," potassium feldspar, and quartz in many upper Precambrian and Lower Cambrian pelitic rocks of the southern Great Basin. Harrison and Grimes (1970, p. O13) reported illite-sericite, chlorite, potassium feldspar, and quartz in argillitic rocks of the Belt Supergroup in northwestern Montana that date from a period of sedimentation about 1,100 m.y. ago. It is possible that the argillaceous materials of interest in the present study were composed mainly of chlorite, micas, illite, quartz, and potassium feldspar. For most of the rocks included in tables 5 and 6, it also appears that the bulk chemistry of the argillaceous material was appropriate for the crystallization of one or more metamorphic micas under conditions of metamorphism that were essentially isochemical, except for the depletion of pore fluids—for no evidence of metasomatism exists. Some of the chemical relations are shown in figures 9 and 10. In figure 9 we have plotted K_2O+Na_2O versus Al_2O_3 for the quartzites listed in table 5. The points fall between or near the lines indicating the ratios of these oxides present in the metamorphic micas recovered from four of these quartzites (Lee and Van Loenen, 1969). In figure 10, K_2O is plotted against Na_2O for these quartzites, and the ratio of these oxides in the metamorphic micas is indicated. Moreover, the published analyses (Lee and Van Loenen, 1969) of micas from four of these quartzites are generally representative of our unpublished analyses of micas recovered from 14 of the quartzites listed in tables 5 and 6.

PROVENANCE

In brief, we may consider the original miogeosynclinal shelf sediments as composed of various proportions of two sedimentary rock types: (1) sandstone with a fair degree of mineralogical maturity but a rather low degree of textural maturity, not nearly as well sorted and well rounded as the Ordovician quartz-

TABLE 5.—*Analytical data for quartzites*

[Chemical analyses of samples 552, 554, 558, and 562 by S. Botts, using single solution procedure described by Shapiro Rb, Sr, and Ba analyses by W. P. Doering, using methods described in text. Semiquantitative spectrographic analyses by methods described by Lee and Van Loenen (1971, p. 10,11). Leaders (---), not applicable or not determined. ND, Precambrian and are Cambrian prospect mountain quartzite. Muscovite and biotite are metamorphic in these rocks]

Sample Lat N. Long W.	146-DL-62 39°01'14" 114°15'05"	380-DL-66 39°01'20" 114°16'11"	418-DL-67 38°54'48" 114°10'50"	419-DL-67 39°13'05" 114°04'15"	428 39°22'30" 114°31'25"	[1]476 39°03'02" 114°20'55"	478 39°13'00" 114°24'35"	503 39°29'05" 114°19'10"	505 39°30'30" 114°19'40"
					Chemical analyses (weight percent)				
SiO_2-------	96.53	90.74	85.74	91.14	81.44	57.40	77.08	95.18	80.93
Al_2O_3------	1.30	4.85	6.65	4.55	8.90	23.19	11.71	2.57	10.74
Fe_2O_3------	.55	.72	1.26	.47	1.18	3.27	2.71	.30	.77
FeO--------	.18	.24	.46	.12	2.57	2.10	.40	.18	.85
MgO--------	.09	.23	.49	.07	.57	1.68	.67	.10	.39
CaO--------	.00	.00	.02	.00	.09	.08	.14	.02	.00
Na_2O-------	.08	.08	.17	.17	.12	.32	.08	.04	.12
K_2O--------	.41	2.25	3.62	2.78	2.84	6.60	4.35	.92	4.44
$H_2O(+)$-----	.14	.47	.60	.24	1.31	3.72	1.58	.21	1.01
$H_2O(-)$-----	.02	.03	.02	.02	.05	.13	.05	.02	.04
TiO_2-------	.45	.10	.65	.06	.61	.85	.79	.10	.16
P_2O_5-------	.02	.01	.07	.03	.09	.13	.01	.01	.03
MnO--------	.00	.01	.01	.02	.01	.07	.01	.00	.01
CO_2--------	.01	.00	.01	.01	.01	.02	.12	.02	.02
Cl---------	.00	.00	.00	.00	.01	.00	.00	.00	.00
F----------	.02	.01	.02	.01	.06	.07	.03	.01	.12
Subtotal---	99.80	99.74	99.79	99.69	99.86	99.63	99.73	99.68	99.63
Less O-----	.01	.00	.01	.00	.03	.03	.01	.00	.05
Total------	99.79	99.74	99.78	99.69	99.83	99.60	99.72	99.68	99.58
					Quantitative X-ray fluorescence analyses (parts per million)				
Rb---------	15.8	53.2	113	-----	112	258	141	34.7	178
Sr---------	4.5	14.4	28.9	-----	15.4	83.5	7.6	9.5	30.8
Ba---------	133	421	465	-----	1757	562	499	279	972
Rb/Sr------	3.49	3.70	3.92	-----	7.27	3.09	18.58	3.64	5.80
					Semiquantitative spectrographic analyses (weight percent)				
B----------	0	0	0	0	0.005	0.05	0.003	0.002	0.002
Be---------	0	0	0	0	.00015	.0005	.0003	0	.0003
Ca---------	.03	.015	.05	.03	.15	.1	.15	.03	.03
Ce---------	0	0	0	0	<.02	<.02	<.02	0	0
Co---------	0	.0005	.0005	.0003	.0007	.003	.001	.0003	.0005
Cr---------	.0003	.0015	.001	.0003	.003	.01	.003	.0015	.002
Cu---------	.0005	.0005	.010	.0003	.0003	.003	.001	.0003	.0003
Ga---------	0	.0007	.001	.0007	.0015	.003	.0015	0	.0015
La---------	0	0	0	0	<.005	.007	<.005	0	0
Mo---------	.0005	0	0	0	0	.0003	0	0	0
Nb---------	0	0	0	0	.002	.002	.0015	.0015	.0015
Ni---------	0	.0007	.001	.0005	.002	.007	.002	0	.0007
Pb---------	0	0	.0015	0	.0015	.0015	0	0	.001
Sc---------	0	0	.0005	0	.0007	.002	.001	0	.0005
V----------	.001	0	.007	0	.007	.015	.007	.0007	.002
Y----------	.001	0	.0015	0	.0015	.003	.0015	.0015	.001
Yb---------	.0002	0	.003	0	.0002	.005	.0002	.0002	.0001
Zr---------	.05	.007	.07	.007	.02	.03	.03	.007	.01
					X-ray modal analyses (weight percent)				
Quartz-----	95	89	72	79	69	20	70	89	69
K-spar-----	<1	4	13	15	ND	ND	4	ND	5
Plagioclase	ND	<1	ND	ND	2	3	<1	ND	<1
Muscovite--	4	7	13	6	21	70	26	11	25
Biotite----	<1	ND	2	ND	8	ND	ND	ND	<1

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[1] Sample 476 contains chlorite and illite(?).

[2] Sample 558 contains about 1 percent garnet.

from eastern White Pine County, Nevada

(1967). All other chemical analyses by E. L. Munson Brandt by methods described by Peck (1964). Quantitative by L. A. Bradley; general limitations of method described in text. X-ray modal analyses by R. E. Van Loenen, detected. <, less than amount shown. Samples 428 and 476 are Precambrian in age; all other samples are

506 39°32'55" 114°19'45"	547 39°14'35" 114°04'50"	548 39°15'15" 114°07'15"	549 39°14'55" 114°07'10"	552 38°59'09" 114°18'50"	554 38°59'35" 114°19'13"	[2]558 39°20'35" 114°14'05"	562 39°18'45" 114°13'00"	569 39°02'22" 114°34'09"
Chemical analyses (weight percent)--Continued								
94.98	91.88	92.74	86.08	89.5	89.4	95.4	94.0	79.83
2.48	3.78	3.57	5.97	5.3	5.5	1.2	2.6	9.99
.35	1.84	1.38	.82	1.0	.55	.70	.31	1.83
.34	.18	.18	2.72	.08	.16	.40	.12	.41
.24	.13	.10	1.37	.19	.16	.22	.06	.55
.00	.00	.00	.00	.03	.00	.00	.00	.00
.01	.03	.03	.27	.31	.12	.00	.09	.11
.81	1.32	1.21	1.44	2.6	2.3	.31	1.1	5.10
.12	.41	.29	.69	.56	.86	.67	.54	1.04
.03	.02	.02	.04	.04	.01	.00	.00	.03
.13	.10	.10	.31	.29	.06	.11	.17	.74
.02	.02	.03	.03	.04	.02	.03	.02	.04
.01	.01	.01	.04	.02	.01	.04	.02	.01
.03	.02	.01	.02	.01	.02	.02	.01	.05
.00	.01	.00	.00	.00	.00	.01	.00	.00
.05	.01	.01	.03	.01	.01	.01	.01	.02
99.60	99.76	99.68	99.83	------	------	------	------	99.73
.02	.00	.00	.01	------	------	------	------	.01
99.58	99.76	99.68	99.82	100	99	99	99	99.72
Quantitative X-ray fluorescence analyses (parts per million)--Continued								
40.5	44.8	39.0	75.1	------	88.3	19.4	32.9	131
11.4	9.0	3.7	36.5	------	24.8	3.9	56.1	41.4
189	221	187	177	------	620	52	465	695
3.55	5.00	10.49	2.06	------	3.56	5.02	.59	3.17
Semiquantitative spectrographic analyses (weight percent)--Continued								
0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003
.0003	0	0	0	0	0	0	0	.0003
.05	.03	.03	.05	.02	.015	.05	.03	.05
0	0	0	<.02	<.02	0	<.02	<.02	0
.0005	0	.0003	.001	.0003	.0003	.0003	0	.0005
.0003	.0007	.0005	.002	.0007	.0002	.0003	.0005	.0015
.0003	.0003	.0001	.003	.0003	.0003	.0015	.0001	.0001
.0005	.0007	.0007	.0007	.0007	.0007	0	0	.0010
0	0	0	<.005	0	0	.0030	0	.0030
0	0	0	0	0	0	0	0	0
.001	.001	.001	.0015	.001	.001	.001	.001	.0020
.0007	.0005	.0005	.0015	.0005	.0005	.0005	.0005	.001
0	0	0	0	.0015	.001	0	.001	.001
0	0	0	.0007	0	0	0	0	.0007
.0007	.0007	.0007	.003	.0015	.0007	.0007	.0007	.003
.001	.001	.001	.0015	.0015	0	.0015	0	.002
.0001	.0001	.0001	.0002	.0002	.0001	.0001	.0001	.0003
.007	.007	.01	.015	.015	.007	.02	.01	.05
X-ray modal analyses (weight percent)--Continued								
90	89	88	82	78	79	95	91	63
ND	<1	ND	ND	15	10	ND	3	10
<1	<1	ND	ND	3	<1	ND	ND	<1
9	10	12	10	2	10	2	6	27
<1	ND	ND	8	2	ND	2	ND	ND

