GEOCHEMICAL DISTRIBUTION OF URANIUM, TUNGSTEN, AND MOLYBDENUM IN THE TOMBSTONE MOUNTAINS BATHOLITH, YUKON

Project 750051: Uranium Reconnaissance Program

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Introduction

The exploration for uranium has been a recent development for the Yukon Territory. Initially, stream sediment sampling was carried out by exploration and mining companies in areas underlain by Proterozoic (Helikian ?) sedimentary and volcanic rocks where several uranium occurrences are associated with intrusive and extrusive breccias. Recently, however, increasing emphasis has been placed on alkaline multi-phase intrusive rocks as not only a source but a host for the 'porphyry uranium' (Armstrong, 1974) type of deposit. Uranium deposits of this type occurring elsewhere in the world include the Bokan Mountain deposits of Alaska (Mackevett,1963), the Rossing deposit of South West Africa (Berning et al., 1976) and the Crocker Well deposit of South Australia (Campana and King, 1958).

During the summer of 1976, 28 490 km^2 of the central Yukon were surveyed at a density of one sample in five square miles in an effort to evaluate the uranium potential of a range of geologically favourable environments (Goodfellow et al., 1976). Detailed studies of selected areas were carried out in conjunction with the reconnaissance survey with the objective of providing additional information on the various chemical and mechanical processes affecting the supply, transport and deposition of elements in the stream system. Samples of stream sediments and water were collected at a density of four samples per line of stream. Rock samples representing the different lithologies were also collected.

One area investigated in greater detail is the Tombstone Mountain area (Detail Area No. 7, Jonasson and Goodfellow, 1976) of the west central Yukon (Fig. 6.1) which is underlain by Cretaceous alkaline plutons that intrude older sedimentary rocks. This area is of particular interest in light of the occurrence of uranium in veins intersecting the pseudoleucite tinguaite phase of the Tombstone batholith.

Geology and Petrography

The Tombstone Mountains are characterized by jagged spires, some of which are bounded by fault-controlled vertical sides, which are intersected by deeply incised streams. Below approximately 1500 m, the stream valleys are filled primarily with glacial and alluvial material, much of which is indigenous.

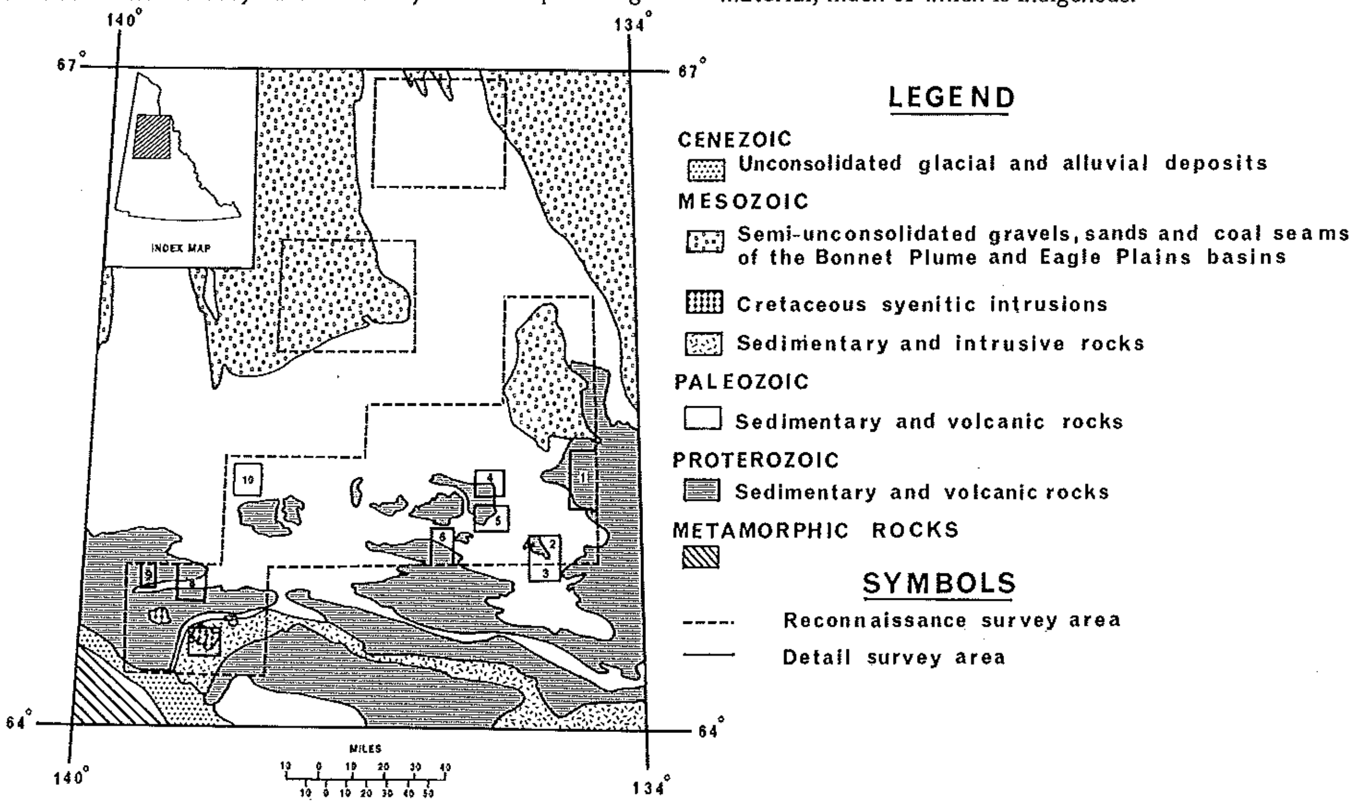

Figure 6.1. General geology of the central Yukon with the outline of the reconnaissance and detailed survey areas (the Tombstone batholith is located in detail area No. 7).

