UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Lithium in rocks from the Lincoln, Helena, and Townsend areas, Montana

by

Elizabeth F. Brenner-Tourtelot, Allen L. Meier, and Craig A. Curtis

Open-File Report 78-430

1978

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Abstract

In anticipation of increased demand for lithium for energy-related uses, the U.S. Geological Survey has been appraising the lithium resources of the United States and investigating occurrences of lithium. Analyses of samples of chiefly lacustrine rocks of Oligocene age collected by M. R. Mudge near Lincoln, Mont. showed as much as 1,500 ppm lithium. Since then we have sampled the area in greater detail, and have sampled rocks of similar ages in the Helena and Townsend valleys.

The lithium-rich beds crop out in a band about 1.3 km long by 0.3 km wide near the head of Beaver Creek, about 14 km northwest of Lincoln, Mont. These beds consist of laminated marlstone, oil shale, carbonaceous shale, limestone, conglomerate, and tuff. Some parts of this sequence average almost 0.1 percent lithium. The lithium-bearing rocks are too low in grade and volume to be economic.

Samples of sedimentary rocks of Oligocene age from the Helena and Townsend valleys in the vicinity of Helena, Mont..were generally low in lithium (3-40 ppm). However, samples of rhyolites from the western side of the Helena valley and from the Lava Mountain area were slightly above average in lithium content (6-200 ppm).

INTRODUCTION

The U.S. Geological Survey is currently studying the geology and appraising the resources of lithium in the United States in anticipation of a growing need for this metal for energy-related uses. In connection with this program, the results of analyses for lithium of 404 outcrop and auger samples collected in 1976-1977 from several localities in Powell, Lewis and Clark, Jefferson, and Broadwater Counties, Montana, are presented in this report. The samples were analyzed for lithium by an atomic absorption method described by Meier (1976). Selected samples were analyzed for potassium, calcium, magnesium, and fluorine by atomic absorption and specific-ion electrode methods. A group of 28 samples from Townsend valley in Jefferson and Broadwater Counties were also analyzed for 23 elements, in addition to lithium, by optical emission spectroscopy. The results of all of these analyses are presented in this report.

ACKNOWLEDGMENTS

M. R. Mudge and R. L. Earhart first discovered the high lithium content of the oil-shale beds along Beaver Creek near Lincoln, Mont. and have contributed much information on the geology of the area. R. K. Glanzman, J. R. Dyni, and J. D. Vine helped in sampling the area. W. R. Greenwood and S. D. Ludington discussed the geology of the Helena and Townsend valleys and collected the samples from these areas.

SAMPLES

Beaver Creek--Near the head of Beaver Creek, about 14 km northwest of Lincoln, Mont., in the Arrastra Mountain quadrangle (fig. 1), beds of Tertiary

Figure 1.--NEAR HERE

sedimentary rocks crop out in a band about 1.3 km long by 0.3 km wide. These beds strike about N. 80° W. and dip 25-35°NE and consists of laminated shale and marlstone, carbonaceous shale, oil shale, limestone, conglomerate, and altered tuff. Leaf impressions, plant debris, and fossil insects are common in these rocks and indicate an Oligocene age (M. R. Mudge, 1976, oral commun.). Semiquantitative spectrographic analyses of samples collected by M. R. Mudge in 1975 showed high lithium contents. Therefore, in the summer of 1976 we sampled these samples (TM6-numbers in table 1) and confirmed the lithium anomaly. In the

Table 1.--NEAR HERE

summer of 1977, we returned to the area to sample in greater detail and to auger the beds to get less weathered samples. Data from these samples are also shown on table 1.

The average lithium content of shales is about 70 ppm (Heier and Billings, 1970). The lithium content in oil-shale sequences can be higher (100-400 ppm) (Tourtelot and Meier, 1976; R. K. Glanzman, 1977, oral commun.), but only averages about 40 ppm in Colorado oil shale (Poulson and others, 1977); the beds on Beaver Creek which average 500 ppm (99 samples) are definitely anomalous. Although some parts of the sequence average almost 0.1 percent lithium, we consider that the lithium content is too low, and the volume of lithium-rich rock is too small to be economic. However, continuing studies on the geochemistry and mineralogy of the Beaver Creek beds may give new information on how to find larger, possibly economic, deposits of this type elsewhere.

Figure 1.--Sample localities in the Lincoln, Helena, and Townsend areas, Montana.

Table 1.--Lithium, potassium, calcium, magnesium, and fluorine contents of samples from Beaver Creek, near Lincoln, Mont. [s, surface sample; a, auger sample, depth in parentheses. Samples are in approximate stratigraphic order from top to base.--, no data; N, not detected. Atomic absorption and specific ion determinations by A. L. Meier; K, Ca, and Mg determined on TM6-samples by 6-step semiquantitative spectrographic analyses by M. J. Malcolm.]

Sample No.	Tag No.	Field Description	Li	K	Ca	Mg	F
			ppm	in percent			
TM766As	MAT 710	Weathered oil shale near top of section red-brown to brown; carbonaceous fragments weathered to orange material	130	1.3	0.12	0.41	0.28
TM766B1s	711	Marl, gray; laminations 0.2-0.5 cm thick; tuffaceous; fossiliferous	120	1.2	.75	.53	.26
TM766B2s	712	Oil shale, dark brown, clayey, paper weathering; grass impressions	110	1.5	.47	.30	.26
TM766C5s	717	Oil shale, dark brown	100	.85	.24	.20	.24
TM766C1s	713	Conglomerate, 2 cm lens; dark brown to dark gray; pebbles 0.5 cm maximum; clay matrix; contains coalified plant debris and ostracods	100	1.4	.58	.36	.26
TM766C2s	714	Clay, bright orange; contains light greenish-gray gel-like clay	44	.78	.18	.21	.24
TM766C3s	715	Marl, gray, and shale, dark-brown in 2-4 mm laminae, hard	110	1.1	.8	.53	.26
TM766C4s	716	Claystone, mottled green-gray to brown-gray, massive-bedded	97	.81	.53	.35	.26
TM766D1s	718	Marl, gray, and shale, dark brown in 2-4 mm laminae, hard	150	.89	.69	.44	.24
TM766D2s	719	Oil shale, dark brown, 0.7 m thick bed	200	.73	.38	.27	.36
TM766D3s	720	Clay, orange and gray green, gel-like	150	.23	.22	.26	.26
TM766E1s	721	Conglomerate lens; contains plant debris, clay balls, and pebbles of Belt rocks	160	1.2	.56	.41	.28
IM766E2s	722	Oil shale, dark brown, 0.4 m thick	250	1.2	.28	.27	.28
TM766E3s	723	Siltstone, gray green, clayey, tuffaceous	110	.80	1.1	.43	.26
TM766E4s	724	Marl, white-weathering, hard, ledge-forming	140	1.4	.77	.44	.26
TM766Fs	725	Claystone, green gray, tuffaceous	150	1.7	.10	.44	.26
TM766Gs	726	Clay, green gray, 1 m thick; contains plant debris, pebbles, cobbles of Belt rocks as much as 10 cm in diameter	160	1.4	.61	.43	.26
TM766H2s	728	Oil shale, dark brown	520	1.2	.92	.57	.44
TM766H1s	727	Nodule in shale (sample TM766H2)	9	.17	3.3	.09	.076
TM766H3s	729	Conglomerate, green gray; contains mud pebbles	260	1.2	.64	.37	.28
TM766H4s	730	Conglomerate, green gray	350	1.1	.96	.41	.30
TM766I1s	731	Claystone, green gray, laminated, calcareous	270	1.3	1.0	.53	.30
TM766I2s	732	Claystone, green gray, harder than TM766I1, weathers shaly	390	1.4	1.3	.30	.34
TM766I3s	733	Claystone, similar to TM766I2 except irregularly bedded; calcite-coated joints	300	1.4	1.0	.36	.28
TM766I4s	734	Marlstone, gray, laminated	580	1.5	.94	.21	.36
TM766I5s	735	Siltstone, orange	300	.93	.09	.53	.26
TM766I6s	736	Oil shale, weathers as paper shale	1,000	1.4	.29	.35	.54
TM766I7s	737	Siltstone, clayey, dark brown; possible slump structures	940	1.8	.51	.20	.52
TM766I8s	738	Marlstone, dark gray brown, very hard	310	1.2	.82	.44	.26
TM766I9s	739	Marlstone, gray; contains coalified plant debris	310	1.5	.83	.27	.30
IM766I10s	740	Claystone, dark brown, irregularly bedded	340	1.5	.65	.26	.30

Table 1.--Lithium, potassium, calcium, magnesium, and fluorine contents of samples from Beaver Creek--Continued