TABLE 6.—*Petrographic data for quartzites from eastern White Pine County, Nevada*

Sample Number	Original sediment	Present rock
[1]146-DL-62	Quartz sandstone with about 4 percent argillaceous cement. Quartz grains subangular to subrounded, with grain size 0.2-0.5 mm.	Light-gray massive quartzite.
[1]380-DL-66	Quartz sandstone with about 4 percent detrital potassium feldspar and 7 percent argillaceous cement. Quartz, potassium feldspar grains subangular and poorly sorted, with grain size 0.06-0.5 mm.	Do.
[1]418-DL-67	Argillaceous quartz, potassium feldspar sandstone. Detrital grains subangular to subrounded and poorly sorted, with grain size 0.03-0.4 mm.	Thin-bedded muscovite quartzite.
[1]419-DL-67	Quartz, potassium feldspar sandstone with argillaceous cement. Original grains obscured by a pronounced directional element and sutured contacts.	Gray quartzitic flagstone.
[2]428	Argillaceous quartz sandstone. Poorly sorted subangular quartz grains 0.05-1.0 mm in size.	Dark-gray schistose quartzite.
[2]476	Mudstone with chert fragments less than 1.0 mm in size.	Greenish-gray phyllite.
478	Argillaceous quartz, potassium feldspar sandstone. Quartz partly recrystallized, but original grains, still visible, subangular to subrounded and 0.05-1.0 mm in size.	Thin-bedded muscovite quartzite.
503	Argillaceous quartz sandstone. Quartz completely recrystallized. Sutured contacts between grains. Original grains obscured.	Coarsely crystalline quartzite.
505	Argillaceous quartz, potassium feldspar sandstone. Original quartz grains obscured during complete recrystallization.	Schistose quartzite.
506	Argillaceous quartz sandstone. Quartz completely recrystallized, with sutured contacts between grains. Original grains obscured.	Coarsely crystalline quartzite.
547	Argillaceous quartz sandstone. Original grains obscured by complete recrystallization and development of pronounced directional element.	Do.
548	------------ do ------------	Do.
549	------------ do ------------	Schistose quartzite.
552	Quartz, potassium feldspar sandstone with argillite cement. Quartz, potassium feldspar grains subangular to subrounded and 0.05-0.4 mm in size.	Gray quartzite.
554	Argillaceous quartz, potassium feldspar sandstone. Quartz, potassium feldspar grains subangular to subrounded and 0.05-1.0 mm in size.	Light-gray quartzite.
558	Quartz sandstone with argillaceous cement. Original grains obscured by complete recrystallization and development of pronounced directional element.	Gray quartzite.
562	------------ do ------------	Gray quartzitic flagstone.
569	Argillaceous quartz, potassium feldspar sandstone. Quartz, potassium feldspar grains subangular to subrounded and 0.05-0.4 mm in size.	Schistose quartzite.

[1] Chemistry of constituent metamorphic micas in Lee and Van Loenen (1969). Radiometric K-Ar ages of micas presented by Lee and others (1970). Radiometric K-Ar ages of constituent micas from all other quartzites presented in Chapter C, this report.

[2] Samples 428 and 476 are Precambrian in age; all others are Precambrian and Cambrian Prospect Mountain Quartzite.

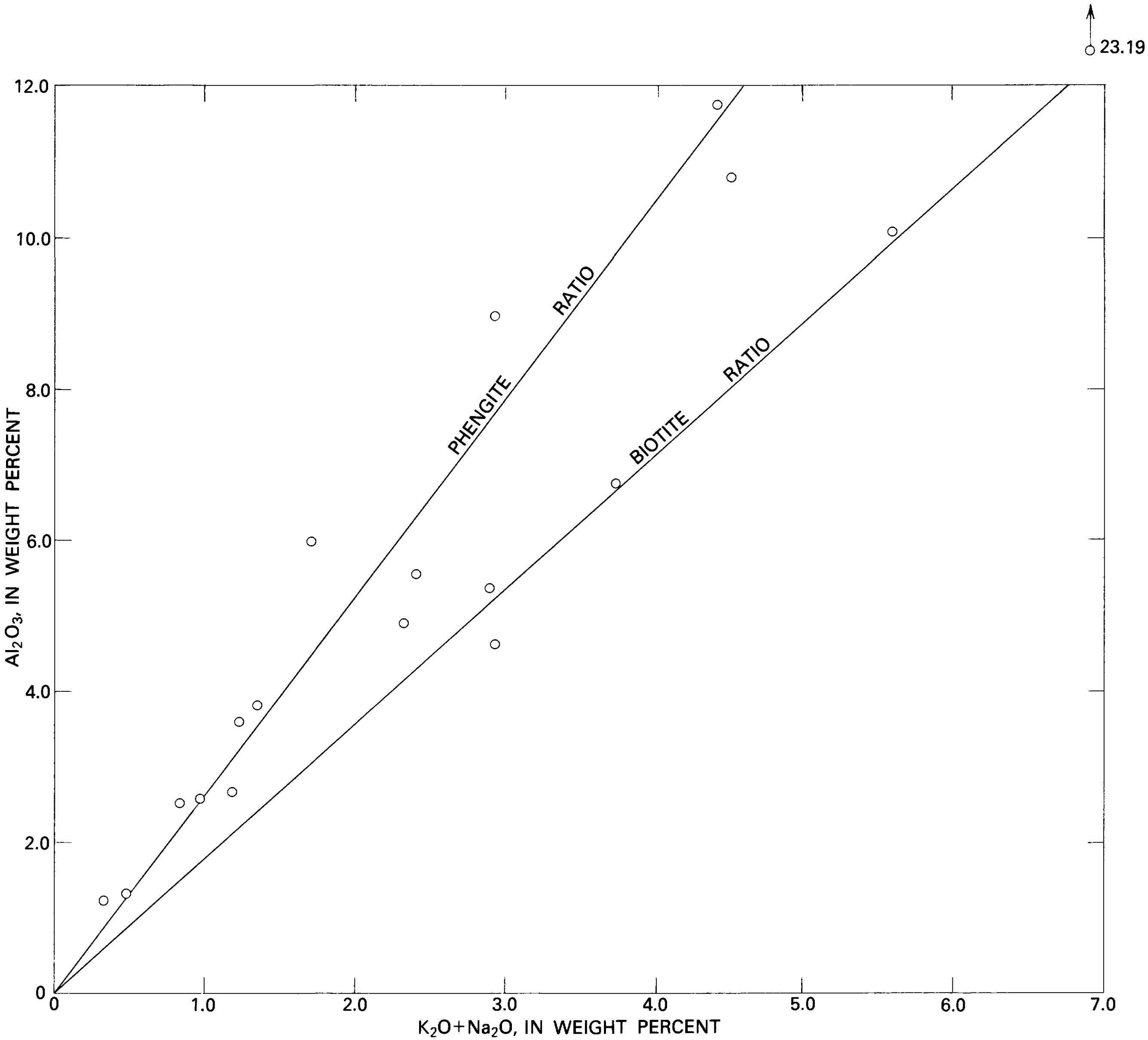

FIGURE 9.—Relation between K_2O+Na_2O and Al_2O_3 contents of quartzites listed in table 5. Phengite and biotite ratios indicated based on analyses in Lee and Van Loenen (1969). Much or all of the K_2O and Na_2O present in each rock contained in metamorphic mica that crystallized from argillaceous material.

ites of the area described by Ketner (1966, 1968); and (2) argillaceous material, possibly composed mainly of chlorite, micas, illite, quartz, and potassium feldspar.

Stewart (1970) showed that these sediments were derived from Precambrian terrane exposed on the craton to the east. The character of these sediments suggests that they may have been derived from a deeply weathered crystalline mass composed mainly of quartz, weathered potassium feldspar, and clay minerals. Stewart and Poole (1974, fig. 4) showed that this type of terrane was available as source material in a pregeosynclinal exposure of metamorphic rocks about 300 km to the east. The inferred paleoequator passed very near the area of study during Cambrian time (Smith and others, 1973, fig. 13), indicating that the sediments were at least transported and deposited in a tropical climate, under conditions conducive to the rapid destruction of ferromagnesian minerals and plagioclase.