From: Report of Activities, Part B;
Geol. Surv. Can., Paper 77-1B (1977)

The geology of the Tombstone Mountains of the west-central Yukon Territory has been mapped most recently by Green (1972) and by Tempelman-Kluit (1970). The area that was surveyed geochemically (Fig. 6.2) is underlain by an alkaline batholith of Cretaceous age which intrudes Cretaceous Keno Hill Quartzite, diorite and gabbro, and Jurassic sedimentary rocks. The petrography of the Tombstone batholith was examined most recently by Tempelman-Kluit (1968) and the following descriptions are taken from that account. The core of the batholith is composed of alkali syenite which is enclosed by monzonite, quartz monzonite and diorite towards the margins. The syenite which makes up the bulk of the intrusion is composed of phenocrysts of orthoclase set in a medium grained allotriomorphic groundmass of microperthitic orthoclase, andesine, aegerine-augite, amphibole, biotite and minor quartz. The accessory minerals are sphene, zircon, apatite and opaques.

Pseudoleucite tinguaite occurs in two areas within the Tombstone batholith. In the first area, pseudoleucite tinguaite is located along the southern margin of the batholith where it occurs in sharp contact with monzonite and Keno Hill Quartzite. The second area is located near the centre of the batholith where pseudoleucite tinguaite is in gradational contact with the enclosing syenite.

Pseudoleucite tinguaite is composed of phenocrysts of pseudoleucite, an intergrowth of potash feldspar and nepheline, set in a groundmass of potash feldspar, nepheline, biotite, fluorite and minor cancrinite. The pseudoleucite phenocrysts show excellent trapezohedral crystal form and contain cancrinite, calcite, plagioclase, biotite and melanite in addition to orthoclase and nepheline. Narrow veins of fluorite and galena cut the rock locally and many pseudoleucite crystals are altered in part to clay minerals and sericite.

Geochemistry

The analytical results for stream sediment and water are presented in Table 6.1. Stream sediments were sieved to minus 80-mesh and analyzed by Chemex Laboratories for Au, Pb, Zn, Co, Ni, Ag, Mn, Fe, Ba, Mo (AAS) and W (colorimetry). Stream waters were collected unfiltered and analyzed by Barringer Research Laboratories, Whitehorse, for U (fluorimetric), F (specific ion electrode) and pH. The water samples were then shipped acidified to the Geological Survey laboratories where they were subsequently analyzed for Au and Pb (flameless AAS).

Most of the sediment in streams draining the Tombstone batholith has been derived by the mechanical breakdown of rock-forming minerals which have been transported as particulates during the heavy spring run-off. Stream sediments range in size from fine silt to boulders, with only minor organic matter present. The low Mn concentrations in stream sediments (Table 6.1), which are in general comparable in Mn levels in the underlying rock (Table 6.2), demonstrate the absence of