Sample No.	Tag No.	Field Description	Li	K	Ca	Mg	F
			ppm	in percent			
TM766Js	MAT 741	Conglomerate, gray-green, clay-cemented; contains pebbles of Belt rocks averaging 1-2 cm in diameter; some as large as 13 cm	200	1.4	1.1	.41	.26
TM766Ks	742	Tuff, gray, in a roll over very coarse conglomerate; marked by low amplitude, short-cycle ripple marks	350	1.9	1.1	.27	.34
TM766L2s	744	Shale, brown, marl, gray-green, and oil shale in thin (2 cm) beds;interbedded	1,100	1.5	.46	.44	.50
TM766L1s	743	Claystone, gray-green	340	1.8	.90	.43	.32
TM766M0s	745	Marlstone, gray, laminated, hard	660	1.1	1.0	.44	.38
TM766M1s	746	Siltstone, orange	810	.74	.55	.43	.50
TM766M2s	747	Marlstone, gray, hard	730	1.2	.98	.09	.44
TM766M3s	748	Marlstone, gray-green, very hard	520	1.6	.53	.57	.32
TM766N1s	749	Claystone, light brown	380	.63	1.1	.37	.38
TM766N2s	750	Oil shale, brown, and marlstone, gray; composite sample of 0.6 m	570	1.2	.56	.80	.18
TM766N3s	751	Marlstone and oil-shale, ledge-forming	110	.50	1.7	1.9	.26
TM766N4s	752	Oil shale, dark brown, weathers as paper shale.	130	1.5	.86	.38	.46
TM653Ds	MAP 864	Shale, paper, light to dark brown, hard, in 2 cm beds, probably correlates approximately to beds represented by samples TM766H and I	1,200	2	1.5	2	--
TM653Es	865	Sandstone, brownish gray, massive, fine-grained; contains cobbles 15 cm in diameter	395	3	10	2	--
TM653Fs	866	Marl and limestone intercalated, light yellow, very fine grained; contains sand grains; red on fracture surface	1,040	5	>10	3	--
TM653Gs	867	Marlstone, light gray, very weathered	1,510	5	2	3	--
TM653As	861	Oil shale, red-black; approximately 5 cm thick	1,050	1.5	>10	3	--
TM653Bs	862	Claystone, dark reddish brown and dark gray	1,090	3	>10	3	
TM653Cs	863	Siltstone, orange; has black coating on fractures	940	.7	.7	2	--
TM653Hs	868	Shale, light brown, silty	600	5	7	2	--
TM653I1s	869	Paper shale, light brown, weathers white	650	3	>10	1	--
TM653I2s	870	Siltstone, brownish-gray, blocky weathering; 15 cm thick; contains carbonaceous debris	180	3	>10	2	--
TM653J	871	Sandstone, gray, fine-grained, lumpy textured, organic-rich; contains concretions	290	5	>10	1.5	--
TM653K	872	Shale, brown, iron-stained, silty, sandy, weathered; beds about 0.5 cm thick	305	5	>10	1.5	--
TM653L	873	Marlstone, brown,massive, tuffaceous; bed about 0.4 cm thick	1,250	5	7	3	--
TM653M	874	Marlstone, gray	380	5	>10	2	--
TM653N	875	Shale, light yellow-brown to light brown, blocky weathering; beds 2-10 cm thick	870	3	>10	3	--
TM653O	876	Marlstone, very light yellow brown, massive (0.3-0.7 m); bed interbedded with thin sandstone stingers	470	5	10	2	--
TM653P	877	Marlstone, very light brownish gray, thinly laminated	790	N	10	7	--
TM653Q	878	Limestone, blue-gray, siliceous	100	2	>10	1.5	--

Table 1.--Lithium, potassium, calcium, magnesium, and fluorine contents of samples from Beaver Creek--Continued

Sample No.	Tag No.	Field Description	Li	K	Ca	Mg	F
			ppm	in percent			
TM653Rs	MAP 879	Conglomerate, yellowish brown, marly; contains pebbles	430	2	5	2	--
TM754Aa(0-0.6m)	MAT 567	Colluvium, medium yellow-brown	440	--	--	--	--
TM754Ba(0.6-1.2m)	568	Colluvium, medium yellow-brown plus clay, orange, silty	350	--	--	--	--
TM754Ca(1.2-1.5m)	569	Clay, orange, silty; shale, dark brown, indurated	360	--	--	--	--
TM754Da(1.5.-1.8m)	570	Shale, dark brown, indurated; conglomerate	330	--	--	--	--
TM754Ea(1.8.-2.4m)	571	Claystone, yellow-brown; contains pebbles	400	--	--	--	--
TM754Fa(2.4-3m)	572	Claystone, yellow-brown; contains pebbles	1,100	1.4	3.7	1.6	0.72
TM754Ga(3-3.6m)	573	Claystone, yellow-brown, pebbly, and oil shale	600	1.2	6.1	1.6	.4
TM754Ha(3.6-4.2m)	574	Shale, dark brown, and marlstone, gray, carbonaceous	610	1.2	6.3	1.5	.37
TM754Ia(4.2-4.9m)	575	Shale, dark brown, and marlstone, gray, finely laminated	680	1.1	3.9	1.1	.4
TM754Ja(4.9-5.5m)	576	do	770	1.6	3.4	2.1	.44
TM754Ka(5.5-6.1m)	577	Oil Shale	760	1.8	3.7	1.6	.44
TM754La(6.1-6.7m)	578	Oil shale and marlstone, gray, finely laminated	610	1.6	6.2	2.4	.44
TM754Ma(6.7-7.3m)	621	do	610	1.3	8.0	4.5	.44
TM754Na(7.3-7.9m)	622	Limestone, gray, sandstone, gray, and oil shale	660	1.4	7.3	3.2	.44
TM754Oa(7.9-8.4m)	623	Oil shale	720	1.4	6.4	2.9	.44
TM754Pa(8.4-9.1m)	624	Limestone, dark gray, and shale, dark brown	390	--	--	--	--
TM754Qa(9.1-9.8m)	625	Limestone, dark gray, and oil shale, thinly laminated	610	1.1	4.4	2.6	.38
TM754Ra(9.8-10.3m)	626	Claystone, dark gray	780	1.2	5.8	4.2	.60
TM754Sa(10.3-11m)	627	Claystone, dark gray, marlstone, dark gray, finely laminated, and siltstone, orange	1,000	1.1	5.3	3.9	.56
TM754Ta(11-11.6m)	628	Claystone, dark olive gray, pebbly	680	1.2	.55	2.8	.52
TM754Ua(11.6-11.9m)	629	Claystone, dark olive gray	750	1.2	6.1	3.0	.44
TM754Va(11.9m)	630	Claystone, dark olive gray, pebbly (bottom of hole)	850	1.3	5.8	3.5	.52
TM753Aa(0-0.6m)	560	Colluvium, medium yellow-brown	190	--	--	--	--
TM753Ba(0.6-1.2m)	561	Claystone, yellow-brown, pebbly	640	2.3	.26	1.0	.4
TM753Ca(1.2-1.8m)	562	do	800	2.0	.40	1.4	.64
TM753Da(1.8-2.4m)	563	do	760	2.2	.55	2.0	.48
TM753Ea(2.4-3.0m)	564	do	590	2.0	1.1	1.6	.36
TM753Fa(3-3.7m)	565	do	480	--	--	--	--
TM753Ga(3.7-4.1m)	566	do (Hard layer stopped auger)	240	--	--	--	--
TM756Aa(0-0.6m)	597	Colluvium, yellow-brown, and shale, dark brown	770	3.5	1.6	1.9	.4
TM756Ba(0.6-1.2m)	598	Shale and claystone, reddish-brown	790	4.4	.39	1.3	.4
TM756Ca(1.2-1.8m)	599	Siltstone, white, hard, tuffaceous, and claystone, reddish-brown	580	2.6	3.1	1.5	.36

Table 1.--Lithium, potassium, calcium, magnesium, and fluorine contents of samples from Beaver Creek--Continued