Other data suggest that the original miogeosynclinal shelf sediments could have been derived from the terrane just described. During our study of age relations in eastern White Pine County, Nev., we have obtained K-Ar radiometric ages for five clastic micas recovered from unmetamorphosed Lower Cambrian detrital sediments. Four of these samples were collected from the

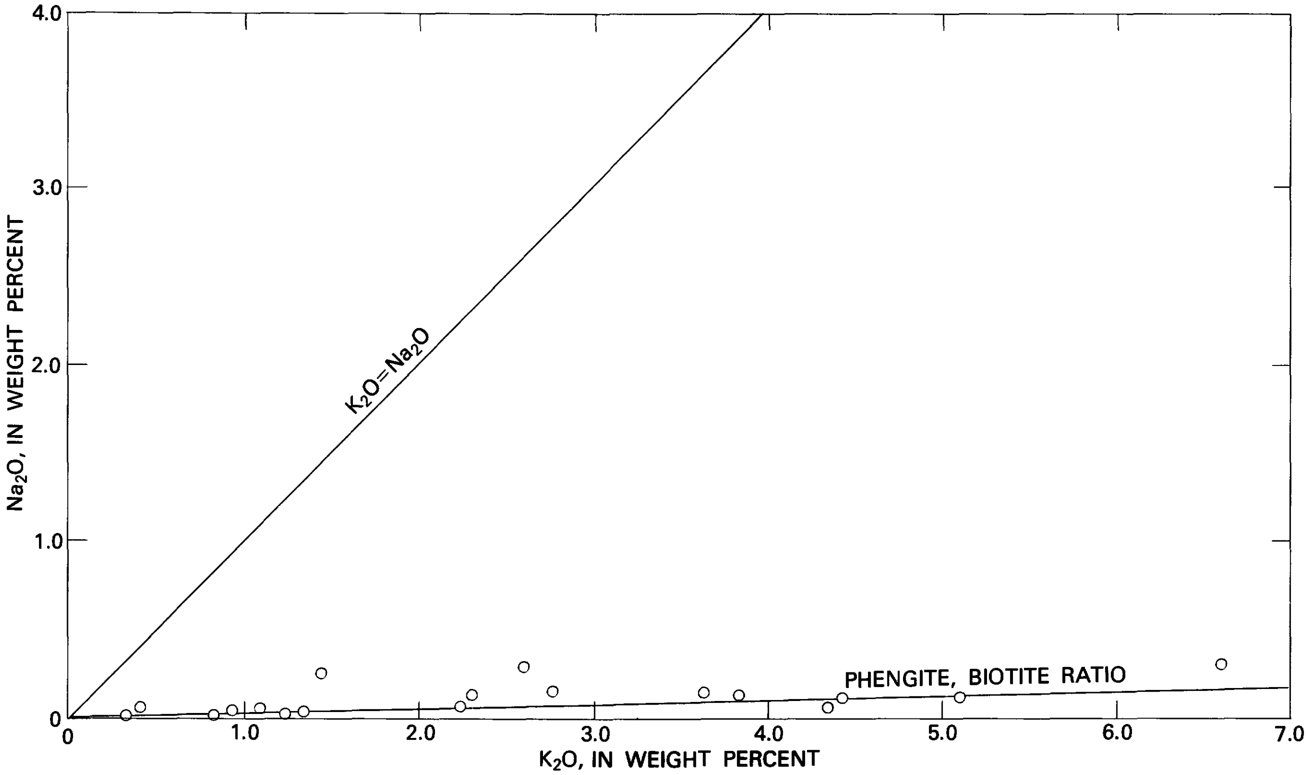

FIGURE 10.—Relation between K_2O and Na_2O contents of quartzites listed in table 5. Phengite, biotite ratio based on analyses in Lee and Van Loenen (1969). Much or all of the K_2O and Na_2O present in each rock is contained in metamorphic mica that crystallized from argillaceous material. Compare Pettijohn (1963, figs. 2, 3).

Schell Creek Range–Duck Creek Range area, within 20 km west of the area of figure 8, and one was collected about 50 km east of the area of figure 8. All five of these clastic micas give K-Ar age results (chapter C, this report) within the range 1,182–1,242 m.y.

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A Radiometric Age Study of Mesozoic-Cenozoic Metamorphism in Eastern White Pine County, Nevada, and Nearby Utah

By DONALD E. LEE, RICHARD F. MARVIN, *and*
HARALD H. MEHNERT

GEOLOGIC STUDIES IN WHITE PINE COUNTY, NEVADA

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A RADIOMETRIC AGE STUDY OF MESOZOIC-CENOZOIC METAMORPHISM IN EASTERN WHITE PINE COUNTY, NEVADA, AND NEARBY UTAH

By DONALD E. LEE, RICHARD F. MARVIN,
and HARALD H. MEHNERT

ABSTRACT

A total of 58 K-Ar radiometric ages have been determined for igneous, detrital, and metamorphic minerals, mostly from eastern White Pine County, Nev., and nearby Utah. A surprising agreement among results for five detrital muscovites from Lower Cambrian sediments indicate a Precambrian provenance that crystallized at least 1,182-1,242 m.y. ago. It is probably more useful to regard the metamorphism in the area as spotty and diverse, rather than regional, for no area-wide metamorphic event is apparent. Tertiary K-Ar ages determined on micas from Precambrian and Cambrian metasedimentary rocks are generally interpreted to have resulted from loss of argon, caused by thermal stresses related to Tertiary activity along the regional thrust faults. However, the time of original crystallization of any one of these metamorphic micas remains an important and unanswered question. Where an intrusive is exposed near the level of a regional thrust fault, K-Ar ages for the igneous micas might reflect postcrystallization movement along the thrust fault. A working hypothesis as to the history of plutons exposed in and near the area is proposed.

INTRODUCTION

A previous study (Lee and others, 1970) presented more than 70 radiometric ages for samples of Jurassic and Tertiary igneous rocks and upper Precambrian to Lower Cambrian metasedimentary rocks from the southern and central Snake Range of eastern Nevada. Potassium-argon ages determined on micas recovered from the Jurassic igneous terrane were found to range from 17.4 to 159 m.y.; ages determined on micas from the Precambrian and Cambrian metasedimentary rocks ranged from 22.7 to 264 m.y. (Ages quoted from the previous study are recalculated using the new decay constants listed in table 7.) The main conclusion reached in the previous study was that the lower K-Ar ages result from loss of argon due to stress related to Tertiary activity along the Snake Range décollement.

The present study reports 58 new K-Ar ages for metamorphic, detrital, and igneous minerals, mostly from eastern White Pine County, Nev. Sampling for this study was designed to meet two closely related objectives:

1. To test the possibility that the main conclusion reached in the previous study also applies to parts of the region other than the southern and central Snake Range. In other words, has there been a modification of K-Ar ages near the level of thrusting in some of the other ranges of eastern White Pine County?
2. To investigate further the metamorphism apparent in parts of eastern White Pine County. Is it regional, as proposed by Misch and Hazzard (1962), and referred to by Armstrong and Hansen (1966), Nelson (1966), and Drewes (1967), or is it rather irregular and spotty, related in part to tectonic elements such as the Snake Range décollement and other thrust faults?

In conjunction with the age investigation, we have obtained chemical analyses of highly purified fractions of 16 of the metamorphic micas dated by K-Ar. A comprehensive discussion of these analyses is beyond the scope of this report, but we can state that they are generally similar to analyses of four phengitic muscovites and one biotite listed by Lee and Van Loenen (1969), who also described the methods of mineral purification used in the present study.

Standard techniques for potassium and argon analysis were used (Evernden and Curtis, 1965). Analytical error for individual K-Ar ages was evaluated in the manner described by Cox and Dalrymple (1967). Throughout this report a given sample number refers to the whole rock and to the mineral or minerals recovered from that rock. Potassium-argon ages are listed in table 7.