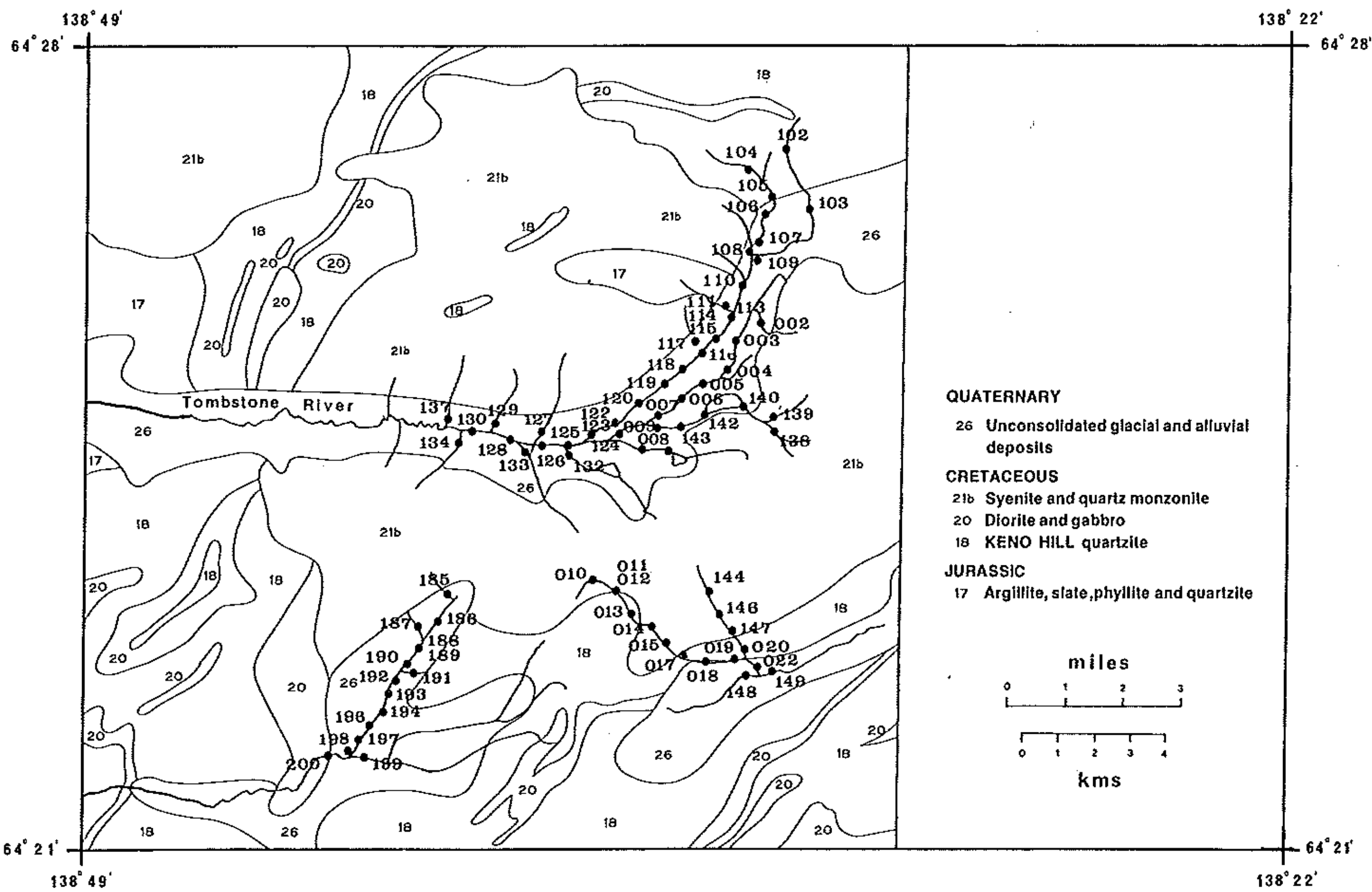

Figure 6.2. Sample number (116B763 series) locations for stream sediments and waters (geology after Green, 1972).