Sample No.	Tag No.	Field Description	Li	K	Ca	Mg	F
			ppm	in percent			
TM756Da(1.8-2.4m)	MAT 600	Siltstone, white, claystone, reddish-brown, and oil shale	640	1.4	2.8	1.3	.35
TM756Ea(2.4-3m)	601	Claystone, medium brown, and conglomerate	320	--	--	--	--
TM756Fa(3-3.7m)	602	do	470	--	--	--	--
TM756Ga(3.7-4.3m)	603	Claystone, medium brown, conglomerate, siltstone, orange	410	--	--	--	--
TM756Ha(4.3-4.9m)	604	Claystone, medium brown, siltstone, orange, and oil shale	530	1.7	6.4	1.8	.27
TM756Ia(4.9-5.5m)	605	do	390	--	--	--	--
TM756Ja(5.5-6.1m)	606	do	510	2.0	6.7	1.8	.30
TM756Ka(6.1-6.7m)	607	Siltstone, carbonaceous, shale and claystone, medium brown	480	--	--	--	--
TM756La(6.7-7.3m)	608	do	430	--	--	--	--
TM756Ma(7.3-7.9m)	609	do	490	--	--	--	--
TM756Na(7.9-8.6m)	610	Siltstone, carbonaceous, red-brown, shale and claystone, medium brown	600	1.3	4.5	1.6	.44
TM756Oa(8.6-9.1m)	611	Oil shale, dark brown, and conglomerate	580	1.6	7.4	2.3	.44
TM756Pa(9.1-9.8m)	612	Oil shale and marl, gray	670	2.0	6.7	2.4	.48
TM756Qa(9.8-10.4m)	613	Marl, light gray, laminated, and oil shale	380	--	--	--	---
TM756Ra(10.4-11m)	614	do	610	2.1	8.4	2.5	.44
TM756Sa(11-11.6m)	615	do	560	1.6	8.2	2.4	.44
TM756Ta(11.6-11.9m)	616	Oil shale, hard	530	2.0	7.9	2.5	.40
TM755Aa(0-0.6m)	579	Colluvium; consists of weathered shale and claystone	160	--	--	--	--
TM755Ba(0.6-1.2m)	580	Claystone, medium yellow-brown	150	--	--	--	--
TM755Ca(1.2-1.8m)	581	Claystone, medium yellow-brown, claystone, bright orange and oil shale	160	--	--	--	--
TM755Da(1.8-2.4m)	582	Claystone, medium yellow-brown, and shale, dark brown	120	--	--	--	--
TM755Ea(2.4-3m)	583	Shale, dark brown, and claystone, orange	110	--	--	--	--
TM755F1a(3-3.4m)	584	Clay, dark brown, sticky	120	--	--	--	--
TM755F2a(3.4-3.7m)	585	Claystone, bright orange	80	--	--	--	--
TM755Ga(3.7-4.3m)	586	Oil shale	120	--	--	--	--
TM755Ha(4.3-4.9m)	587	Claystone, dark orange-brown to brown, pebbly	120	--	--	--	--
TM755Ia(4.9-5.5m)	588	Claystone, dark brown carbonaceous, and oil shale	120	--	--	--	--
TM755Ja(5.5-6.1m)	589	Shale, medium-dark brown, and oil shale	140	--	--	--	--
TM755K1a(6.1-6.4m)	590	Claystone, dark gray, pebbly	120	--	--	--	--
TM755K2a(6.4-6.7m)	591	Claystone, dark brown, and oil shale	140	--	--	--	--
TM755La(6.7-7.3m)	592	Claystone, dark brownish-gray, wetter	130	--	--	--	--
TM755Ma(7.3-7.9m)	593	Claystone, black	150	--	--	--	--
TM755Na(7.9-8.5m)	594	Claystone, dark gray-black, very wet	170	--	--	--	--
TM755Pa(8.5m)	596	Claystone, dark gray-black, very wet, from bottom of hole	150	--	--	--	--
TM757Aa(0-0.6m)	617	Colluvium, light yellow-brown, and marlstone, light gray	740	2.3	3.2	1.9	.48

Table 1.--Lithium, potassium, calcium, magnesium, and fluorine contents of samples from Beaver Creek--Continued

Sample No.	Tag No.	Field Description	Li	K	Ca	Mg	F
			ppm	In percent			
TM757Ba(0.6-1.2m)	MAT 618	Marlstone, organic-rich, hard	840	2.1	6.2	2.4	.76
TM757Ca(1.2-1.8m)	619	Marlstone, gray-brown, hard	360	--	--	--	--
TM757Da(1.8-2.1m)	620	Marlstone, gray, very hard (stopped auger)	340	--	--	--	--
TM747Aa(0-0.6m)	516	Colluvium, light gray-brown	130	--	--	--	--
TM747Ba(0.6-1.2m)	517	Claystone, dark brown, spongy, pebbly	150	--	--	--	--
TM747Ca(1.2-1.8m)	518	Conglomerate cemented with dark gray clay, calcite	96	--	--	--	--
TM747Da(1.8-2.4m)	519	Conglomerate; contains lenses of dark brown clay	86	--	--	--	--
TM747Ea(2.4-3m)	520	do	110	--	--	--	--
TM747Fa(3-3.7m)	521	Conglomerate, light gray; contains dark brown clay lenses	86	--	--	--	--
TM747Ga(3.7-4.3m)	522	do	67	--	--	--	--
TM747Ha(4.3-4.9m)	523	Conglomerate, light gray, clay, dark brown, and siltstone, yellowish-gray brown	90	--	--	--	--
TM747Ia(4.9-5.5m)	524	do	67	--	--	--	--
TM747Ha(5.5-6m)	525	do (Hard rock ended hole.)	86	--	--	--	--
TM746Aa(0.06m)	492	Colluvium, yellow-brown	74	--	--	--	--
TM746Ba(0.6-1.2m)	493	do	83	--	--	--	--
TM746Ca(1.2-1.8m)	494	Claystone, dark brown to yellow-brown	110	--	--	--	--
TM746Da(1.8-2.4m)	495	Claystone, dark brown and gray	100	--	--	--	--
TM746Ea(2.4-3m)	496	Oil shale, tough	96	--	--	--	--
TM746Fa(3m)	497	Oil shale	90	--	--	--	--
TM746Ga(3-3.7m)	498	Shale, medium brown and marl gray	90	--	--	--	--
TM746Ha(3.7-4.3m)	499	Oil shale	92	--	--	--	--
TM746Ia(4.3-4.9m)	500	Shale, medium brown	93	--	--	--	--
TM746Ja(4.9-5.5m)	501	Oil shale and carbonaceous shale, tough	82	--	--	--	--
TM746Ka(5.5-6.1m)	502	Shale, dark brown to gray-brown	92	--	--	--	--
TM746La(6.1-6.7m)	503	do	96	--	--	--	--
TM746Ma(6.7-7.3m)	504	Shale, dark brown, paper shale, and tuff, blue-gray	98	--	--	--	--
TM746Na(7.3-7.9m)	505	Claystone, dark gray to black, pebbly	96	--	--	--	--
TM746Oa(7.9-8.6m)	506	do	92	--	--	--	--
TM746Pa(8.6-9.4m)	507	Claystone, dark brown	80	--	--	--	--
TM746Qa(9.4-10.1m)	508	Claystone, dark brown, wet	92	--	--	--	--
TM746Ra(10.1-10.7m)	509	Claystone, gray, conglomeratic	93	--	--	--	--
TM746Ta(10.7m)	510	Claystone, black	95	--	--	--	--
TM745Aa(0-1.2m)	482	Colluvium and dark brown clay	120	--	--	--	--
TM745Ba(1.2-1.8m)	483	Claystone, dark brown, weathered	120	--	--	--	--
TM745Ca(1.8-2.4m)	484	Claystone, dark to medium yellow-brown	120	--	--	--	--
TM745Da(2.4-3m)	485	Claystone, medium brown, plastic	110	--	--	--	--
TM745Ea(3-3.7m)	486	Claystone, dark brown	120	--	--	--	--

Table 1.--Lithium, potassium, calcium, magnesium, and fluorine contents of samples from Beaver Creek--Continued