POTASSIUM-ARGON AGES

HOUSE RANGE, UTAH

Before proceeding to an area-by-area discussion of the geochronology, consider the age determined for a muscovite recovered from a sample of Lower Cambrian

TABLE 7.—*Potassium-argon ages of selected minerals from the northeastern part of the Basin and Range province*

[Analyzed by R. F. Marvin, H. H. Mehnert, Viola Merritt, W. T. Henderson, Lois Schlocker, and R. E. Zartman, U.S. Geological Survey.
Constants: $^{40}K\lambda_{\varepsilon} = 0.581 \times 10^{-10}\ yr^{-1}$; $\lambda_{\beta} = 4.962 \times 10^{-10}\ yr^{-1}$.
Atomic abundance: $^{40}K = 1.167 \times 10^{-4}$. ^{40}Ar = radiogenic isotope, columns 7 and 9]

Sample Number	Location		Rock type[1]	Mineral	Mesh size	K_2O (Weight percent)	^{40}Ar (10^{-10} moles/g)	Radiogenic ^{40}Ar (percent)	$^{40}Ar/^{40}K$	Age (m.y.) ±2σ
	Lat N. ° ′ ″	Long W. ° ′ ″								
				Western House Range, Millard County, Utah						
471	39 14 55	113 25 40	Єp	Muscovite	-100, +140	8.78	226.0	98	0.104	1242±50
				Western House Range, Millard County, Utah						
471	39 14 55	113 25 40	Єp	Muscovite	-100, +140	8.78	226.0	98	0.104	1242±50
				Northern Snake Range, Nevada						
478	39 13 00	114 24 35	pЄЄpm	Muscovite	-150	[2]10.99	14.16	95	0.00520	87.4±2.2
501	39 29 00	114 18 10	Єp	---do	-100	[2]10.79	8.056	92	.00301	51.1±1.4
	39 29 00	114 18 10	---do	Biotite	-100	[2]9.41	5.940	82	.00255	43.3±1.6
503	39 29 05	114 19 10	pЄЄpm	Muscovite	-60, +100	[2]10.86	9.062	90	.00337	57.1±1.7
505	39 30 30	114 19 40	---do	---do	-100	[2]11.03	8.712	63	.00319	54.1±1.7
506	39 32 55	114 19 45	---do	---do	-100	[2]11.02	8.895	90	.00326	55.2±1.5
	39 32 55	114 19 45	---do	Biotite	-100	7.42	5.440	90	.00296	50.2±2.1
547	39 14 35	114 04 50	---do	Muscovite	-30, +60	10.54	3.177	67	.00122	20.8±0.5
548	39 15 15	114 07 15	---do	---do	-60, +100	[2]10.80	3.545	71	.00132	22.7±0.5
	39 15 15	114 07 15	---do	Muscovite[3]	-60, +100	[2]10.80	3.522	75	.00132	22.5±0.5
549	39 14 55	114 07 10	---do	Muscovite[4]	-60, +140	7.18	3.177	48	.00179	30.5±1.0
	39 14 55	114 07 10	---do	Muscovite	-60, +140	[2]7.12	3.142	35	.00178	30.4±1.0
	39 14 55	114 07 10	---do	Biotite	-60, +140	[2]9.07	6.234	86	.00277	47.1±1.6
558	39 20 35	114 14 05	Єp	Muscovite	-60, +140	9.99	5.924	83	.00239	40.7±1.4
560	39 19 05	114 12 00	Sheared intrusive	Biotite	-60, +140	8.73	3.895	84	.00180	30.7±1.0
561	39 19 00	114 12 35	pЄЄpm	Muscovite	-60, +100	[2]10.69	5.731	74	.00216	36.9±0.8
562	39 18 45	114 13 00	---do	---do	-60, +140	10.56	5.602	68	.00214	36.5±0.8
				Kern Mountains, Nevada and Utah						
RM-1	39 44 00	114 14 00	Intrusive	Muscovite	-10, +30	10.07	10.22	69	0.00410	69.2±1.6
244	39 35 55	114 07 55	---do	---do	-100	[2]10.78	8.012	56	.00300	50.9±1.8
245	39 35 55	114 07 55	Aplite dike	---do	-100	[2]10.79	7.545	45	.00282	47.9±2.0
564	39 38 05	114 03 35	Cataclastic intrusive	Muscovite + quartz	-100	6.31	2.264	83	.00145	24.7±1.1
566	39 38 15	114 03 05	Mafic sill in marble	Biotite + quartz	-200	6.63	2.754	56	.00168	28.6±2.5
	39 38 15	114 03 05	---do	Amphibole[5]	-200	.553	.2752	61	.00201	34.3±1.1
567	39 38 30	114 02 30	Cataclastic intrusive	Biotite + quartz	-60, +100	8.22	3.040	82	.00149	25.5±0.9
				Precambrian rocks, southern Snake Range, Nevada						
472	39 02 20	114 20 25	pЄpw	Muscovite + quartz	-200	7.62	12.21	94	0.00647	108±4
473	39 02 20	114 20 25	---do	---do	-100, +200	9.16	65.26	93	.0287	437±16
476	39 03 02	114 20 55	pЄstr	---do	-100	8.56	13.27	91	.00626	105±4
499	39 03 05	114 20 45	---do	---do	-100	8.39	23.24	97	.0112	183±6
536	39 08 35	114 22 00	pЄstr(?)	---do	-230	6.92	7.503	87	.00437	73.8±2.4
				Wheeler Peak area, southern Snake Range, Nevada						
552	38 59 09	114 18 50	pЄЄpm	Muscovite + quartz	-100	5.82	28.01	96	0.0194	307±7
554	38 59 35	114 19 13	---do	---do	-100	9.00	13.22	92	.00593	99.3±3.3
555	39 00 05	114 19 15	---do	---do	-100	9.91	20.97	97	.00854	141±5

			Mount Wheeler mine area, southern Snake Range, Nevada							
2-MW-60	38 53 52	114 19 12	Vein gangue----------	Sericite-----------	-100	8.48	25.30	98	0.0120	196±7
			Lexington Creek area, southern Snake Range, Nevada							
378	38 51 29	114 13 04	Intrusive-------------	Muscovite----------	-100, +200	10.72	13.67	88	0.00514	86.3±1.9
531	38 51 12	114 12 05	---do-----------------	---do--------------	-100, +200	10.47	12.67	89	.00488	82.2±1.8
532	38 51 40	114 10 56	---do-----------------	---do--------------	-100, +200	10.32	11.83	89	.00463	77.9±1.8
			McCoy Creek area, Schell Creek Range, Nevada							
427	39 22 30	114 31 25	p€--------------------	Muscovite----------	-100, +200	[2]10.50	9.792	88	0.00376	63.6±2.4
428	39 22 30	114 31 25	---do-----------------	Biotite------------	-100, +200	8.51	5.680	79	.00269	45.8±1.9
	39 22 30	114 31 25	---do-----------------	Muscovite----------	-100	[2]10.36	9.356	85	.00364	61.7±2.3
430	39 22 26	114 31 40	---do-----------------	---do--------------	-80	[2]10.48	13.30	90	.00512	86.1±2.4
435	39 22 21	114 34 08	---do-----------------	Muscovite + quartz--	-100	8.54	90.37	99	.0427	617±22
571	39 21 36	114 35 36	p€€pm-----------------	---do--------------	-60	10.09	241.1	99	.0964	1177±30
572	39 22 25	114 31 58	Amphibolite-----------	Amphibole[5]----------	-200	.332	.4815	61	.00585	98.0±2.9
			Other areas, Schell Creek Range, and Duck Creek Range, Nevada							
368	39 14 00	114 32 13	p€--------------------	Muscovite + quartz--	-100	8.41	11.19	83	0.00537	90.2±3.1
393	39 15 43	114 30 35	Intrusive-------------	Biotite------------	-140	8.72	4.463	84	.00207	35.2±1.2
394	39 15 43	114 30 35	Xenolith--------------	---do--------------	-140	8.45	4.260	86	.00203	34.7±1.2
	39 15 43	114 30 35	---do-----------------	Amphibole----------	-140	1.03	.5356	64	.00210	35.8±0.8
538	39 28 19	114 37 00	€p--------------------	Muscovite + quartz--	-100	9.86	241.5	99	.0969	1199±40
569	39 02 22	114 34 09	p€€pm-----------------	Muscovite----------	-100	[2]10.89	10.68	93	.00396	66.9±1.5
575	39 15 32	114 43 43	---do-----------------	---do--------------	-60	10.41	256.8	98	.0976	1205±29
576	39 15 36	114 44 02	€p--------------------	---do--------------	-100	9.93	238.6	99	.0970	1182±40
			Egan Range, Nevada							
383	39 38 05	114 53 20	Sheared intrusive------	Muscovite + quartz--	-100	10.44	3.807	89	0.00147	25.2±0.7
384	39 37 40	114 52 55	---do-----------------	---do--------------	-100	10.46	5.503	90	.00212	36.2±1.0
386	39 48 20	114 53 25	---do-----------------	---do--------------	-100	10.30	5.218	84	.00204	34.9±1.0
439	39 22 13	114 52 58	p€€pm-----------------	---do--------------	-100	8.12	7.787	84	.00387	65.4±2.4
			Toana Range, Nevada							
511	41 00 55	114 17 30	p€€pm-----------------	Muscovite----------	-100	[2]10.89	11.59	92	0.00430	72.5±2.0
512	41 00 55	114 17 30	---do-----------------	---do--------------	-100	[2]10.85	12.06	93	.00449	75.6±2.1

[1] p€€pm, Precambrian and Cambrian Prospect Mountain Quartzite. €p, Cambrian Pioche Shale. p€pw, unnamed Precambrian unit (pre-Willard Creek Quartzite of Misch and Hazzard (1962)). p€str, Precambrian Strawberry Creek Formation of Misch and Hazzard (1962). p€, late Precambrian McCoy Creek Group of Misch and Hazzard (1962).

[2] Potassium determinations are part of complete mineral analyses by methods described by Peck (1964); Elaine L. Munson Brandt, analyst. Except as noted, each of the other potassium values is an average of two determinations made with a Perkin-Elmer flame photometer, using a lithium internal standard. (Brand names in this report are for illustration purposes only and do not constitute endorsement by the U.S. Geological Survey.)

[3] Subjected to ultrasonic vibration for 1 hour.

[4] Specific gravity less than 2.86.

[5] Potassium determined by mass spectrometry.