Table 6.1

Chemical Analyses of Stream Sediments and Waters from the Tombstone Mountains

	STREAM SEDIMENT												STREAM WATER				
SAMPLE NO	Zn	Cu	Pb	Ni	Co	Ag	Mn	Fe	Ba	Mo	W	U	U	F	Cu	Pb	pH
116B 763002	103	55	31	15	8	0.1	325	1.90	1130	10	20	48.1	0.08	290	4.2	0.8	7.4
03	94	37	31	11	4	0.0	220	1.90	1230	9	20	60.1	0.22	300	1.2	0.8	7.3
04	91	35	26	21	8	0.1	380	2.25	1200	10	8	28.3	0.03	300	1.1	0.8	7.3
05	63	21	21	12	5	0.1	280	1.90	1160	13	45	31.8	0.08	380	0.7	<0.5	7.4
06	63	20	20	12	5	0.1	140	1.55	1140	9	20	26.5	0.04	400	2.2	2.5	7.3
07	88	26	26	16	7	0.1	425	2.15	1230	11	15	41.5	0.10	410	1.4	1.6	7.3
08	65	19	28	8	5	0.1	255	1.90	1150	8	100	157.5	0.14	340	1.6	1.7	7.2
09	105	25	29	14	6	0.1	560	2.15	1170	14	50	133.0	0.12	400	0.8	0.7	7.3
10	270	57	200	14	8	0.1	450	2.30	830	3	15	29.0	0.12	310	0.8	1.0	7.3
11	220	70	136	26	15	0.1	755	3.30	1060	14	15	99.6	0.60	370	3.5	3.3	7.1
12	225	71	124	24	15	0.1	475	3.30	1080	11	20	115.4	0.06	390	1.7	1.2	7.2
13	182	70	172	39	25	0.1	500	4.90	700	47	20	14.9	0.04	210	0.8	0.7	7.1
14	166	34	110	18	11	0.2	680	2.50	800	9	8	55.5	0.06	400	<0.5	<0.5	7.3
15	164	33	103	20	11	0.2	640	2.40	880	7	5	74.4	0.10	450	1.2	<0.5	7.4
17	120	90	74	11	5	0.1	495	1.75	920	2	10	44.8	0.12	490	<0.5	<0.5	7.3
18	98	17	62	9	5	0.1	510	1.70	860	2	2	54.7	0.10	550	<0.5	0.5	7.5
19	106	25	68	11	6	0.1	465	1.70	800	2	2	51.4	0.12	570	<0.5	<0.5	7.4
20	130	31	74	14	8	0.1	570	2.10	960	1	2	66.3	0.08	500	<0.5	0.7	7.1
22	91	22	50	11	5	0.1	385	1.60	880	1	2	50.8	0.06	560	1.5	<0.5	7.4
116B 763102	104	200	21	42	22	0.1	310	5.10	870	8	6	12.0	0.02	26	1.6	<0.5	6.5
103	74	92	16	34	26	0.1	520	2.80	1270	4	2	11.6	0.02	24	0.6	<0.5	6.2
104	149	275	60	59	35	0.2	270	4.30	820	7	2	33.2	0.04	30	2.5	<0.5	6.6
105	178	390	62	83	136	0.6	3000	5.85	700	27	6	71.6	0.02	36	1.7	<0.5	6.8
106	54	30	17	16	12	0.1	250	2.05	770	5	2	11.2	0.18	42	1.0	<0.5	6.9
107	104	82	32	32	12	0.1	495	2.75	980	3	6	17.3	0.02	48	1.0	<0.5	6.9
108	102	75	36	23	20	0.1	720	2.65	970	4	6	29.7	0.08	68	1.3	<0.5	7.0
109	72	67	26	29	15	0.1	245	2.10	970	4	20	23.1	0.02	66	0.8	<0.5	7.0
110	95	37	25	18	10	0.1	350	2.05	1350	4	15	21.1	0.04	92	1.0	<0.5	7.0
111	150	116	35	30	17	0.1	440	3.50	1280	8	6	22.8	0.02	132	2.7	<0.5	7.0
113	110	73	25	19	18	0.1	540	2.35	1460	4	10	19.4	0.74	100	1.3	<0.5	6.8
114	106	44	21	20	17	0.1	525	2.10	1480	4	20	25.9	0.04	142	1.9	<0.5	7.1
115	98	41	19	19	14	0.1	425	2.10	1360	3	10	26.9	0.04	144	1.9	<0.5	7.1
116	80	37	17	16	11	0.1	340	1.70	1380	2	6	20.6	0.04	144	1.1	<0.5	7.1
117	135	86	29	20	16	0.1	515	2.70	1440	11	6	45.6	0.04	300	1.0	<0.5	7.1
118	86	38	18	17	12	0.1	375	1.90	1390	2	6	24.8	0.02	172	0.7	<0.5	7.1
119	89	40	19	18	12	0.1	345	1.90	1480	4	2	22.4	0.02	156	2.7	<0.5	7.1
120	55	27	16	12	7	0.1	270	1.40	1370	1	2	13.2	0.02	184	1.6	<0.5	7.2
122	61	26	16	13	9	0.1	285	1.40	1480	2	6	19.1	0.02	210	1.5	<0.5	7.3
123	57	25	14	12	7	0.1	275	1.40	1360	2	20	19.5	0.04	210	1.1	<0.5	7.2
124	60	27	15	13	8	0.1	280	1.35	1530	2	6	16.5	0.02	220	2.2	<0.5	7.2
125	67	28	17	14	10	0.1	330	1.50	1500	2	6	20.8	0.09	360	1.4	<0.5	7.3
126	66	28	16	13	9	0.1	305	1.50	1440	2	2	19.1	0.10	370	4.5	4.0	7.3
127	77	38	21	13	6	0.1	295	2.10	1130	3	6	20.8	0.02	152	1.0	<0.5	7.0
128	74	29	17	14	9	0.1	365	1.60	1500	2	10	0.6	0.08	360	0.8	<0.5	7.2
129	90	32	20	16	9	0.1	420	2.00	1070	2	2	24.9	0.04	240	0.8	<0.5	7.2
130	58	24	17	11	7	0.1	300	1.50	1380	3	15	29.5	0.06	360	1.5	<0.5	7.2
131	112	43	70	13	14	0.1	1520	2.60	970	87	60	578.5	0.46	300	2.1	2.5	6.9
132	97	25	18	13	7	0.1	495	2.25	1130	12	30	76.7	0.06	350	1.0	<0.5	7.0
133	76	24	31	7	6	0.1	660	1.80	1480	5	6	48.3	0.20	280	1.0	0.7	7.1
134	47	11	15	6	5	0.1	350	1.35	1500	4	10	27.5	0.40	410	1.0	0.9	7.3
135	90	27	21	22	11	0.1	950	2.70	1000	60	200	90.4	0.64	310	0.5	<0.5	6.7
137	71	23	36	11	7	0.1	300	2.40	1100	5	2	23.0	0.02	168	0.5	<0.5	6.9
138	48	8	32	2	2	0.1	275	1.10	1500	1	8	61.8	1.00	176	0.8	0.6	7.0
139													0.92	280	1.1	0.8	7.1
140	79	21	28	8	5	0.1	225	1.60	1070	12	50	223.1	0.56	330	0.7	<0.5	7.2
142													0.24	300	0.9	<0.5	7.0
143	87	24	31	10	5	0.1	255	1.75	1040	15	75	218.4	0.26	330	0.7	<0.5	7.0
144													0.04	400	1.0	0.9	6.6
146													0.20	440	0.5	<0.5	7.0
147	160	36	80	28	10	0.1	660	2.70		1	2	51.6	0.10	460	0.5	<0.5	6.7
148	79	31	36	19	7	0.1	400	1.80	1140	1	2	6.2	0.02	72	0.8	<0.5	7.6
149													0.06	500	1.1	0.8	7.4
185	175	53	145	14	10	0.1	755	2.60	880	4	2	15.6	0.02	220	0.9	1.3	7.3
186	115	29	83	11	6	0.1	380	2.30	1080	2	5	14.5	0.02	220	3.2	3.5	7.2
187	180	32	109	11	7	0.1	665	2.25	1040	2	60	23.0	0.02	84	1.1	1.4	7.4
188	220	40	144	10	12	0.1	940	3.60		1	2	20.6	0.02	260	1.5	<0.5	7.3
189	180	41	114	13	10	0.6	795	2.60	940	3	2	28.7	0.02		1.0	3.8	
190	200	37	148	11	10	0.2	800	2.90	1010	2	2	31.4	0.02	280	1.0	12.0	7.3
191	140	18	138	14	9	0.4	500	1.65	780	1	2	11.0	0.10	126	1.0	1.0	7.8
192	155	30	107	12	9	0.2	585	2.20	1000	2	2	28.2	0.02	240	2.2	2.4	7.4
193	285	41	630	11	8	1.8	855	2.75	1000	2	2	21.8	0.02	240	2.2	2.1	7.5
194	325	49	1040	11	9	1.8	1020	2.95	990	4	10	20.1	0.02	240	1.0	1.4	7.5
196	215	38	495	9	7	1.8	695	2.55	1090	1	2	23.3	0.02	230	2.0	16.0	7.5
197	180	38	350	12	8	1.4	555	2.50	1050	2	2	17.5	0.02	240	2.6	13.0	7.5
198	210	45	430	17	10	1.6	660	2.55	960	2	2	18.2	0.02	240	1.5	1.0	7.4
199	88	24	23	21	8	0.1	310	1.95	1040	1	2	3.6	0.02	60	2.1	7.0	7.9
116 763200													0.02	56	3.0	16.0	7.6