Sample No.	Tag No.	Field Description	Li	K	Ca	Mg	F
			ppm	in percent			
TM745Fa(3.7-4.3m)	MAT 487	Claystone, dark brown, wet	60	--	--	--	--
TM745Ga(4.3-4.9m)	488	Claystone, dark brown to dark gray, pebbly	91	--	--	--	--
TM745Ha(4.9-5.2m)	489	Oil shale	130	--	--	--	--
TM745Ja(5.2-5.5m)	490	Oil shale, very tough, bottom of hole	150	--	--	--	--
TM744Aa(0-0.6m)	479	Colluvium and dark brown clay	260	--	--	--	--
TM744Ba(0.6-1.2m)	550	Siltstone, yellow-brown, clayey; contains cobbles	180	--	--	--	--
TM744Ca(1.2-1.8m)	551	Conglomerate and siltstone, yellow-brown	150	--	--	--	--
TM744Da(1.8-2.4m)	480	do	140	--	--	--	--
TM744Ea(2.4-3m)	552	do	130	--	--	--	--
TM744Fa(3-3.7m)	481	Siltstone, yellow-brown; contains boulders	140	--	--	--	--
TM743Aa(0-0.6m)	465	Colluvium, yellow-brown, and clay, medium gray	730	2.5	0.8	1.9	2.8
TM743Ba(0.6-1.2m)	466	Claystone, medium brown, silty, pebbly	530	2.4	2.4	1.7	.48
TM743Ca(1.2-1.8m)	467	do	400	--	--	--	--
TM743Da(1.8-2.4m)	468	do	330	--	--	--	--
TM743Ea(2.4-3m)	469	do	370	--	--	--	--
TM743Fa(3-3.7m)	470	Claystone, medium brown, and conglomerate	410	--	--	--	--
TM743Ga(3.7-4.3m)	471	do (less conglomerate)	300	--	--	--	--
TM743Ha(4.3-4.9m)	472	do (more conglomerate)	220	--	--	--	--
TM743Ia(4.9-5.5m)	473	do	150	--	--	--	--
TM743Ja(5.5-6.1m)	474	do	180	--	--	--	--
TM743Ka(6.1-6.7m)	475	do (more clay)	200	--	--	--	--
TM743La(6.7-7.6m)	476	Claystone, very dark brown, organic rich	210	--	--	--	--
TM743Ma(7.6-8.2m)	477	Claystone, medium dark brown	220	--	--	--	--
TM743Na(8.2-8.8m)	478	Claystone, dark brown, grades downward into pebbly zone; hole stopped by hard layer	260	--	--	--	--
TM742Aa(0-0.9m)	448	Colluvium, medium dark brown, clayey	110	--	--	--	--
TM742Ba(0.9-1.5m)	449	Claystone, medium brown	110	--	--	--	--
TM742Ca(1.5-2.1m)	450	do	90	--	--	--	--
TM742Da(2.1-2.7m)	451	do	97	--	--	--	--
TM742Ea(2.7-3.4m)	452	Claystone, medium brown, plastic	83	--	--	--	--
TM742Fa(3.4-4m)	453	Clay, medium yellow, very plastic	62	--	--	--	--
TM742Ga(4-4.6m)	454	Claystone, medium dark brown, silty	83	--	--	--	--
TM742Ha(4.6-5.2m)	455	Claystone, dark brown	85	--	--	--	--
TM742Ia(5.2-5.8m)	456	Claystone, dark brown, pelletal	100	--	--	--	--
TM742Ja(5.8-6.4m)	457	Clay, dark gray-brown, plastic	110	--	--	--	--
TM742Ka(6.4-7m)	458	Clay, yellow-brown, fluid	100	--	--	--	--
TM742Ma(7-7.6m)	459	Clay, yellow-brown, sticky (sample from auger stem)	130	--	--	--	--
TM742Na(~8.2m)	460	Clay, blue	100	--	--	--	--

Table 1.--Lithium, potassium, calcium, magnesium, and fluorine contents of samples from Beaver Creek--Continued

Sample No.	Tag No.	Field Description	Li	K	Ca	Mg	F
			ppm	in percent			
TM656As	MAP 916	Paper shale, light brown	80	--	--	--	--
TM656Bs	917	Sandstone, light gray-green, tuffaceous	39	--	--	--	--
TM655GGs	915	Paper shale, light to dark brown; 0.3 m thick	93	--	--	--	--
TM655FFs	914	Paper shale, light to dark brown; 0.5 m thick	94	--	--	--	--
TM655EEs	913	Claystone, very pale brown, crumb texture; 1.3 cm thick	104	3	10	1	--
TM655DDs	912	Paper shale, light- to dark-brown, kerogenaceous	110	3	5	1	--
TM655CCs	911	Oil shale, brown, no bedding; 5 cm thick	97	--	--	--	--
TM655BBs	910	Oil shale interbedded with light gray tuffaceous siltstones; 0.5 m interval	94	2	7	1	--
TM655AAs	909	Shale, brown, laminated (0.3-0.6 cm), soft	100	2	7	1	--
TM655Zs	908	Claystone, gray-green to brown; 2-5 cm thick	65	--	--	--	--
TM655Ys	907	Claystone, brown; 22 cm thick	70	--	--	--	--
TM655Xs	906	Claystone, rust-colored, silty; 7.6 cm thick	55	N	3	.7	--
TM655Ws	905	Claystone, brown, silty; 10 cm thick	68	--	--	--	--
TM655Vs	904	Oil shale, dark brown to black, silty; 5 cm thick	92	1	7	.7	--
TM655Us	903	Claystone, yellowish-gray, silty; contains black flecks; 2.5 cm thick	26	N	>10	.5	--
TM655Ts	902	Clay, banded brown-gray and green-gray; 18 cm thick	33	--	--	--	--
TM655Ss	901	Claystone, gray-green, blocky weathering; 10 cm thick	30	N	3	.7	--
TM655Rs	900	Claystone, gray, thinly laminated; 8 cm thick	50	.7	3	.7	--
TM655Qs	899	Shale, dark brown; 2.5 cm thick	90	--	--	--	--
TM655Ps	898	Claystone, dark yellowish-gray; 20 cm thick	41	N	2	.7	--
TM655Os	897	Clay, gray-brown to gray-green; 30 cm thick	50	--	--	--	--
TM655Ns	896	Paper shale, brown, fissile; 0.15-.3 cm layers; 20 cm thick	84	1.5	7	1	--
TM655Ms	895	Clay, orange and green-gray lenses 0.3 cm; 8 cm thick	74	1	1	.5	--
TM655Ls	894	Shale, brown, hard, laminated with marlstone; 15 cm thick	90	--	--	--	--
TM655Ks	893	Oil shale, almost black, weathers blocky; 13 cm thick	82	--	--	--	--
TM655Js	892	Clay, yellow-brown to brilliant orange, silty	50	7	7	.3	--
TM655Is	891	Oil shale and marlstone, dark gray-brown; 30 cm thick	62	--	--	--	--
TM655Hs	890	Clay, light yellowish-gray-green; 10 cm thick	40	N	5	.5	--
TM655Gs	889	Claystone, gray, massive, blocky weathering	110	--	--	--	--
TM655Fs	888	Siltstone, light yellow-brown, very fine grained; 2.5 cm thick	110	--	--	--	--
TM655Es	887	Claystone, pale gray to light yellow-brown, blocky weathering, conchoidal fracture	110	--	--	--	--
TM655Ds	886	Claystone, dark yellow-brown, black on bedding surfaces, shaly; interbedded 0.3 cm white clay	130	--	--	--	--
TM655Cs	885	Claystone, light green to yellow-brown	56	3	.7	1.5	--
TM655Bs	884	Oil shale, dark brown	110	.7	3	.7	--

Table 1.--Lithium, potassium, calcium, magnesium, and fluorine contents of samples from Beaver Creek--Continued

Sample No.	Tag No.	Field Description	Li	K	Ca	Mg	F
			ppm	in percent			
TM655As	MAP 883	Clay, very light yellow brown; occurs as a weathering product of shale	120	3	0.7	0.7	--
TM741Aa(0-0.6m)	MAT 430	Colluvium, dark brown, and shale	120	--	--	--	--
TM741Ba(0.6-1.2m)	431	Shale and claystone, bedded, dark brown	100	--	--	--	--
TM741Ca(1.2-1.8m)	432	do	100	--	--	--	--
TM741Da(1.8-2.4m)	433	do	110	--	--	--	--
TM741Ea(2.4-3m)	434	do	86	--	--	--	--
TM741Fa(3-3.7m)	435	Shale, dark brown, and clay, light gray, plastic	89	--	--	--	--
TM741Ga(3.5m)	436	Clay, light gray, plastic; separated from TM741F	64	--	--	--	--
TM741Ha(3.7-4.3m)	437	Shale, dark brown	100	--	--	--	--
TM741Ia(4.3-4.9m)	438	Shale, dark brown, coaly intervals	87	--	--	--	--
TM741Ja(4.9-5.5m)	439	Oil shale, hard	100	--	--	--	--
TM741Ka(5.5-5.8m)	440	do	84	--	--	--	--
TM741La(5.5-6.1m)	441	do	93	--	--	--	--
TM741Oa(6.1-6.7m)	442	do	92	--	--	--	--
TM741Pa(6.7-7.2m)	443	do	96	--	--	--	--
TM741Qa(6.7-7.3m)	444	do	96	--	--	--	--
TM741Ra(7.3-7.9m)	445	do	97	--	--	--	--
TM741Sa(7.9-8.5m)	446	Claystone, brownish-gray	52	--	--	--	--
TM741Ta(8-8.5m)	447	Coal, marcasitic, and claystone, gray	74	--	--	--	--

Two suites of samples were selected from those collected in 1976 and submitted for 6-step semiquantitative spectrographic analysis by the method described by Myers, Havens, and Dunton (1961). The results of the analyses are reported arbitrarily as midpoints within geometric brackets 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth. The precision of a reported value is approximately plus or minus one bracket at 68 percent or two brackets at 95 percent confidence.