Pioche Shale collected on the west flank of the House Range, Millard County, Utah. As shown on the geologic map of southwestern Utah compiled by Hintze (1963), no thrust faults are exposed in the area, although it should be noted that Hose and Danĕs (1973) have shown that the House Range itself should be underlain by a thrust of very large magnitude. No evidence of metamorphism has been seen in the field, and petrographic evidence shows clearly that the dated mica is detrital in the Pioche Shale. The age (1,242 m.y.) of this mica is of more than passing interest, for, as brought out in the discussion to follow, four other detrital micas recovered from Lower Cambrian clastic rocks of eastern White Pine County, Nev., gave similar Precambrian Y ages.

NORTHERN SNAKE RANGE, NEVADA

In the northern Snake Range, erosion has exposed hundreds of square kilometers of Lower Cambrian metasediments which originally were less than a few hundred meters below the sole of the Snake Range dĕcollement. (See the map of Hose and Blake, 1976.) From field, petrographic, and radiometric age evidence described below, we interpret the metamorphism to have resulted from the heat and tectonic overpressures developed during inception of the dĕcollement and from subsequent movements on the dĕcollement.

Sample 478 (fig. 11), Prospect Mountain Quartzite, was originally a poorly sorted impure sandstone with quartz grains less than 1 mm in diameter. The original argillaceous impurities have recrystallized into a fine-grained metamorphic muscovite, now surrounding detrital quartz grains and comprising about 27 percent of the rock. The lower plate appears to have been eroded to a depth of about 200 m at the sample site. Muscovite 478 gave a Late Cretaceous age of 87.4 m.y., appreciably older than any of the other samples from the northern Snake Range discussed below or included in the study of Lee and others (1970).

Samples 501, 503, 505, and 506 were collected from lower plate rocks on the northwestern flank of the northern Snake Range (fig. 11). Sample 501 is Pioche Shale; the others are Prospect Mountain Quartzite. Nelson (1966, p. 922, and map, p. 924, 925) noted the presence of staurolite in these rocks. In the area of these samples (fig. 11), which covers a horizontal distance of about 6 km, we did not detect any staurolite, either in the field or during petrographic and mineral separation work in the laboratory.

The metamorphic micas in these samples are so abundant and well crystallized that it was easy to recover clean concentrates for analyses. The quartz grains in samples 503, 505, and 506 (Prospect Mountain Quartzite) show evidence of pronounced strain and recrystallization, with sutured contacts except where shielded by mica. The orientation of the micas is determined mainly by the outlines of the original detrital quartz grains, but in sample 506 a faint directional element is evident in thin section. The four muscovite ages (table 7) all are in the range 51.1–57.1 m.y., whereas biotites 501 and 506 gave ages of 43.3 and 50.2 m.y., respectively. Many studies (for example, Lee and others, 1970) have shown that muscovite is superior to biotite in retaining argon during periods of geothermal stress. We interpret these ages as hybrid, related to heat produced by movement along the thrust.

Samples 547, 548, and 549, all Prospect Mountain Quartzite, were collected from the Hampton Creek drainage on the east side of the range. This is a high-grade metamorphic terrane unique among the areas discussed here. Between sample sites 547 and 548 is abundant development of garnet and staurolite in rocks of appropriate composition. No detailed study of this metamorphism has been made.

Sample 547 is from a relatively undisturbed outcrop of coarsely crystalline quartzite within a mass of contorted quartzite. The rock is about 90 percent quartz and 10 percent muscovite. The muscovite is arranged in thin layers. The quartz has been recrystallized and shows pronounced strain in thin section. Sample 548 is somewhat richer in muscovite than 547, but is otherwise very similar. Sample 549 is a quartz-muscovite-biotite schist. In thin section the rock shows a very strong planar element. The quartz has been recrystallized and shows pronounced strain; sparse amounts of garnet and staurolite have formed.

Muscovite 547 gave an age of 20.8 m.y. During the mineral separation process many of the micas in table 7 were subjected to ultrasonic vibration for a few minutes. To check for possible loss of radiogenic argon during this procedure, muscovite 548 was split into two fractions. One part received no ultrasonic treatment, and the other was subjected to an hour of ultrasonic vibration. The two fractions gave practically identical ages of 22.7 and 22.5 m.y.

As emphasized by Lee and Van Loenen (1969), the metamorphic (phengitic) muscovites recovered from these Lower Cambrian metasediments are homogeneous and fractionate over a very narrow specific gravity range during centrifuging in heavy liquids. Muscovite 549 proved to be an exception, so one fraction lighter and one heavier than specific gravity 2.86 were analyzed. The two fractions gave practically identical ages of 30.4 and 30.5 m.y. Both fractions were very clean; the low K_2O values listed in table 7 result from the fact that this muscovite contains about 38

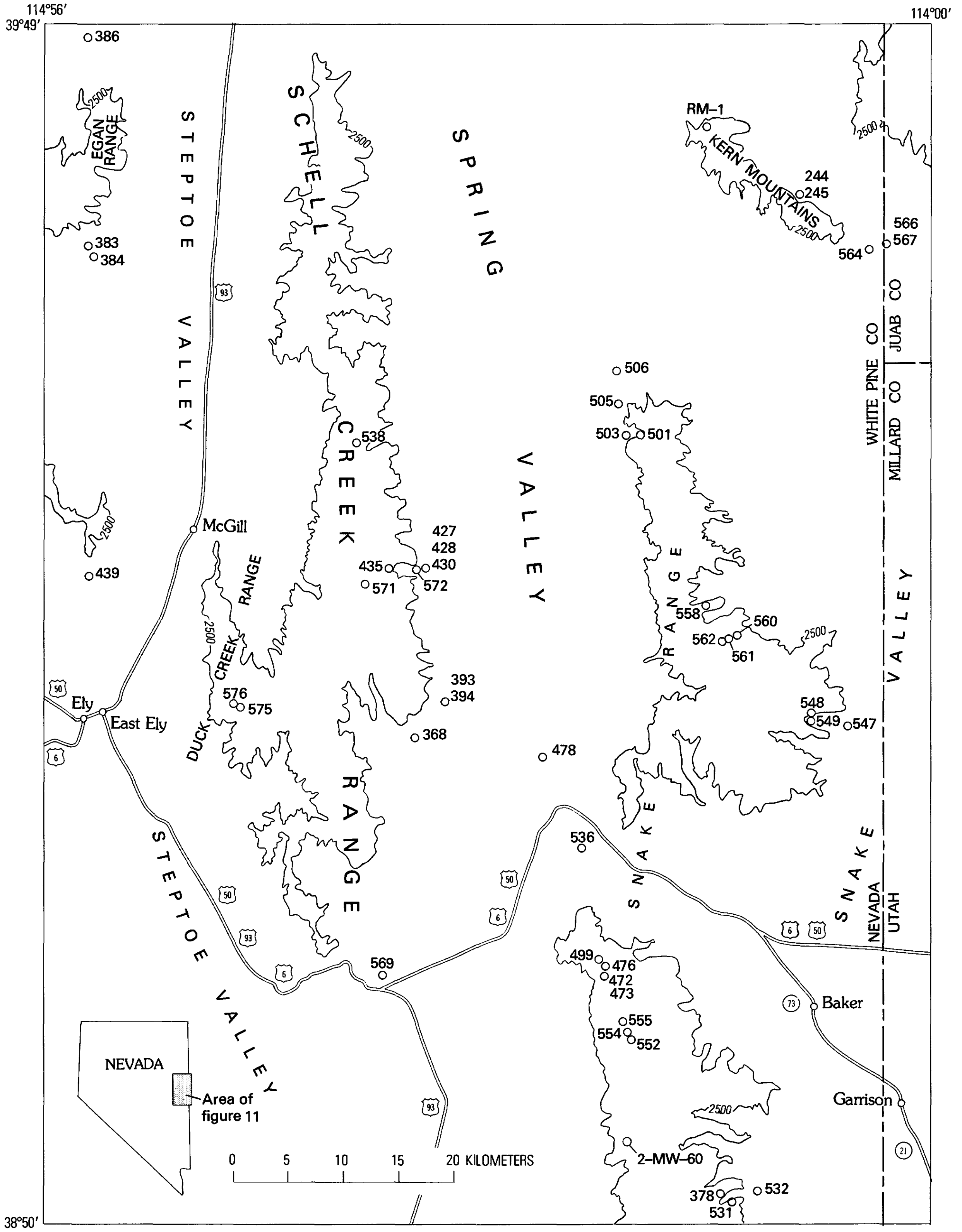

FIGURE 11.—Map of part of eastern Nevada and western Utah, showing sample localities. Sample locality 471 is about 50 km east of the map area, localities 511 and 512 are about 133 km north. The 2500-m contour lines are not shown in the southwestern part of the map area. Base from U.S. Geological Survey 1:250,000 Ely, Nevada, Utah (1956, rev. 1971); Lund, Nevada, Utah (1956, rev. 1970).

percent of the paragonite molecule. Sample 549 is unusual in another respect: The biotite gave an age of 47.1 m.y., much higher than the coexisting (paragonitic) muscovite. As already noted, the opposite relation is normally expected. It is possible that distortion of the muscovite structure due to the presence of the paragonite molecule led to unusually easy diffusion of radiogenic argon when the mica was under thermal stress.

It is difficult to interpret the apparent ages of these micas. They probably indicate Miocene movement on the overlying thrust, possibly complicated and (or) complemented by the presence of a Miocene hot spot.