Stream Sediment: Fe in %, other elements in ppm Stream Water: All elements in ppb

Table 6.2

Chemical analyses of rocks from the Tombstone Mountains

Sample No.	Cu	Pb	Zn	Co	Ni	Mn	Fe	U[1]	U[2]	Ag	W	Mo	Ba	Rock Type
116B765002	9	40	16	2	2	133	0.88	9.4	16.4	0.2	2	7.9	540	Monzonite
03	2	40	68	2	2	77	0.66	13.6	22.2	0.2	2	3.8	330	"
04	3	17	36	2	2	319	2.42	34.0	60.0	0.2	2	2.5	210	"
05	4	32	47	5	2	365	1.32	3.6	5.1	0.2	4	2.5	1880	Syenite
06	4	17	16	2	2	139	0.70	2.4	3.0	0.2	4	3.8	1860	"
07	5	48	68	7	2	460	2.75	5.2	10.0	0.2	4	7.2	1840	"
08	4	64	54	2	2	494	2.00	20.0	31.3	0.2	4	11.6	470	Monzonite
09	3	80	88	5	2	674	2.27	16.8	26.1	0.2	2	3.8	1560	Syenite
10	4	48	91	2	2	572	2.00	14.4	24.7	0.2	2	4.4	230	Pseudoleucite tinguaite

Notes: all elements in ppm except Fe which is in %
[1] uranium determined fluorimetrically
[2] uranium determined by delayed neutron activation

inorganic matter as a scavenger of trace and minor elements. The mechanical derivation of most sediments is attested to by the overall similarity in major element chemistry between the stream sediments and rocks from the Tombstone batholith. Because of the large difference in Ba between the syenite and monzonite of the Tombstone batholith (Table 6.2), the distribution of Ba in stream sediments is particularly effective in differentiating the syenitic core from the monzonitic margins of the batholith.

The high Cu and Ni in the minus 80-mesh fraction of stream sediment compared to their concentrations in the underlying rocks undoubtedly results from their hydromorphic dispersion and sorption onto the surfaces of fine particulate material. The Cu concentration of stream water certainly supports this interpretation.

The high Zn, Ni and to a lesser extent, Cu and Pb in sediments (763102-763117) from streams draining the northeastern contact of the batholith reflect the Jurassic shales which have been mapped in this area. The low pH of streams draining these pyritic shales is important in the dissolution of metals from the underlying Jurassic shales.

The distribution of U in stream sediments (Fig. 6.3) outlines two areas of high U potential within the Tombstone batholith. The first area has U concentrations ranging up to 115 ppm (Table 6.1) in sediments from streams draining the southern contact of the batholith where U mineralization in the form of pitchblende occurs in veins intersecting pseudoleucite tinguaite. The second area contains U concentrations ranging up to 576 ppm in sediments from three tributaries of the Tombstone River which intersect the centre of the batholith where syenite has been mapped. At their confluences with the Tombstone River, the U content of stream sediments decreases rapidly to background levels, presumably due to an overwhelming dilution effect.

The concentrations of U in stream sediments most likely resulted from a combination of mechanical and chemical processes. From Table 6.2 it is clear that approximately 50 per cent of the U is present in the rock in a readily leachable form, possibly associated with fluorite and apatite, or occurring as pitchblende; the remainder is tied up in minerals such as zircon and sphene which are relatively resistant to decomposition. Consequently, it is not surprising that the U anomalies in the coarse fraction (-20 + 80 mesh) of stream sediments are coincident with U anomalies in the fine fraction (-80 mesh).

The distribution of U in stream water (Fig. 6.4) is very similar to the U pattern in stream sediments. In general, two areas are outlined within the Tombstone batholith that have U concentrations ranging up to 1 ppb. The high concentrations of U and F (Fig. 6.5) further suggest that a portion of the U may be associated with fluorite or apatite, both of which are accessory minerals in the pseudoleucite tinguaite (Tempelman-Kluit, 1968). The high F associated with U in tributaries of the Tombstone River draining from the centre of the batholith suggests that this area should be investigated for additional occurrences of tinguaite which is considered to be the host for U along the southern contact.

