UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

URANIUM AND THORIUM IN PRECAMBRIAN CRYSTALLINE ROCKS OF THE MEDICINE BOW MOUNTAINS, NORTH-CENTRAL COLORADO

by

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INTRODUCTION

Reconnaissance mapping in the Medicine Bow Mountains of northern Colorado has revealed two plutons that have intruded a complex sequence of interbedded metasedimentary and metaigneous rocks. One pluton, named the Rawah batholith by McCallum and others (1975), occupies more than 1550 km^2 (600 mi^2) and is a major geologic feature in this portion of the State. Granitic rocks of the Rawah batholith have been dated at 1.71± b.y. (McCallum and Hedge, 1976) and they are equivalent to Boulder Creek age plutons to the south (Peterman and others, 1968). Descriptions of rocks in the Rawah batholith are given by Hermelin (1970), Filson (1973), Hartmann (1973), McCallum and others (1975), McCallum and Hedge (1976), and Griswold (1980). The second pluton occupies approximately 65 km^2 (50 mi^2) and appears to be an isolated intrusion of the Sherman batholith which covers several thousand square kilometers in southeastern Wyoming and adjacent areas of Colorado. This pluton is referred to as the Boswell Creek stock and is considered to be approximately 1.40± b.y. old. Rocks of portions of this pluton have been described by Hartmann (1973) and Fechner (1979).

The Front Range immediately east of the Medicine Bow Mountains (fig. 1) has long been considered a U-Th province, and Precambrian granitoid rocks have been studied to assess their potential as possible source rocks for U (Phair and Gottfried, 1964; Sims and Sheridan, 1964). Increased activity in the field of energy-related exploration rekindled interest in the region. This study was initiated primarily to determine U and Th background values in the recently recognized Rawah batholith. A secondary goal was to evaluate the regional distribution of U and Th in all of the Precambrian granitoid rocks in the Colorado Medicine Bow Mountains. This objective was accomplished utilizing trend surface analysis.