One suite of 19 samples was selected from the upper more lithium-rich part of the section at Beaver Creek (see table 1 for a description of the samples), and the other suite of 19 samples from the lower part of the section. The results from the semiquantitative analyses are presented in table 2. The average

Table 2.--NEAR HERE

element contents in the two sample suites were also compared (table 3). Significant

Table 3.--NEAR HERE

differences were found between the two suites. The high lithium suite contains more of the alkali and alkali-earth elements and less aluminum (both suites contain greater than 10 percent Si). The high lithium suite is more carbonate-rich. The presence of elements such as arsenic and boron in the high lithium suite suggests an input from hot springs (Hem, 1970).

Helena and Townsend valleys--Reconnaissance samples were collected from sedimentary and volcanogenic rocks of Tertiary age in Helena and Townsend valleys (fig. 1). Rocks sampled include tuffs, tuffaceous sandstones and claystones, carbonaceous shales, and conglomerates. The volcanic components in these sediments are presumed to be related to some of the volcanic rocks in the Elkhorn Mountains.

Table 4 shows the lithium content of the samples. Samples TM7-67A through TM7-76B (28 samples in all) were collected in the Townsend valley; the remaining 40 samples were collected in the Helena valley.

Table 4.--NEAR HERE

Table 2.--Semiquantitative spectrographic analyses of selected samples from Beaver Creek near Lincoln, Montana

[Sample descriptions in table 1. Mollie Jane Malcolm, analyst. N, not detected; L, below limit of determination; G, greater than 10 percent.]

Element	[1]Li	Al	Na	Fe	Ti	Mn	As	B	Ba	Be	Co	Cr	Cu	Ga	Mo	Ni	Pb	Sc	Sr	V	Y	Yb	Zr
Sample number	ppm	percent			ppm																		
TM653D	1,200	3	1	2	0.15	500	N	70	500	3	7	20	50	7	5	30	10	5	150	30	15	2	70
TM653E	395	G	2	3	.3	500	N	100	700	2	5	20	30	10	5	7	10	10	300	50	20	3	100
TM653F	1,040	7	1	1.5	.15	200	N	150	700	N	L	20	20	10	5	5	15	7	700	70	30	3	50
TM653G	1,510	G	1.5	5	.3	300	N	200	700	1.5	5	30	30	15	7	7	15	10	100	70	30	3	100
TM653A	1,050	3	.7	.7	.1	200	2,000	70	700	N	5	7	10	5	7	5	15	7	700	50	15	1.5	15
TM653B	1,090	7	2	3	.2	200	3,000	100	500	N	5	30	15	10	N	15	10	10	200	70	20	3	100
TM653C	940	G	3	7	.2	700	N	50	700	2	10	7	100	10	10	20	15	20	200	100	20	3	100
TM653H	600	G	1	5	.3	200	N	500	700	1.5	5	20	30	10	5	5	15	7	150	70	30	3	70
TM653I1	650	7	1.5	3	.2	500	N	150	1,500	2	5	15	50	7	7	7	15	15	2,000	70	20	3	50
TM653I2	180	7	3	3	.2	500	N	100	500	N	5	15	30	10	N	L	15	10	700	50	20	3	50
TM653J	290	7	1	2	.15	300	N	100	500	N	5	20	10	10	N	5	10	10	500	50	20	3	50
TM653K	335	10	1	3	.2	200	N	200	500	N	5	30	20	10	5	7	15	10	500	50	20	3	70
TM653L	1,250	10	1	5	.2	300	N	500	700	N	7	20	30	10	3	7	15	7	300	70	20	3	70
TM653M	380	10	2	3	.2	300	N	200	500	2	5	20	20	10	5	5	15	7	500	70	20	3	70
TM653N	870	5	1	2	.2	700	N	100	700	N	5	15	20	7	5	5	10	7	700	70	20	2	20
TM653O	470	10	2	3	.2	500	N	150	700	N	L	20	30	15	N	L	15	10	300	50	20	3	50
TM653P	790	1	.7	1	.02	700	N	20	300	2	5	7	7	L	N	10	10	N	2,000	30	N	N	20
TM653Q	100	5	1	1	.1	300	N	30	300	N	N	15	7	5	N	L	10	7	500	30	20	2	30
TM653R	430	10	2	5	.2	700	N	100	500	3	7	20	30	15	N	15	20	10	200	50	20	2	100
TM656A	80	10	.7	2	.2	500	N	30	1,500	N	7	30	30	10	10	10	15	10	300	70	20	2	70
TM656B	39	10	1.5	2	.5	3,000	N	N	700	N	L	10	100	10	N	L	N	10	150	100	20	2	70
TM656E	104	G	.7	3	.2	300	N	70	700	N	5	15	20	15	N	5	15	7	70	30	15	2	50
TM656D	110	7	.5	5	.2	300	N	50	700	N	5	15	70	10	N	5	15	7	30	30	20	2	70
TM656C	94	7	.7	3	.2	500	N	50	1,000	N	5	20	30	15	N	5	15	7	70	50	50	5	70
TM656AA	100	7	.7	2	.2	500	N	70	1,000	1.5	L	20	30	15	N	5	15	7	100	50	50	5	70
TM656X	55	10	.3	5	.1	70	N	70	3,000	1.5	N	7	30	20	N	5	15	5	300	15	50	5	100
TM656Y	92	5	.5	3	.2	1,500	N	50	1,500	1.5	5	20	50	10	N	5	15	7	150	50	100	10	70
TM656U	26	5	.3	1.5	.05	3,000	N	20	300	N	N	2	10	15	N	N	15	N	100	7	150	15	50
TM656J	30	G	.2	3	.1	50	N	50	3,000	1.5	N	2	20	20	N	N	15	L	300	7	50	5	100
TM656R	50	10	.5	3	.1	100	N	50	1,500	1.5	N	10	30	20	N	L	15	5	200	15	30	5	100
TM656P	41	G	.5	3	.1	50	N	50	3,000	1.5	N	5	30	20	N	L	20	L	200	10	30	5	150
TM656N	64	7	.5	3	.2	700	N	30	700	3	10	20	50	10	N	10	15	7	200	70	30	5	70
TM656M	74	G	.7	7	.5	30	N	50	1,000	N	N	10	70	20	10	N	15	10	500	50	20	3	150
TM656O	50	G	1	5	.5	1,500	N	30	1,500	N	15	10	150	20	10	7	15	15	150	150	30	3	150
TM656H	40	G	.7	5	.3	70	N	50	3,000	N	5	7	100	20	N	L	15	10	300	30	50	5	150
TM656C	56	10	.7	10	.2	3,000	N	100	700	2	5	30	30	15	N	7	50	15	50	100	50	7	100
TM656B	110	G	.7	7	.3	100	N	50	3,000	N	L	7	100	30	5	L	15	10	200	50	50	7	150
TM656A	120	G	.5	7	.2	1,000	N	70	700	1.5	10	15	50	15	5	10	20	7	30	70	20	3	100

[1] Li analyzed by atomic absorption.

Table 3.--Comparison of mean element contents of a high-lithium suite of samples with a low-lithium suite from Beaver Creek near Lincoln, Montana

[Sample descriptions in table 1]

	High lithium suite, n = 19 Samples TM653D-R		Low lithium suite, n = 19 Samples TM656A, B, TM1655EE, DD, BB, AA, X-U, S, R, P, N, M, J, H, C-A	
Element	Mean	Standard deviation	Mean	Standard deviation
	in ppm			
Li	713	407	71	30
	in percent			
Al	8.5	4.3	10.9	3.9
Na	1.5	.71	.63	.28
K	3.3	1.7	1.7	1.7
Fe	3.1	1.7	4.2	2.3
Ca	10.7	5.3	6.1	4.7
Mg	2.5	1.3	.8	.32
Ti	.19	.07	.23	.14
	in ppm			
Mn	410	190	860	1,050
B	150	130	50	20
Ba	630	250	1,500	980
Be	1.0	1.1	.82	.95
Co	4.9	2.2	4.1	4.2
Cr	18	6.9	13	8.3
Cu	28	21	53	38
Mo	3.6	3.2	2.1	3.8
Ni	8.5	7.0	4.4	3.3
Pb	13	2.9	16.6	9.0
Sc	8.9	4.0	7.4	4.0
Sr	560	550	180	120
V	58	18	50	37
Y	20	6.5	44	33
Yb	2.6	.80	5.1	3.1
Zr	62	29	97	36

Table 4 .--Lithium contents of tuffaceous sediments of Oligocene age in the Helena and Townsend Valleys, Montana