Sample 558 appears to be from a quartzite horizon within the Pioche Shale; 560 is from a knob of Cretaceous-Tertiary (Hose and Blake, 1976) granodiorite just north of Deadman Creek, and 561 and 562 are Prospect Mountain Quartzite, both collected less than 2 km southwest of 560. Sample sites 560, 561, and 562 probably are not more than a few meters below the sole of the thrust. Sample 558 is from a rather massive quartzite, and samples 561 and 562 are from quartzitic flagstones. Petrographic study shows the quartz to be completely recrystallized and drawn out to express a planar element approximately parallel with the present surface and presumably with the overlying thrust. The micas are alined in the same plane. Sample 561 is about 94 percent quartz and 6 percent muscovite; sample 562 contains slightly less quartz and a few percent potassium feldspar. Sample 558 is more iron rich; it contains metamorphic biotite, and a few scattered grains of garnet and staurolite were detected during mineral separation. Thin-section study of 560 (intrusive) shows incipient cataclasis.

Muscovites 558, 561, and 562 gave ages of 40.7, 36.9, and 36.5 m.y., respectively. Biotite 560 gave 30.7 m.y. The muscovite ages are hybrid, related to heat produced by movement along the thrust and distance below the sole. The biotite age probably also is hybrid. That it indicates the time of emplacement of the pluton is unlikely, for the incipient cataclasis noted above indicates a cooled and completely crystallized magma.

KERN MOUNTAINS, NEVADA AND UTAH

Intrusive rocks crop out over an area of about 130 km^2 in the Kern Mountains of Nevada and Utah. Previous attempts to date these rocks radiometrically have met with frustration (Best and others, 1974, p. 1283). Our data (tables 7, 8) do not resolve the problem, but they do point up some striking similarities between the Kern Mountains and the southern Snake Range, Nevada.

Most of the Kern Mountains intrusive is an unusual two-mica granite, practically identical to the Pole Canyon–Can Young Canyon granitoid rock of the southern Snake Range described by Lee and Van Loenen (1971, p. 5, 38). Muscovite RM-1, from a rock of this type, gave an age of 69.2 m.y.

Samples 244 (two-mica granite) and 245 (aplite) were collected less than 3 m apart. Muscovites 244 and 245 gave K-Ar ages of 50.9 and 47.9 m.y., respectively. Whole-rock rubidium and strontium data for samples 244 and 245 are listed in table 8. A two-point whole-rock isochron (not shown) based on these data gives an apparent age of 71±6 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.719. Such a high initial ratio suggests that the pluton originated from melting of the crust. Best and others (1974) found similarly high initial $^{87}Sr/^{86}Sr$ ratios and postulated a minimum age of 60 m.y. for the granite.

TABLE 8.—*Whole-rock rubidium and strontium data for samples 244 and 245*

[Zell Peterman, U.S. Geological Survey, analyst. Decay constants for ^{87}Rb: $\lambda_\beta = 1.42 \times 10^{-11} yr^{-1}$. Isotope abundance: $^{87}Rb/Rb = 0.283$ g/g]

Sample No.	Rb	Sr_n	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
	(in ppm)			
245	213	14.6	42.1	0.7614
244	123	313	1.14	.7204

Nelson (1966, p. 938) stated: "The rocks in the easternmost part of the Kern Mountain pluton have been subjected to cataclasis and shearing which, as determined from the orientation of the shear planes, is believed to be related to the eastward-directed décollement thrusting . . ." Although in the eastern part of the Kern Mountains the main décollement has been completely eroded away (R. K. Hose, written commun., 1978), the cataclasis described by Nelson is practically identical to that described by Lee and Van Loenen (1971, p. 6, 40) for the Can Young Canyon–Kious Basin area of the southern Snake Range, where it has clearly resulted from late (17–19 m.y., Lee and others, 1970) movement on the Snake Range décollement. Muscovite 564 and biotite 567, recovered from cataclasized Kern Mountains intrusive rocks, gave ages of 24.7 and 25.5 m.y., respectively. Sample 566 was collected from a mafic sill in marble closely associated with cataclastic intrusives. The biotite and amphibole from this rock gave ages of 28.6 and 34.3 m.y., respectively.

The pattern of K-Ar ages listed for the Kern Mountains in table 7 is similar to the pattern found in the intrusive rocks of the southern Snake Range and lends itself to a similar interpretation. The ages (24.7 and 25.5 m.y.) on the cataclastic (eastern) portion of the Kern Mountains intrusive date a late movement on the overlying décollement, which effected the cataclasis. Farther to the west, in undeformed intrusive, where the muscovites were less completely degassed by thermal stresses related to the thrusting, the apparent ages increase to as much as 69.2 m.y. However, in the Kern Mountains there is an additional complication not encountered in the southern Snake Range—the protoclastic border facies described by Best and others (1974). The biotite and muscovite dated (23.3 and 48.2 m.y., respectively) by Armstrong (1970) apparently were collected very near this border facies; these micas probably have been partially degassed by the protoclasis. Two other muscovite K-Ar ages listed by Best and others (1974) are 63.9 and 47.1 m.y.

Best and others (1974) postulated two intrusive events, with the younger being Oligocene in age, about 31 m.y. ago. The 34.3-m.y. age given by amphibole 566 may be related to this younger event. Our data indicate a minimum age of 70 m.y. for the main Kern Mountains intrusive event. A U-Pb age on zircon seems the next likely step. However, if sample 244 is representative of the main intrusive event, zircons will be difficult to obtain, for they are present mainly as tiny acicular inclusions in sparsely distributed apatite (Lee and others, 1973). Pending accumulation of further data, we can only conclude as Best and others (1974, p. 1285) did: "We are only beginning to realize how complex the Mesozoic-Tertiary magmatic and metamorphic history of the hinterland of the Sevier orogenic belt is and to study the rocks in the detail they deserve."

PRECAMBRIAN ROCKS, SOUTHERN SNAKE RANGE, NEVADA

Five samples were collected from the upper Precambrian sequence of the southern Snake Range described by Misch and Hazzard (1962). No high-grade metamorphic minerals such as garnet and staurolite were detected in any of these rocks, either in the field or in the laboratory.

Sample 472 is from the unnamed unit underlying the Willard Creek Quartzite of Misch and Hazzard (1962). This rock was originally a rather clean, poorly sorted sandstone composed of quartz grains less than 3 mm across. The original argillaceous cement has crystallized to a very fine grained muscovite sparsely distributed between the grains of clastic quartz, which now show evidence of strain and some recrystallization. Muscovite 472 furnished an age of 108 m.y.

Sample 473 is a minor variant of the unnamed unit. The rock was originally a very impure sandstone. It is present in outcrop as a massive dark-green chloritic rock with spotty brown stains resulting from altered pyrite. Flakes of clastic mica as much as 2 mm across are visible in hand specimen. Some very fine grained and sparsely distributed metamorphic mica is visible in thin section, but all of this metamorphic mica probably was eliminated by taking only the +200 mesh material for analysis. The clastic mica from this rock gave an age of 437 m.y.

Sample 476 is from a greenish-gray phyllitic interval in the Strawberry Creek Formation of Misch and Hazzard (1962). The original sediment was probably a mudstone containing a few chert fragments less than 1 mm across. As seen in thin section it is now a felt of extremely fine grained metamorphic muscovite laid in quartz and peppered with many tiny tourmaline euhedra that clearly grew in place. Muscovite 476 gave an age of 105 m.y.

Sample 499 also is from the Strawberry Creek Formation. The rock was originally a fairly well sorted sandstone with subangular quartz grains mostly about 0.3 mm across. In thin section the quartz shows evidence of strain and partial recrystallization. The clastic quartz grains are surrounded by a fine-grained metamorphic mica that gave an age of 183 m.y.

Sample 536 was collected just below a thrust surface in Precambrian rocks mapped by Hose and Blake (1976). It probably is part of the Strawberry Creek Formation. The original sediment was a silty chert. It is now a greenish-gray phyllite, seen in thin section as a crinkled felt of very fine grained muscovite set in chert-like material. The muscovite gave an age of 73.8 m.y.

In addition to these samples, metamorphic muscovite 330 (Lee and others, 1970), collected from the Strawberry Creek Formation about 1.5 km east of sample locality 499, gave an age of 125 m.y.

Misch and Hazzard (1962, p. 297, 300) described both contact and regional metamorphism in the area of these samples. Any contact metamorphism would be due to the intrusive referred to as the Osceola stock by Armstrong (1966). Several K-Ar ages determined on micas from this stock range from 51.2 to 154 m.y. (Lee and others, 1970) and show a general tendency to increase from east to west. The intrusive ages determined suggest a history similar to that of the Jurassic (160 m.y.) granitoid rocks exposed a few kilometers to the south (Snake Creek-Williams Canyon area), and on the basis of available information, it is reasonable to suppose that the Osceola stock crystallized about 160 m.y. ago.

Interpretation of the ages of these muscovites from Precambrian metasediments is difficult because of their wide age range—437 to 73.8 m.y. It appears that diagenesis, contact, load, and dynamic metamorphism, and detrital mica have all had some effect on the age of each sample. The oldest age is predominantly a detrital age, and the youngest results mainly from dynamic metamorphism related to Tertiary thrust faulting. The last event, dynamic metamosphism, was not intense enough to re-equilibrate the earlier formed detrital, diagenetic, and (or) metamorphic micas.