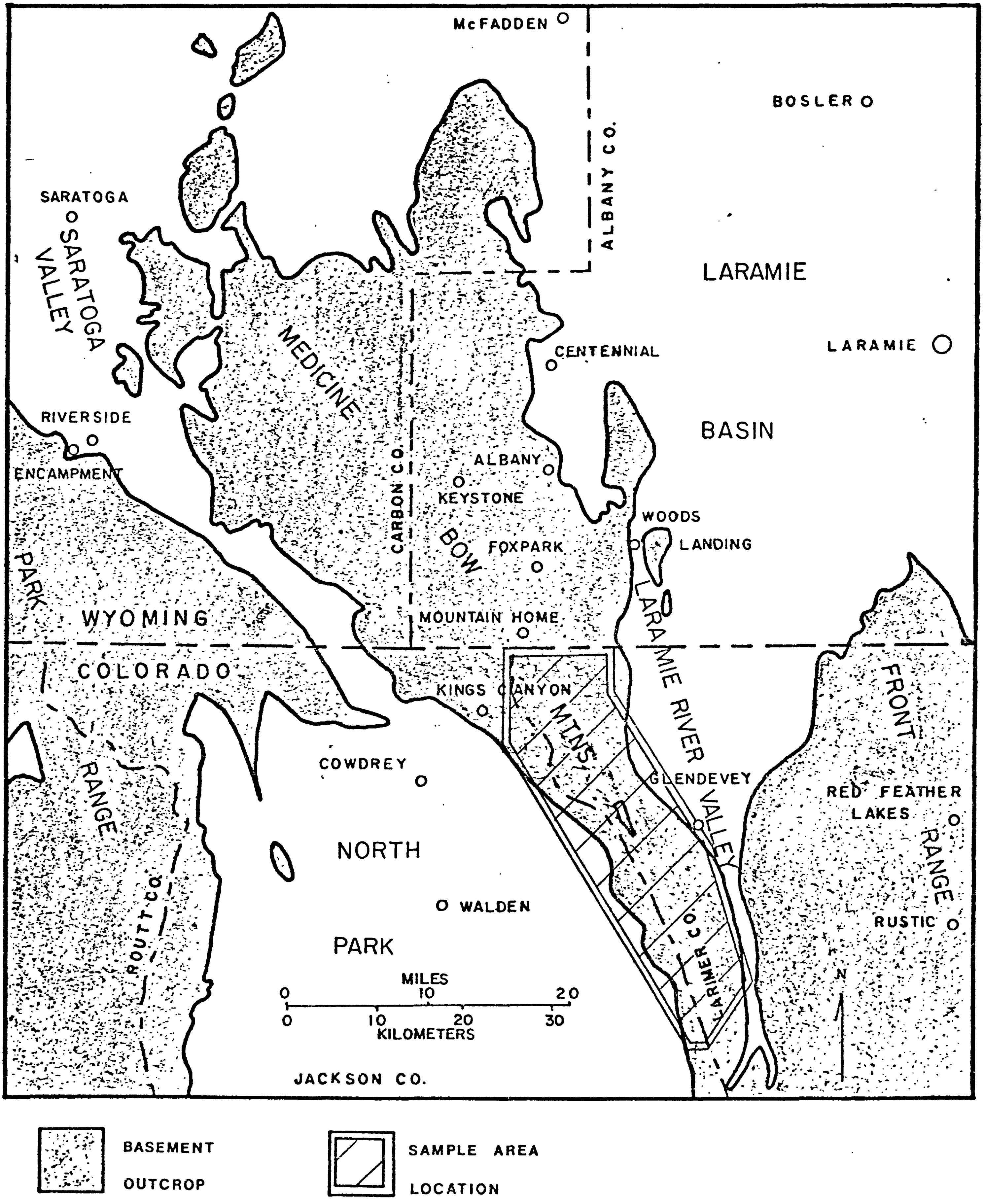

Figure 1. Location of sample area in Medicine Bow Mountains, Colorado.

GEOLOGIC DISCUSSION

The core of the Medicine Bow Mountains in north-central Colorado is composed predominantly of Precambrian plutonic rocks. Most abundant are granitoid rocks of the Precambrian Rawah batholith that were emplaced into a complex sequence of interbedded metamorphic rocks during and immediately following a major regional metamorphic event (McCallum and others, 1975). The Rawah batholith is cut near the Colorado-Wyoming border by a stock of the Precambrian Sherman granite. Phanerozoic sedimentary rock flanking the Precambrian core of the Medicine Bow Mountains along the southwestern and northeastern margins define the synclinal basins of North Park and the Laramie River Vallies respectively (fig. 1).

Metamorphic Rocks

Metamorphic rocks in the Medicine Bow Mountains consist of a complex sequence of pelitic, quartzofeldspathic, and calcareous units interbedded with hornblende gneiss and intruded by metadiorite, meta-quartz diorite, metagabbro and metapyroxenite. These rocks were metamorphosed to upper amphibolite facies grade by a regional metamorphic episode that took place at least 1750 m.y. ago (Hedge and others, 1967, p. 554). The metamorphic units in the Colorado Medicine Bow Mountains occur predominantly as xenoliths in the Rawah batholithic rocks except to the northwest (just outside map area, pl. 1) where a nearly continuous sequence of metasedimentary-metaigneous (?) units marks the northern extent of the batholith. Abundant migmatite zones and extensive textural and chemical variations in the granitoid rocks suggest that assimilation or partial melting of metamorphic host rocks was important at least locally.

Rawah Batholith

Plutonic rocks of the Rawah batholith vary compositionally from quartz diorite to granite as defined by Streckeisen (1976); however, biotite-rich granite (equivalent to quartz monzonite of older literature and common usage in the western United States) with roughly equivalent concentrations of quartz, alkali feldspar, and plagioclase is the predominant rock type in the Medicine Bow Mountains. Hybrid phases are common, especially near batholith margins (for example near King's Canyon and Chambers Lake at the northwest and southern margins of the study area, respectively) where appreciable assimilation or partial melting has taken place.

Textures in Rawah batholith rocks are highly variable. Medium- to coarse-grained allotriomorphic equigranular phases predominate, although coarse porphyritic and very fine-grained saccharoidal phases are common locally (McCallum and Hedge, 1976, p. 33). Alinement of tabular microcline phenocrysts in many of the porphyritic phases is probably a primary feature. The foliation defined by phenocrysts generally parallels foliations of xenolithic metamorphic rocks. A well-defined cataclastic foliation is prominent in much of the northwestern portion of the batholith.

Rocks of the Rawah batholith were emplaced approximately 1.71$\pm$ b.y. ago (McCallum and Hedge, 1976) during and immediately following a major episode of amphibolite grade regional metamorphism.