Sample No.	Tag. No.	Field Description	County	Section	T.	R.	Lithium in ppm
77-BG-314G	MAT 632	Fossil soil with clasts	Jefferson	NW¼ 11	9N	3W	82
315G	633	Fossil soil, pale green-gray, overlies Helena Dolomite of Precambrian Y age	do	do	do	do	200
316G	634	Massive tuff, light-colored	do	do	do	do	71
317G	635	Tuff, silicified	do	do	do	do	65
318G	636	Iron-rich vein in massive tuff	do	do	do	do	19
TM7-60A	643	Clay seam cutting metamorphosed Helena Dolomite of Precambrian Y age	do	do	do	do	140
60B	644	Tuff, very light green; contains clasts of Precambrian dolomite	do	do	do	do	25
60C	645	Tuff, light gray, altered; contains clasts of granitic rocks	do	SW¼ 2	do	do	89
58A	637	Rhyolite	do	SW¼ 14	do	do	65
58B	638	Clay gel, yellow-green, next to rhyolite	do	do	do	do	12
58C	639	Rhyolite, white, altered	do	do	do	do	6
58D	640	Tuff, light-colored, lapilli	do	do	do	do	100
59A	641	Yellow alteration zone in white coarse-grained micaceous tuff	do	SW¼ 1	do	do	51
59B	642	Tuff, white, coarse-grained, fluviatile, devitrified	do	do	do	do	32
61A	646	Tuff, yellow-gray, fluviatile	Lewis and Clark	SE¼ 26	10N	do	28

Table 4.--Lithium contents of tuffaceous sediments of Oligocene age in the Helena and Townsend Valleys, Montana--Continued

Sample No.	Tag. No.	Field Description	County	Section	T.	R.	Lithium in ppm
TM7-61B	MAT 647	Crystal tuff, medium-yellow; contains pumice fragments, double-terminated smoky quartz crystals	Lewis and Clark	SE¼ 26	10N	3W	37
62A	648	Clay, green-gray, platy, 20 percent white lithic fragments, popcorn weathering surface	do	SW¼ 27	11N	2W	20
62B	649	Tuff, altered, yellowish white, pumiceous, black stains, light brown gel streaks	do	do	do	do	15
62C	650	Shale, brown, lignitic, siliceous	do	do	do	do	7
62D	651	Flat-pebble conglomerate green clay pebbles in yellow-gray clay matrix; also contains sand-sized fragments of rocks and quartz	do	do	do	do	16
62E	652	Clay, green-gray, weathered	do	SE¼ 28	do	do	9
62F	653	Flat-pebble conglomerate-clay matrix-green-brown	do	do	do	do	16
62G	654	do	do	do	do	do	19
62H	655	Flat-pebble conglomerate, yellow	do	do	do	do	18
62I	656	Paper shale, carbonaceous	do	do	do	do	24
63A	657	Clay, dark yellow-green, gel-like	do	NW¼ 28	do	do	12
63B	658	Claystone, yellow; contains white altered pumice fragments	do	do	do	do	11
63C	659	Claystone, brown-gray, hard	do	do	do	do	17
63D	660	Clay, green	do	do	do	do	40

Table 4 .--Lithium contents of tuffaceous sediments of Oligocene age in the Helena and Townsend valleys, Montana--Continued

Sample No.	Tag. No.	Field Description	County	Section	T.	R.	Lithium in ppm
TM7-64A	MAT 661	Claystone, dark-green to black	Lewis and Clark	W cen 28	11N	2W	18
64B	662	Claystone, pale-gray	do	do	do	do	16
64C	663	Tuff, pale-gray, clayey; contains pumice fragments	do	do	do	do	16
64D	664	Chert, mottled yellow to red; occurs as a pod in white pumiceous tuff	do	do	do	do	3
64E	665	Claystone, dark-green, siliceous, shard textures, surrounds TM7-64D	do	do	do	do	9
64F	666	Claystone, light-green; contains pumice fragments, underlies TM7-64E	do	do	do	do	10
64G	667	Gel, yellow-green	do	do	do	do	13
64H	668	Shale, purple-gray, clayey, carbonaceous	do	do	do	do	21
65A	669	Clay, brown, gel-like	do	N cen 29	do	do	34
65B	670	Claystone, green-gray, shaly-weathering	do	do	do	do	44
65C	671	Claystone, dark red-gray	do	do	do	do	47
67A	682	Sandstone, white, tuffaceous, medium-grained, calcareous	Broadwater	NE¼ 35	4N	1W	6
67B	683	Conglomerate, light yellow-gray, tuffaceous, calcareous	do	do	do	do	18
68A	684	Sandstone, white, tuffaceous, medium-grained, calcareous	do	NW¼ 36	do	do	16

Table 4 .--Lithium contents of tuffaceous sediments of Oligocene age in the Helena and Townsend valleys, Montana--Continued

Sample No.	Tag. No.	Field Description	County	Section	T.	R.	Lithium in ppm
TM7-68B	MAT 685	Siltstone, very light gray brown, tuffaceous, manganese stained, weathered	Broadwater	NW¼ 36	4N	1W	20
68C	686	Manganese nodule from TM7-68B	do	do	do	do	7
70	691	Siltstone, light orange pink, tuffaceous; contains white pumice fragments	do	N cen 36	do	do	30
69A	687	Tuff, altered, pink to white	do	NW¼ 25	do	do	24
69B	688	Tuff, altered, white, fine-grained	do	do	do	do	11
69C	689	Tuff, pumiceous, light-gray to white	do	do	do	do	12
69D	690	Tuff, silty, light orange pink, pumiceous	do	do	do	do	34
71A	692	Siltstone, brown, sandy	do	SE¼ 25	do	do	30
71B	693	Claystone, brown, siliceous, crude bedding	do	do	do	do	32
72A	694	Claystone, medium brown-gray; contains seams of green gel-like clay	do	do	do	do	24
72B	695	Claystone, green and red mottling	do	do	do	do	41
73A	696	Calcrete, light tan to brown	do	SW¼ 30	do	1E	8
73B	697	Cylindrical concretions in TM7-73A	do	do	do	do	8
74A	698	Tuff, gray, devitrified; contains pink pumice fragments	Jefferson	NW¼ 11	3N	1W	26
74B	699	Similar to TM7-74A except contains some green fragments	do	do	do	do	33

Table 4.--Lithium contents of tuffaceous sediments of Oligocene age in the Helena and Townsend valleys, Montana--Continued

Sample No.	Tag. No.	Field Description	County	Section	T.	R.	Lithium in ppm
TM7-74C	MAT 700	Clay, pink, gel-like	Jefferson	NW¼ 11	3N	1W	33
74D	701	Sandstone, yellow-green to light gray tuffaceous; contains biotite flakes	do	do	do	do	20
74E	702	Claystone, medium brown, siliceous, banded light gray to yellow brown	do	do	do	do	40
75A	703	Claystone, brown, siliceous, plant imprints; coated with yellow-green alteration product	do	do	do	do	36
75B	704	Siltstone, light-green, dense, consolidated	do	do	do	do	19
75C	705	Claystone, mottled gray to pink gray to greenish gray; contains reed fragments	do	do	do	do	11
75D	706	Claystone, pale red, weathers green, leathery texture; popcorn weathering surface	do	do	do	do	14
75E	707	Tuff, brown-gray, weathers gray; contains pumice fragments	do	do	do	do	19
76A	708	Sandstone, dark green-brown, clayey, ashy, white salt on weathered surface	do	do	do	do	22
76B	709	Claystone, light brown, siliceous	do	do	do	do	29

The samples of tuff collected on the western side of the Helena valley (table 4) are anomalously high in lithium, containing as much as 100 ppm. Published estimates indicate an average of about 50 ppm Li in rhyolites (Heier and Billings, 1970); our experience in sampling rhyolitic tuffs and other light-colored tuffs throughout the Western United States indicates a slightly lower average value in unaltered tuffs. In contrast, samples of sedimentary rocks collected in the eastern part of the Helena valley and in the Townsend valley contain low amounts of lithium. Fossil teeth from these rocks indicate an early Oligocene age (R. G. Schmidt, 1977, oral commun.). Either these rocks are older than the lithium-rich sedimentary rocks on the west side of the valley or the lithium has been leached from the rocks since they were deposited.

The mean lithium content of the samples from the Townsend valley is 22 ppm. These samples were also analyzed for 23 other elements by semiquantitative spectrographic analysis (table 5). Samples TM7-68B and TM7-68C come from a

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Table 5.--NEAR HERE

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small manganese deposit in the lower Oligocene sedimentary-tuff sequence (Freeman, Ruppel, and Klepper, 1958). As can be seen, these samples contain large amounts of vanadium, molybdenum, and cobalt, suggesting the possible presence of uranium in the manganese deposits.