WHEELER PEAK AREA, SOUTHERN SNAKE RANGE, NEVADA

In the earlier paper (Lee and others, 1970), we had difficulty explaining the 264-m.y. age obtained for a muscovite recovered from a sample of Prospect Mountain Quartzite near the top of Wheeler Peak. In order to check this result, we collected three additional samples of Prospect Mountain Quartzite: sample 552 from the top of Wheeler Peak (elevation about 3,982 m), sample 554 (at 3,640 m), and sample 555 (at 3,440 m). Petrographic study of these samples, as well as the 264-m.y. sample from near the top of Wheeler Peak, shows that all four have these features in common:

1. All are rather clean quartzites. (Samples 552 and 554 contain about 90 percent SiO_2.)
2. The original sediments were poorly sorted, with subrounded to subangular detrital grains of quartz and minor feldspar less than 1 mm in diameter.
3. The original argillaceous cement has crystallized to an extremely fine grained muscovite surrounding the detrital quartz.
4. There has been little if any recrystallization of the detrital quartz.
5. The detrital quartz shows little evidence of strain; most grains extinguish sharply under crossed nicols.

Muscovites 552, 554, and 555 gave ages of 307, 99.3, and 141 m.y., respectively, showing little relation to present altitude, position within the stratigraphic section, or distance below any eroded thrust fault. The evidence would seem to indicate a very low grade static or load metamorphism. The lack of agreement among these ages probably is due to: (1) the presence of small amounts of detrital mica in some samples, and (or) (2) local differences in chemical conditions (i.e., PH_2O) conducive to the crystallization of metamorphic mica during burial.

MOUNT WHEELER MINE AREA, SOUTHERN SNAKE RANGE, NEVADA

Sample 2-MW-60 was collected from an irregularly shaped beryl veinlet about 1,195 m back in the Pole Canyon adit of the Mount Wheeler mine. The occurrence of beryllium at this mine was described by Stager (1960), and Lee and Erd (1963) described the phenakite (Be_2SiO_4) present in sample 2-MW-60. A concentrate of sericite from this sample gave an age of 196 m.y., suggesting that the plutonic history of this area may have been initiated by an Early Jurassic episode of mineralization. However, this idea is tentative, and further data on the age of this mineralization are needed.

LEXINGTON CREEK AREA, SOUTHERN SNAKE RANGE, NEVADA

Samples 378, 531, and 532 were collected from a small quartz monzonite pluton exposed in the lower reaches of the north fork of Lexington Creek. The map of Whitebread (1969) shows this intrusive cut by a thrust fault, and both Whitebread and Drewes (1958) noted the foliated nature of the intrusive. Except for variations near the margins of the pluton, most of this foliation tends to strike NW. and dip moderately NE. The predominantly NW. strike of this foliation is almost normal to the direction of movement of the upper plate of the thrust as deduced by Drewes (1958, p. 230), and the foliation may have been caused by movement on the thrust before the pluton was completely crystallized. Muscovites 378, 531, and 532 gave Late Cretaceous ages of 86.3, 82.2, and 77.9 m.y., respectively.

The Snake Creek-Williams Canyon intrusive mass exposed 10-20 km to the north has been dated as Middle Jurassic (~160 m.y., Lee and others, 1968), and was completely crystallized and "dry" (Lee and Van Loenen, 1971, p. 6, 40) when partially cataclasized by late (17-19 m.y., Lee and others, 1970) movement on the Snake Range décollement. If, as seems likely in view of the other Jurassic intrusive, the Lexington Creek pluton also is Jurassic in age, the observations noted above may be explained by the following sequence of events:

1. Penecontemporaneous Jurassic thrusting and emplacement of the pluton, with development of foliation in the pluton by movement along the overlying thrust surface.
2. A period of quiescence, with cooling and complete crystallization of the foliated pluton.
3. Partial loss of radiogenic argon from the igneous muscovite, resulting from thermal stresses related to renewed (post-Cretaceous) movement on the thrust surface. All three sample sites probably are within about 20 m of the eroded thrust surface.

MCCOY CREEK AREA, SCHELL CREEK RANGE, NEVADA

More than 2,500 m of upper Precambrian section and at least 1,200 m of overlying uppermost Precambrian and Lower Cambrian Prospect Mountain Quartzite are exposed in the McCoy Creek area (Misch and Hazzard, 1962, p. 309). Samples 427 and 428 are the quartzite and mica schist, respectively, of Misch and Hazzard's (1962, p. 308, 309) A_1 of unit A. Both were collected about 100 m above a thrust surface within the Precambrian section. (See the map of Hose and Blake, 1976.) Both 427 and 428 were from originally poorly sorted sediments, with subangular quartz grains from 0.05 to

1.0 mm across. The original argillaceous impurities now are well-crystallized metamorphic micas that tend to surround the detrital quartz. Muscovites 427 and 428 gave ages of 63.6 and 61.7 m.y., respectively, and biotite 428 gave 45.8 m.y.

Sample 430, from the upper quartzite of Misch and Hazzard's A_2 of unit A, was collected about 150 m stratigraphically above 427 and 428, and about 250 m above the thrust. Most of the detrital quartz in 430 is less than 0.5 mm in diameter. The metamorphic muscovite is not as well crystallized as in 427 and 428, and a few of the larger flakes of muscovite are detrital. Thus the age (86.1 m.y.) probably was determined on a mixture of clastic and metamorphic mica.

Sample YAG 192B of Armstrong and Hansen (1966, p. 123), a "very fine-grained carbonaceous phyllite" that gave a whole-rock K-Ar age of 39 m.y., apparently was collected from Misch and Hazzard's unit C, stratigraphically above 430.

Sample 435, a phyllitic argillite, is from the upper part of Misch and Hazzard's unit E, about 1500 m stratigraphically above sample 430, and far removed from any thrust fault mapped by Hose and Blake (1976). Petrographic study shows that the muscovite in this rock is clearly detrital. The muscovite (with quartz) concentrate recovered gave an age of 617 m.y.

Sample 571 is from the Prospect Mountain Quartzite, from what was originally a shaly sandstone. Although some cryptocrystalline white mica has formed in the rock, this material is so fine grained that it was undoubtedly lost in the washing and separation processes, and the age determined (1,177 m.y.) must be ascribed to the coarser grained clastic mica readily apparent in thin section.

Finally, sample 572 is from an amphibolite that intrudes the central part of Misch and Hazzard's unit B, about 300 m stratigraphically above sample 430. The amphibole recovered from sample 572 gave an age of 98.0 m.y.

Taken as a group, the six mica ages determined for samples collected in the McCoy Creek area are difficult to reconcile with the idea of a regional metamorphism of Mesozic age. Nor do they lend themselves to a unique interpretation. They increase with distance above the thrust fault, which is up-section. The increase of apparent ages within a distance of 1,700—1,800 m of Precambrian section, from 45.8 m.y. (biotite 428) to 617 m.y. (muscovite 435) is too large to be explained on the basis of cooling with uplift. Those ages determined on the well-crystallized metamorphic micas 427 and 428 most probably relate to Tertiary movement along the thrust fault within the upper Precambrian section. The 86.1-m.y. age (muscovite 430) is a mixed metamorphic-detrital mica age, and the 617-m.y. age (muscovite 435) is a mixed detrital-authigenic age. The age of detrital muscovite 471 (1,177 m.y.) is similar to the age (1,242 m.y.) determined for detrital muscovite 471, from the western House Range, Utah. The 98.0-m.y. age (amphibole 472) is a minimum age for the amphibolite.

OTHER AREAS, SCHELL CREEK RANGE, AND DUCK CREEK RANGE, NEVADA

Eight mineral ages were obtained for other areas in the Schell Creek Range and the contiguous Duck Creek Range. Sample 368 was collected near the top of the Precambrian section, south of the mouth of Indian Creek, about 2 km north of Cleve Creek. The rock was originally a rather clean, poorly sorted sandstone, with quartz grains and chert fragments from less than 0.01 to more than 1.0 mm across. The original argillaceous material is now a well-crystallized metamorphic muscovite that tends to outline the clastic quartz grains, which show evidence of strain. Where not shielded by muscovite the contacts between quartz grains have been recrystallized. Muscovite 368 gave an age of 90.2 m.y.

Samples 393 and 394 (a xenolith) were collected about 6 km NE. of 368, from a granodiorite only a few hundred square meters in outcrop area. Biotite 393 gave an age of 35.2 m.y.; biotite and amphibole 394, 34.7 and 35.8 m.y., respectively. The intrusive appears to be early Oligocene in age.

Sample 538, unmetamorphosed Lower Cambrian Pioche Shale, was collected on the north side of upper Piermont Creek canyon. The clastic muscovite recovered from this rock gave an age of 1,190 m.y., very similar to the ages obtained for the Lower Cambrian clastic micas already described.

Sample 569 was collected from a shaly unit within the Prospect Mountain Quartzite, about 1.7 km north of Majors Place. About 23 percent of the rock is a very homogeneous, well-crystallized metamorphic muscovite that shows preferred orientation and gave an age of 66.9 m.y.

Samples 575 (Prospect Mountain Quartzite) and 576 (Pioche Shale) were collected just below a thrust fault. (See the map of Hose and Blake, 1976.) Despite the fact that these samples were collected from the uppermost part of the lower plate, petrographic study shows the rock to be practically unmetamorphosed. The clastic muscovites recovered from samples 575 and 576 gave ages of 1,205 and 1,182 m.y., respectively, very similar to the ages obtained for the three other Lower Cambrian clastic micas already noted.