The presence of galena veinlets intersecting the pseudoleucite tinguaite (Tempelman-Kluit, 1968) undoubtedly explains the association of high Pb (Fig. 6.5) with U and F in streams draining the southern contact. The presence of galena and sphalerite in this area is indicated further by the high Pb (200 ppm) and Zn (270 ppm) in stream sediments. The abnormally high Pb (16 ppb) in waters and Ag, Pb and Zn in sediments from streams draining the southwestern contact reflect the presence of Ag-Pb-Zn (Spotted Fawn Property) mineralization known to occur in veins intersecting the Keno Hill Quartzite (Cockfield, 1919). The concentration of Pb in stream waters is well within the solubility limits of $PbCO_3$ for the neutral to slightly alkaline pH conditions of streams draining the Tombstone batholith.

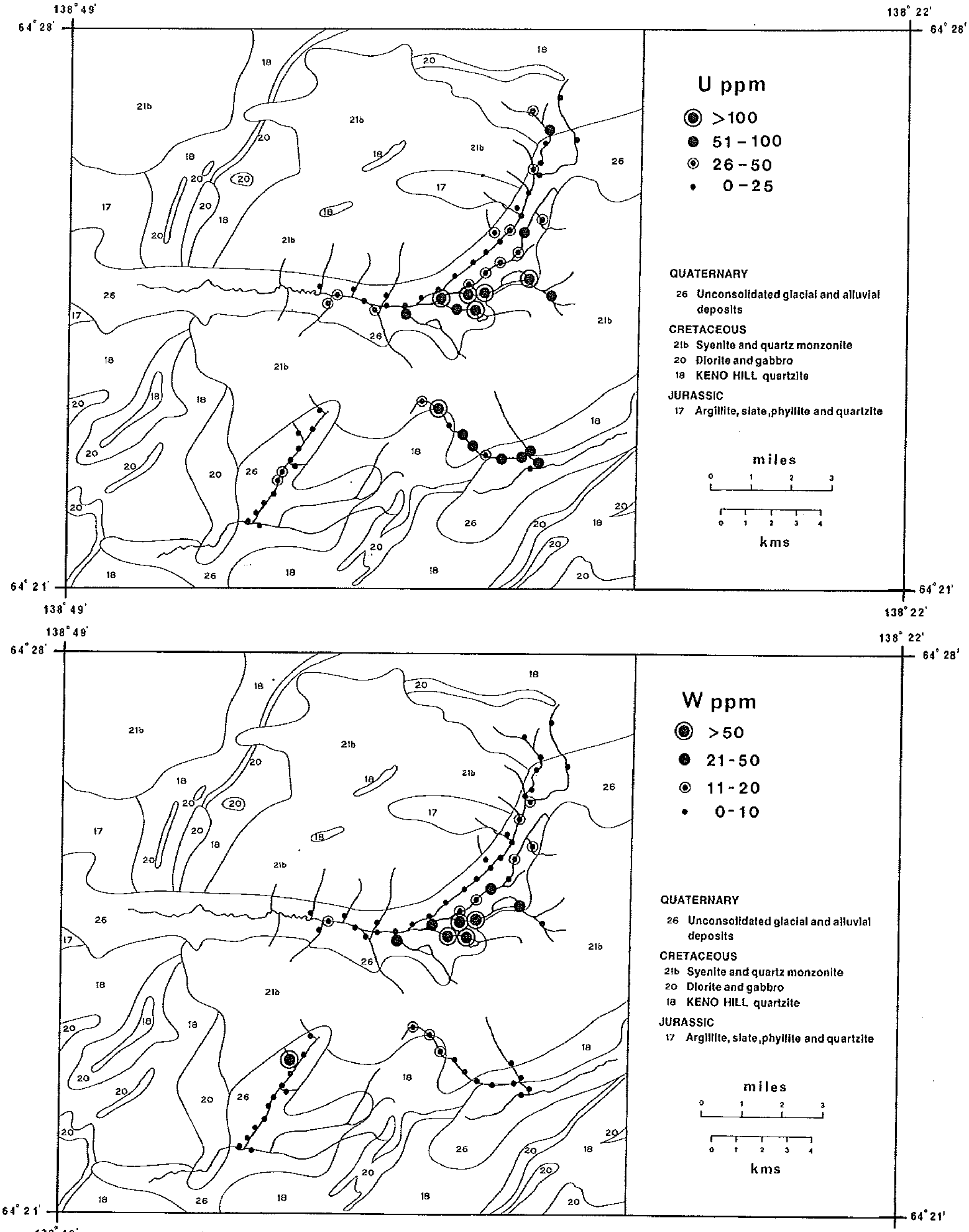

Figure 6.3. Distribution of U and W in sediments (minus 80-mesh fraction) from streams draining the Tombstone batholith.