Sherman Granite

A stock of Sherman Granite (Boswell Creek stock) intrudes the Rawah batholith in the northern portion of the Colorado Medicine Bow Mountains (fig. 2). The pluton is composed predominantly of granite of intermediate composition (quartz monzonite of older literature), although minor amounts of potassic granite do occur. The pluton is much more homogeneous than the Rawah batholith and xenoliths of host rocks are relatively uncommon. The predominantly coarse-grained allotriomorphic granular granitoid rocks of the

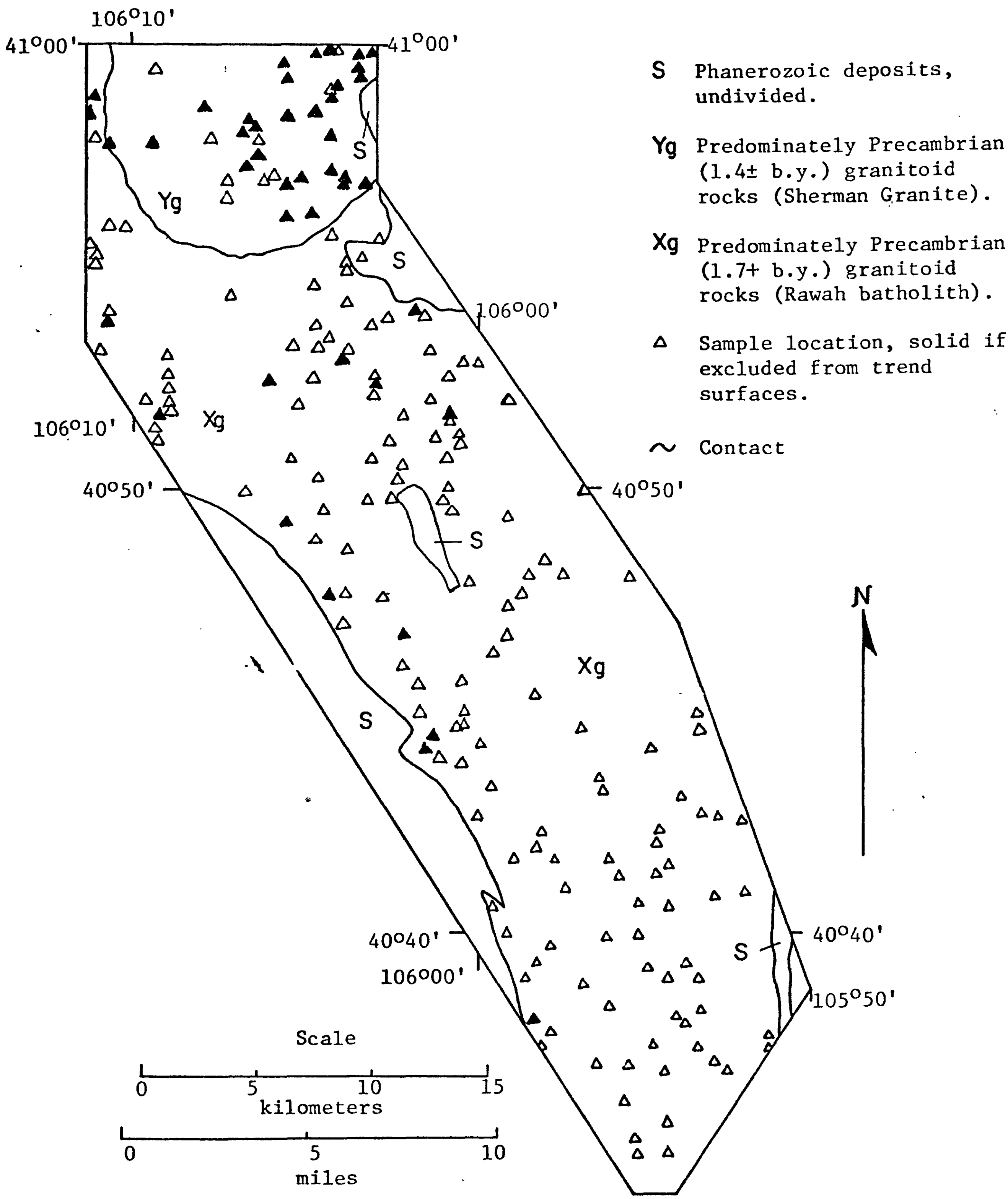

Figure 2. Sample distribution map, Medicine Bow Mountains, Colorado.

pluton are cut by fine- to medium-grained, granitic to granodioritic dikes and minor quartz veins. A weak cataclastic fabric is generally present in the dikes (Hartmann, 1973). The pluton is cut by a complex network of both radial and somewhat annular, annealed faults. Contacts of the Boswell Creek pluton with Rawah batholith rocks are commonly sheared and annealed.