The ages discussed in this section lend little support either to the idea of a regional metamorphic event, or to the idea of cooling with uplift. Muscovite 368 (90.2 m.y.) was collected only a few hundred meters from where the upper Precambrian section rises above the valley fill. We can only speculate that results for this sample indicate some thermal stress (degassing), resulting either from Tertiary movement on a concealed thrust fault, or from the contact effects of a concealed pluton, related in age to the Oligocene pluton about 6 km to the northeast (samples 393 and 394).

The map and cross section *O-O'* of Drewes (1967) indicate that sample 569 was collected about 600 m below the eroded sole of the Schell Creek Range thrust. We ascribe the apparent age of muscovite 569 (66.9 m.y.) to Tertiary movement on this thrust fault.

The three clastic micas (538, 575, and 576) discussed in this section and the two described in earlier sections (471, western House Range, and 571, McCoy Creek area) all were recovered from the Pioche Shale or Prospect Mountain Quartzite; and all gave ages in the range 1,182–1,242 m.y. The surprising agreement among these results indicate an approximate minimum age for the crystalline terrane that provided the source material for the Lower Cambrian clastic sediments in this region.

The lack of metamorphism of samples 575 and 576, collected just under the sole of a thrust, is difficult to explain. We speculate that an irregular interface between the upper and lower plates at the time of movement, with sample sites 575 and 576 on the lee side of a rise, might have sheltered these rocks from tectonic overpressures, and might thus account for this lack of metamorphism.

EGAN RANGE, NEVADA

Samples 383 and 384 are from a quartz monzonite pluton in the Warm Springs area of the northern Egan Range, Nevada. The intrusive has been sheared and deformed where these samples were collected. The map and cross section *E-E'* of Fritz (1968) show the intrusive exposed just below the level of Fritz's thrust sheet *I*. In his explanatory text, Fritz concluded that the thrusting is Mesozoic in age, and that the intrusions in the area postdate the thrusting and may have been guided by one or more of the thrust faults. Muscovites 383 and 384 gave ages of 25.2 and 36.2 m.y., respectively. Armstrong (1966, p. 596) listed a date of 38 m.y. for a biotite from this same intrusive, determined on a sample apparently collected about 1 km SW. of our sample 384. We attribute the shearing and deformation noted above to stresses related to late movement on the overlying (eroded) thrust fault. Moreover, we regard the ages to be spuriously young, reflecting degassing of the micas at the time of this late thrusting. The intrusive may have crystallized much earlier than 38 m.y. ago.

Sample 386 is from the "Big Rock" area of intrusive outcrop in the southern part of the Cherry Creek district of the northern Egan Range. The intrusive is cut by shears in the area of the sample site, which is about 100 m east of a fault within the intrusive that dips about 30° E-NE. (See the map of Adair, 1961.) The alteration and deformation of parts of this intrusive were clearly recognized by Adair (1961, p. 43), who stated: "The fact that thrust faults exist in and around this igneous body can hardly be questioned." Muscovite 386 gave an age of 34.9 m.y. Again, we interpret this age to be spuriously young and suggest that the intrusive may actually have crystallized much earlier.

Sample 439 is from the Prospect Mountain Quartzite on the south flank of Heusser Mountain in the central Egan Range. The rock was originally an argillaceous sandstone, with poorly sorted, mostly subangular quartz grains. Metamorphism has resulted in development of a finely crystalline mica arranged around and between the clastic quartz grains that show evidence of strain. Where not shielded by metamorphic mica, the quartz has been recrystallized along grain boundaries.

Muscovite 439 gave an age of 65.4 m.y. The sample was collected about 1 km south of an exposed pluton (map of Woodward, 1964), which Armstrong (1970, p. 215) dated as 33.6 m.y. (biotite K-Ar age). One might conclude that the 65.4-m.y. age we obtained reflects heating and degassing by the intrusive. However, Woodward mapped and described a major Mesozoic thrust fault that before erosion extended over both the site of sample 439 and the Heusser Mountain pluton to the north. Thus it is possible that both ages (65.4 and 33.6 m.y.) have been modified by stresses related to Tertiary movement on the Mesozoic thrust fault. With the data now available, we prefer the latter interpretation.

TOANA RANGE, NEVADA

Samples 511 and 512 are Prospect Mountain Quartzite. In outcrop 511 is somewhat lighter in color than 512, but microscope study shows both to be rather clean quartzites. Recrystallization has resulted in sutured contacts between quartz grains, which show evidence of strain. Sparse, well-crystallized metamorphic mica occurs. Muscovites 511 and 512 gave ages of 72.5 and 75.6 m.y., respectively. A Tertiary-Jurassic pluton has intruded the Prospect Mountain Quartzite, and Cambrian carbonate rocks have been thrust over the quartzite (map of Stewart and Carlson, 1974). If the intrusive is Tertiary, the ages (72.5 and 75.6 m.y.) may reflect degassing by heat stress resulting from contact action; if it is Jurassic, the ages may indicate the time of latest movement on the thrust.

DISCUSSION

Here we draw on the data in table 7 and those listed by Lee and others (1970) in order to suggest a working hypothesis relating to the history of plutons in the region of figure 11, comment on the nature of the metamorphism in the region of figure 11, and point up an important unanswered question regarding the apparent K-Ar ages of micas recovered from the metasedimentary rocks.

We propose a working hypothesis to help interpret the history of plutons exposed in the region of figure 11 and adjacent parts of the eastern Great Basin. It is based on a sequence of events as exemplified in the southern Snake Range:

1. Intrusion of plutonic rocks penecontemporaneous with and spatially related to thrust faulting during the Mesozoic orogeny postulated by Misch and Hazzard (1962). This would imply a genetic relation between the thrust faulting and the magmatic activity.
2. A period of quiescence, with cooling and complete crystallization of the plutonic rocks.
3. Renewed thrusting (as recent as 17–19 m.y. ago in the southern Snake Range), leading to stress, shearing, or even cataclasis in the associated plutons, with partial to total degassing of the constituent micas, and consequent postcrystallization K-Ar ages for those micas. This would suggest that other plutons in and near the region of figure 11 might be much older than indicated by K-Ar age results for the constituent micas.

In addition to the southern Snake Range, we have in this study noted that thrust faults and plutons are exposed in close proximity at the present level of erosion in the northern Snake Range, the Kern Mountains, the northern and central Egan Range, and the Toana Range. A study of relevant maps shows the same spatial relation in many other parts of the eastern Great Basin.

A regional metamorphism in the area of figure 11 was postulated by Misch and Hazzard (1962), and the concept has been adopted by many other students of the area. We regard the metamorphism of the area as spotty rather than regional. Contact metamorphism is associated with the plutons, low-grade static metamorphism occurs in some of the clastic sediments, and a dynamic metamorphism resulted from movement along the regional thrust faults; in places dynamic metamorphism is superimposed on the contact and (or) static types of metamorphism. Some of the Lower Cambrian clastic rocks show very little evidence of recrystallization (538 and 571), even where exposed beneath the sole of a thrust (575 and 576). In the Hampton Creek area of the northern Snake Range, an area of perhaps less than 100 km^2 might be regarded as staurolite-grade regional metamorphic terrane.

We prefer the concept of a spotty rather than regional metamorphism because it more nearly indicates the problems we face in our efforts to understand the geologic history of the area. Misch and Hazzard (1962, p. 289) themselves recognized static, thermal, and dynamic metamorphism in the area, with different combinations of the three having produced "various kinds of polymetamorphic rocks." Hose and Blake (1976, p. 25) stated: "The metamorphic rocks in White Pine County are extremely diverse in character and origin." Similar observations could no doubt be culled from the literature. Our purpose here is to stress these observations, as opposed to the idea of an area-wide metamorphic event.

Where micas from lower plate metasedimentary rocks gave Tertiary K-Ar age dates, we consider that they indicate a maximum date for the time of most recent movement along the overlying thrust surface. However, we immediately face the question: When did any one of these metamorphic micas first crystallize from argillaceous material in the original clastic sediment? The importance of this question can hardly be overemphasized, for the Tertiary date might indicate the actual time of formation of the mica, or might result from degassing of a much older mica (formed originally perhaps as a result of tectonic overpressures during earlier movement along the thrust surface), or in some cases, it might be the result of another type of metamorphism. For now we can only delineate the problem.

CONCLUSIONS

Based on the results of this study, and the data listed by Lee and others (1970), we conclude:

1. Where an intrusive is exposed near a level of thrusting, uncorroborated K-Ar age data are suspect as being spuriously young.
2. The distribution of Tertiary K-Ar ages in upper Precambrian and Lower Cambrian metasedimentary and Jurassic igneous terrane is incompatible with the idea of cooling with uplift, but relates instead to Tertiary movement along the regional thrust faults.
3. An important and unanswered question with regard to any one of the micas from lower plate metasedimentary rocks is this: Does the K-Ar age obtained for the mica indicate the time of crystallization, or merely that of degassing of the mica in response to stresses resulting from late movement along the overlying thrust surface?

4. In the present state of our knowledge it is probably more useful to regard the metamorphism in the area of figure 11 as spotty and diverse rather than regional, which tends to connote a widespread metamorphic event.
5. The surprising agreement (1,182-1,242 m.y.) among the K-Ar ages determined for five unmetamorphosed clastic micas recovered from Lower Cambrian sediments would seem to indicate a Precambrian Y provenance that crystallized at least 1,182-1,242 m.y. ago.

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