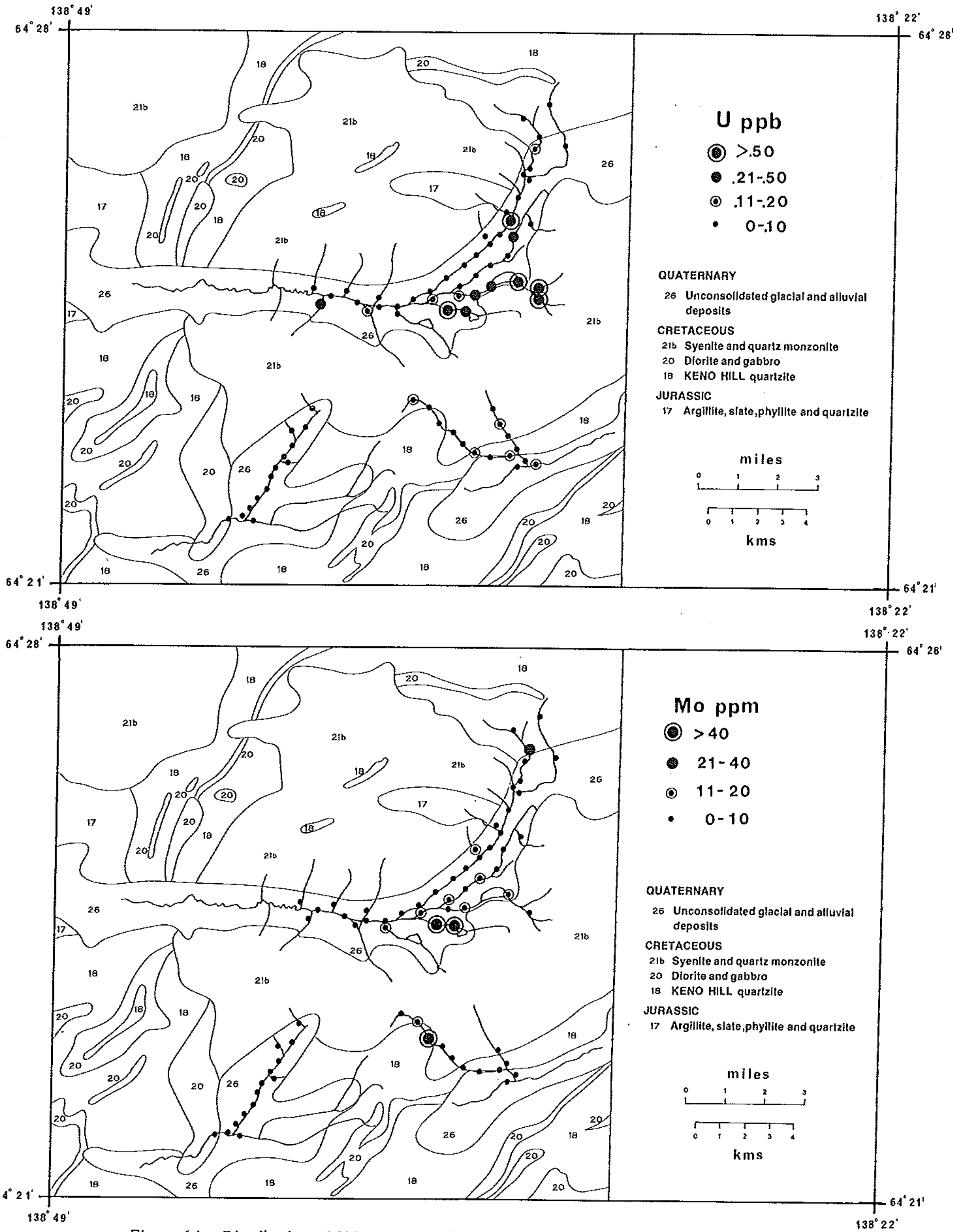

Figure 6.4. Distribution of U in waters and Mo in sediments (minus 80-mesh fraction) from streams draining the Tombstone batholith.