For the general trace-element contents of the samples from the Townsend valley, the geometric mean is a truer measure of average; the geometric mean is less affected by the high values in the manganese samples. The only element that appears anomalous is beryllium; its contents are slightly higher than are generally found in sedimentary rocks. Regression analysis was used to test for a correlation between beryllium and lithium contents, but none was found. However, lithium does tend to correlate with magnesium. The best fit curve gave $1/Y = A + B/X$; X = Li, Y = Mg, where $r = 0.67$ which is statistically significant at the 1 percent level ($rx = 0.01$ at 26 d.c. = 0.48). Possibly, the lithium occurs with magnesium in a clay mineral.

Table 5.--Semiquantitative spectrographic analyses of samples of tuffaceous sediments of Oligocene age collected in the Townsend Valley, Montana. [J. M. Motooka, analyst. Sample descriptions and localities given in Table 4, --. insufficient data for calculation]

Field Number	Number	Fe	Mg	Ca	Ti	Mn	B	Ba	Be	Co	Cr	Cu	La	Mo	Nb	Ni	Pb	Sc	Sn	Sr	V	Y	Zn	Zr	Li[1/]
		In percent				In ppm																			
TM7-67A	MAT 682[2/]	1.5	0.1	0.5	0.03	500	15	100	10	< 5	N	5	N	N	70	5	50	N	10	N	20	70	N	150	6
67B	683	2	.5	.7	.1	300	20	300	7	< 5	50	7	30	N	50	10	30	7	N	150	100	70	200	150	18
68A	684	1.5	1	1	.05	700	20	200	15	< 5	20	7	N	N	70	7	100	< 5	10	100	50	70	300	150	16
68B	685	5	.5	1.5	.2	>5000	20	>5000	3	100	20	50	50	20	N	20	30	15	N	700	500	50	N	100	20
68C	686[3/]	3	.3	1	.15	>5000	20	>5000	2	500	50	50	N	500	N	70	N	15	N	1500	10000	20	N	100	7
70	691	2	1.5	1.5	.15	300	30	700	7	10	50	15	30	N	20	10	30	10	N	300	100	50	N	150	30
69A	687	1.5	1.5	1	.07	2000	15	200	5	5	30	7	50	N	50	7	70	5	N	200	100	70	N	150	24
69B	688	2	.7	.5	.05	1500	20	150	10	< 5	N	5	20	N	70	5	100	< 5	10	100	50	70	<200	150	11
69C	689	2	.2	.7	.07	300	20	200	10	< 5	20	5	20	N	70	5	50	< 5	N	100	50	70	<200	150	12
69D	690	3	1	1	.15	300	30	>5000	2	15	100	20	30	N	N	20	50	15	N	300	150	30	N	100	34
71A	692	3	1	.7	.5	200	20	500	1.5	10	70	15	30	N	N	10	20	15	N	150	150	20	N	150	30
71B	693	3	1.5	1.5	.7	500	30	700	3	15	70	20	50	N	<20	15	30	15	N	300	150	30	N	150	32
72A	694	3	1	1	.3	200	30	700	2	15	70	20	30	N	N	15	30	10	N	200	150	10	N	70	24
72B	695	3	.7	1	.3	200	20	300	2	10	20	10	N	N	N	10	10	10	N	150	100	20	N	100	41
73A	696	3	1	>20	.15	2000	10	200	1	5	50	10	N	N	N	7	30	7	N	150	100	10	N	50	8
73B	697	1	.5	20	.1	2000	10	150	1	< 5	N	5	N	N	N	5	30	5	N	150	50	10	N	50	8
74A	698	.7	.7	1	.1	200	15	100	10	N	N	< 5	N	N	50	5	50	< 5	N	150	30	70	N	100	26
74B	699	1	1.5	1	.05	200	15	30	15	N	N	5	N	N	30	5	70	< 5	10	150	30	70	N	100	33
75A	700	1	1.5	1	.03	300	15	50	15	5	N	7	N	N	30	10	50	< 5	10	150	100	70	N	70	33
75B	701	1.5	.7	.5	.07	300	20	50	15	< 5	N	< 5	N	N	50	5	50	< 5	10	100	50	50	N	70	20
76A	702	1	.7	.5	.15	200	20	150	10	< 5	N	7	N	N	50	< 5	30	5	N	150	30	100	N	100	40
76B	703	2	1	.7	.15	200	20	150	10	5	N	10	20	N	70	5	70	7	N	150	50	100	N	100	36
77A	704	2	.7	.3	.3	100	20	200	7	5	20	10	20	N	<20	7	30	7	N	150	150	30	N	150	19
77B	705	1.5	1.5	.3	.3	70	30	300	7	10	30	15	20	N	20	15	50	10	N	150	500	20	N	150	11
78B	706	.5	.7	.3	.3	50	30	200	15	5	20	15	20	7	<20	10	70	10	N	150	50	20	N	100	14
78E	707	.7	.5	.5	.03	200	20	20	15	N	N	< 5	N	N	70	5	70	N	15	100	20	70	N	100	19
78A	708	1	1	.7	.3	300	30	300	3	10	50	15	20	N	20	20	30	7	N	200	150	30	N	150	22
78B	709	3	1.5	.7	.2	300	30	200	15	7	10	15	30	N	50	10	70	10	10	200	70	70	N	100	29
Geometric mean		2.3	.9	2.4	.16	1190	21	1290	7.8	27	28	13	<20	--	31	11	46	--	7	230	470	50	--	114	22
Std. deviation		1.4	.4	5.7	.1	2550	6	3080	5.2	94	28	12	--	--	28	12	24	--	5	280	1870	27	--	34	10
Geometric mean		1.9	.8	.9	.12	420	19	270	5.7	6	10	9	--	--	13	9	37	--	--	150	94	40	--	109	20

1/ Lithium analyzed for by atomic absorption
2/ 0.5 ppm Ag
3/ 50 ppm Cd

Other areas--Outcrops of Tertiary sedimentary rocks near Lincoln, Mont., were sampled (fig. 1). In general, the lithium contents were low (table 6)

Table 6.--NEAR HERE

and are similar to the values found in the Helena and Townsend valleys.

Samples of igneous rocks were collected by S. D. Ludington from the Lava Mountain area (fig. 1). The lithium content of the samples of granites and granodiorites are near the published averages for these rock types (Heier and Billings, 1970). However, the lithium values for unaltered rhyolite rocks ($\leq$ 150 ppm) are as much as three times the published averages and are comparable to the lithium content of rhyolites in the Thomas Mountains associated with the Spor Mountain beryllium deposit in Utah (Lindsey, 1977; R. K. Glanzman, 1977, oral commun.). Therefore, all of the rhyolitic rocks in the area should be sampled and analyzed for lithium; the anomaly suggests that even higher concentrations are possible. Also, as can be seen in table 4, the altered rhyolitic rocks are significantly lower in lithium. Thus, it is possible that the lithium leached from the altered rhyolites has been concentrated somewhere in sedimentary rocks younger than the rhyolites. The beds on Beaver Creek may represent such a concentration.

Table 6. Lithologic log [illegible] Montana area

Field No.	Tag. No.	Field Description	Location Section	T.	R.	Li ppm
TM748A	MNT 526	Claystone, yellow-brown, pebbly	S cen 29	15N	9W	46
TM748B	527	Claystone, brownish-gray; contains limonite stringers	do	do	do	40
TM748C	528	Tuff, very light gray, limonitic	do	do	do	39
TM748D	529	Claystone, light grayish brown, contains fossil snails and mollusks	do	do	do	36
TM749A	530	Claystone, gray, pebbly	NE 34	do	do	39
TM749B	531	Limestone, gray, lithic, brown weathering rind	do	do	do	36
TM749C	532	Limestone, very dark gray	do	do	do	72
TM749D	533	Claystone, yellow-gray; residium of 49C	do	do	do	54
TM749E	534	Claystone, dark gray, indurated	do	do	do	110
TM749F	535	Claystone, dark brownish-gray; has white weathering silt; crumbly	do	do	do	85
TM749G	536	Clay, brown, "gumbo;" has weathering salt	do	do	do	32
TM749H	537	Clay, less weathered than 49G, gray-green; carbonaceous	do	do	do	15
TM749I	538	Carbonaceous shale	do	do	do	9
TM749J	539	Siltstone, light yellow-gray; contains clay seams	do	do	do	23
TM749K	540	Claystone, green-gray, 2-3 cm thick	do	do	do	28
TM749L	541	Claystone, green-gray, pebbly	do	do	do	20
TM749M	542	Siltstone and claystone, lignitic	do	do	do	24
TM749N	543	Claystone, green-gray, and bright yellow; contains plant fragments	do	do	do	21
TM750A	544	Limestone, gray (0-0.6m)[1/]	do	do	do	39
TM750B	545	Limestone, gray, and clay, green-gray (0.6-1.2m)	do	do	do	90
TM750C	546	Limestone, gray, and clay, green-gray, sandy (1.2-1.8m)	do	do	do	43
TM750D	547	Claystone, green-gray, pebbly (1.8-2.4m)	do	do	do	32
TM750E	548	do (2.4-3m)	do	do	do	31
TM750F	549	do (3-3.7m)	do	do	do	56
TM751A	553	Sandstone, mottled red and gray, tuffaceous; contains quartz crystals	Cen 9	14N	8W	34
TM751B	554	Welded crystal tuff, red and yellow	do	do	do	22
TM751C	555	Clay, grayish-yellow, tuffaceous, gel-like	SE 9	do	do	15
TM751D	556	Chert, white and dark brown	do	do	do	9
TM751E	557	Porphyry, fine-grained, manganese-stained	do	do	do	42
TM751F	558	Claystone, red-brown to gray, gel-like	SW 10	do	do	17
TM752	559	Claystone, mottled red and gray	do	do	do	40
77SL004[2/]	LDN 602	Quartz monzonite	SW 33	7N	1W	9
77SL206	700	Rhyolite	NE 30	8N	2W	100
77SL206D	816	Soil above rhyolite	do	do	do	37
77SL207	701	Rhyolite	do	do	do	92
77SL207D	817	Soil above rhyolite	do	do	do	29

Table 6.--Lithium values in samples of Tertiary rocks in the Lincoln, Montana area--Continued

Field No.	Tag. No.	Field Description	Location			Li
			Section	T.	R.	ppm
77SL212	LDN 706	Rhvolite	NE 30	8N	2W	83
77SL212D	829	Soil above the rhyolite	do	do	do	34
77SL208	702	Rhyolite	do	do	do	110
77SL209	703	do	do	do	do	100
77SL210	704	do	do	do	do	100
77SL211	705	do	do	do	do	110
77SL213	707	do	do	do	do	96
77SL214	708	do	do	do	do	82
77SL215	709	do	do	do	do	100
77SL216	710	do	do	do	do	100
77SL029	606	Quartz monzonite	SW 24	do	3W	21
77SL030	607	Rhyolite	do	do	do	150
77SL034	626	Granodiorite	NW 11	do	2W	8
77SL035	671	do	do	do	do	13
77SL036	672	Altered rhyolite	NW 30	do	do	49
77SL037	673	do	do	do	do	22
77SL038	674	do	do	do	do	52
77SL043	695	Quartz monzonite	NE 30	do	do	28
77SL044	696	do	SE 19	do	do	22
77SL045	751	Quartz porphyry	NE 30	do	do	88
77SL046	752	Rhyolite	do	do	do	120
77SL057	254	Granite	NE 11	do	do	12
77SL058	255	Granodiorite	do	do	do	8
77SL077	241	Altered quartz monzonite	NE 21	7N	3W	7
77SL091	920	Granite	SW 19	8N	2W	70
77SL092	921	Breccia	do	do	do	84
77SL093	922	Granite	do	do	do	56
77SL094	923	Rhyolite	do	do	do	150
77SL096	924	do	SW 29	do	do	67
77SL097	925	Rhyolite glass	do	do	do	7
77SL098	926	Altered quartz monzonite	do	do	do	27
77SL099	927	Aplite	NE 31	do	do	4
77SL101	976	Quartz monzonite	SE 11	do	do	6
77SL102	977	do	SW 12	do	do	10
77SL159	LDV 159	Altered aplite	SE 16	7N	3W	4
77SL160	140	Altered quartz monzonite	NE 21	do	do	8
77SL162	142	Altered aplite	NW 22	do	do	6
77SL163	143	Quartz monzonite	do	do	do	19

Table 6.--Lithium values in samples of Tertiary rocks in the Lincoln, Montana area-- Continued

Field No.	Tag No.	Field Description	Location			Li
			Section	T.	R.	ppm
77SL180	LDT 282	Quartz monzonite porphyry	SW 34	8N	1W	11
77SL188	290	do	NW 3	7N	do	11
77SL189	291	Quartz vein	do	do	do	9
77SL196	298	Altered quartz monzonite porphyry	SE 34	8N	do	9
77SL198	300	Welded tuff	do	do	do	21
77SL201	303	Altered quartz monzonite porphyry	NW 35	do	do	7

1/ Sample series TM750 collected by augering; numbers in parentheses give depth of sample.

2/ 77SL samples collected by S. D. Ludington, summer 1977. Samples are not in stratigraphic order.

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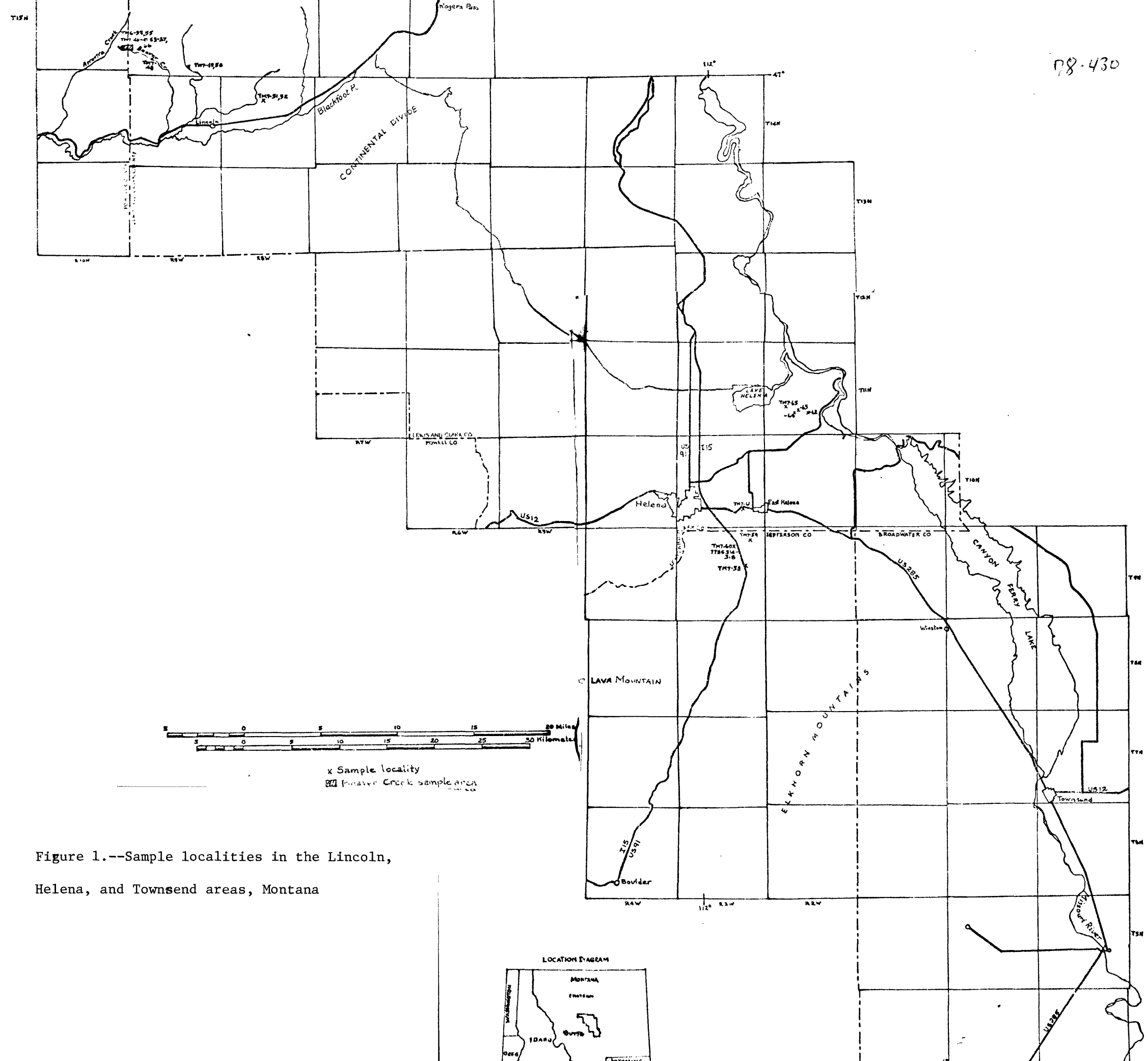

Figure 1.--Sample localities in the Lincoln, Helena, and Townsend areas, Montana