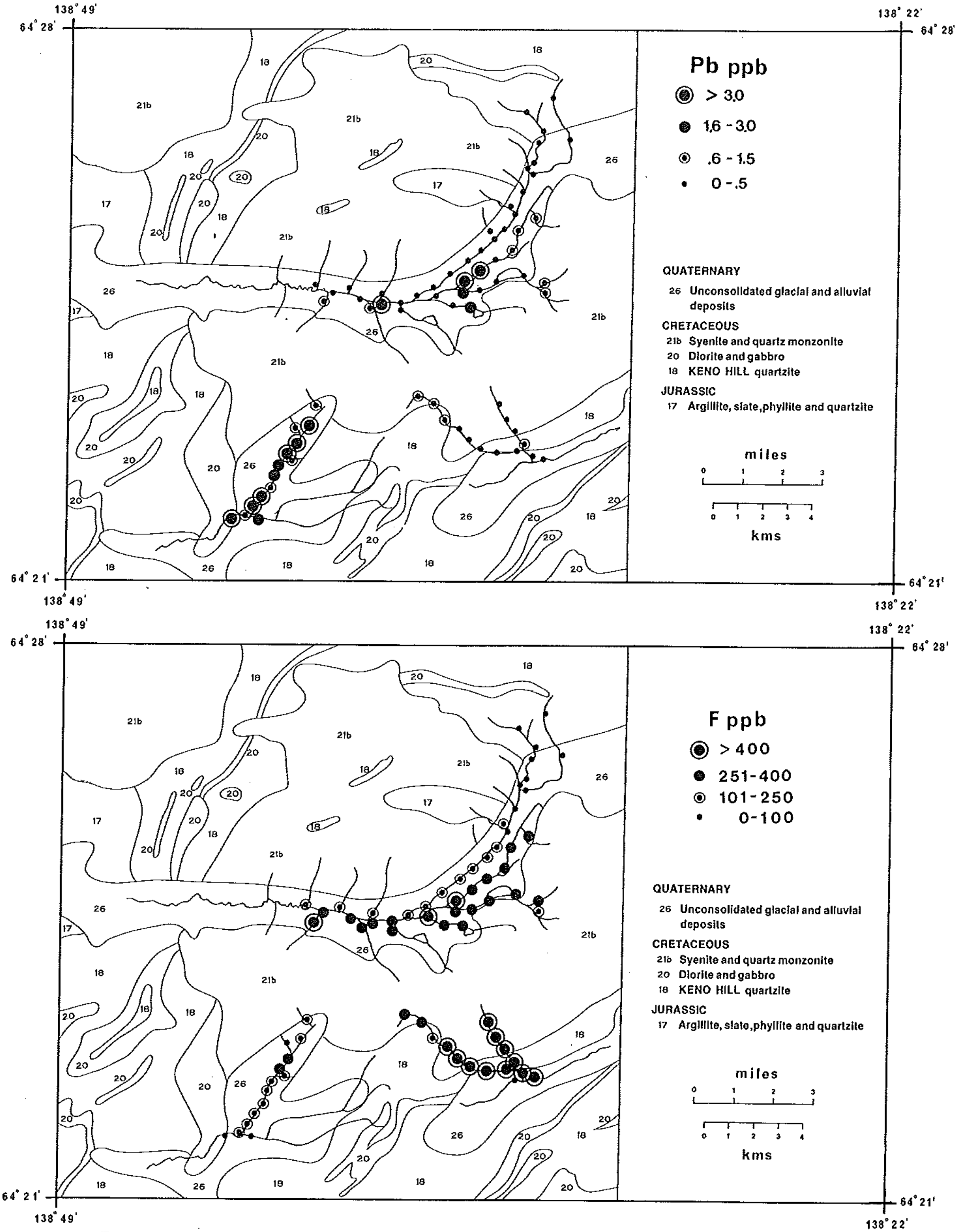

Figure 6.5. Distribution of Pb and F in waters from streams draining the Tombstone batholith.

The high Pb in stream waters from tributaries of the Tombstone River draining the central sections of the batholith is spatially associated with the U anomaly in this area. However, the stream sediments, unlike those draining the southern contact, contain background levels of Pb, Zn and Ag suggesting that the mineral associations in these sections of the batholith are different.

For all streams intersecting the Tombstone batholith, there is close spatial association of high W (Fig. 6.3), Mo (Fig. 6.4) and U in the stream sediments. Certainly, a U – Mo association is not unusual but W is less commonly associated with U in similar geological environments described elsewhere (Mackevett, 1963; Semenov, 1974). By examining their distribution in the underlying rocks (Table 6.2), it is apparent that although the U – Mo association is present, there is no clear association of W with U. One possible explanation for what appears to be contradictory evidence of the W – U association in stream sediments and rocks is that W is not directly associated with the U mineralization but spatially zoned about it. One possible mode of occurrence would be in scheelite veins similar to W showings present in acid plutons from the Keno Hill area.

Discussion

The Tombstone batholith represents a multiphase intrusion which is zoned from syenite at the core to pseudoleucite tinguaite at the southern contact where it intrudes monzonite and quartzite (Tempelman-Kluit, 1968). The tinguaite, which may represent the end product of an oversaturated differentiation series, contains abnormally high concentrations of U, likely associated with fluorite. Under processes of fractional crystallization in a closed system, U would be retained in a halogen-rich and carbonate residual magma as a complex ion (Bohse et al., 1974).

Uranium deposits associated with differentiated plutonic rocks would be expected to occur where the residual halogen-rich magma concentrated at the apical area of the magma chamber, or was intruded into the enclosing rocks. Sørenson et al. (1974) have demonstrated that the Kavenfjeld U deposit of South Greenland formed by the partitioning of U into a halogen-rich residual magma which later solidified. Other U deposits which are considered to have formed under similar processes include the Rössing of South Africa (Backström, 1970) and the Ross Adams of Alaska (Mackevett, 1963), both of which contain U associated with fluorite veins which intersect a highly differentiated igneous complex.

In terms of exploration, the principal criterion of a "uranium porphyry" type of deposit would be a highly differentiated complex that formed under a closed system, thus retaining the volatiles. Miarolitic granitic rocks indicate that at least some of the volatiles escaped, perhaps due to a decrease in pressure, sometime during the crystallization process. Consequently, the U would be expected to be dispersed into cavities throughout the rock and would therefore be unlikely to form U concentrations, at least initially. Massive plutonic rocks, however, indicate that the volatiles were retained and the U may be expected to be concentrated in the residual magma.

This interpretation of the origin of U in the Tombstone batholith is supported by the geochemistry of stream sediments and waters, and rocks. The association of U with F is supported by the presence of fluorite veins which intersect pseudoleucite tinguaite along the southern contact where U in the form of veins occurs. This area of U mineralization is outlined by high U, Mo, W, Pb and Zn in stream sediments and U, F and Pb in stream waters. A second area near the centre of the batholith is also outlined by similar element associations in tributaries of the Tombstone River where no tinguaite has yet been mapped. However, in light of the geochemical response, it must be considered an area of high U and W potential.

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