Similar rocks described in the northern Front Range by Eggler (1967, 1968) have been dated at 1.41± 0.03 b.y. by Peterman and others (1968).

Phanerozoic Sedimentary Deposits

The Colorado Medicine Bow Mountains are bounded on the southwest and west by the North Park basin and on the northeast and east by the Laramie River valley (fig. 1). Deposition of sedimentary materials has occurred intermittently in these areas at least since Pennsylvanian time, and, excluding Holocene alluvial, colluvial and eolian processes, ceased in the Pleistocene with deposition of alpine, glacial till and outwash. Major sedimentary units mapped during the course of this study include, in order from oldest (Pennsylvanian) to youngest (Pleistocene) the Fountain Fm., Casper Fm., Satanka Fm., Forelle Fm., Red Peak Fm. of the Chugwater Group, Jelm Fm., Sundance Fm., Morrison Fm., Dakota Group, Benton Group, Niobrara Fm., Pierre Shale, North Park Fm., and Wisconsin till. Descriptions of the sedimentary units are given by Beckwith (1942), Kiever (1968), and Camp (1979).

STRUCTURE

The structural evolution of the Colorado Medicine Bow Mountains is being studied by M. E. McCallum, and a preliminary tectonic map of the area is available (McCallum and others, unpub. mapping). At least three episodes of Precambrian faulting and(or) shearing are evident in the crystalline rocks of the Colorado Medicine Bow Mountains. Widespread shearing apparently accompanied or closely postdated the emplacement of the Precambrian X granitoid rocks of the Rawah batholith, and some portions of the pluton (northwestern areas) show a prominent pervasive cataclastic fabric. This translational event was followed by another episode of shearing that occurred well after the crystallization of the Rawah batholith but prior to the intrusion of the Proterozoic Sherman Granite. The second episode of shearing was less pervasive than the first and is reflected by well-defined shear zones that commonly cross cut the earlier cataclastic fabric. Material sheared during these two deformational events is typically recrystallized, and major shear zones are generally intensely silicified and epidotized. Some fault zones contain the retrograde metamorphic products stilpnomelane and piemontite. The third major faulting episode took place after the emplacement of the Sherman pluton, although some minor, local faulting and cataclasis apparently accompanied intrusion of the Sherman Granite. These late Precambrian faults are generally annealed with epidote, quartz, and(or) specular hematite locally. However, most of these faults are much narrower and more sharply defined than the shear zones of the first two translational episodes. Post-Precambrian faults are moderately abundant, and many reflect reactivation of earlier fault zones. The younger faults generally are not annealed and typically contain breccia, gouge, and earthy hematite. Some of these faults are locally enriched in U, and anomalous levels of Cu and Mo have been reported from several faults. Fluorite is moderately abundant in a number of the post-Precambrian faults in the northwestern part of the district.

TREND SURFACES

Trend surfaces are polynomial functions fitted to sample data by the method of least squares. Linear regression analysis involves fitting the data to a line in some randomly oriented X-Y coordinate system. Trend surface analysis involves fitting the data (that is, some variable Z) to a planar surface in some X-Y system (Davis, 1973). For example, a 1^{o} trend surface is a plane in the chosen X-Y coordinate system which dips toward low values in the variable Z. A 2^{o} surface is an undulatory plane that might more closely fit the data than a 1^{o} surface. Each successive order may fit the data more precisely until actual data points are plotted. By choosing planar surfaces that fit most of the data but essentially ignore anomalously low or high values, an estimate of the regional variation of a data variable (for example, U content) in a chosen study area may be obtained. Methods for determining statistical validity of trend surfaces and establishing the best-fit planes are discussed by Davis (1973). Good examples of applications of trend surfaces to petrology are provided by Whitten (1961), Baird and others (1967), and Mathews and others (1975).

PROCEDURES

One hundred ninety-nine rock samples (table 1, pl. 1) were selected from collections from the Medicine Bow Mountains at a mean density of one/3.9 km^2 (1/1.5 mi^2) (fig. 2). The samples were collected by M. E. McCallum, R. H. Filson, M. L. Griswold, and W. K. Camp during the course of geologic mapping in the region. Represented in the suite are rocks from the Rawah batholith, Sherman Granite and related phases, metamorphic xenoliths, and shear-zone material. The samples were analyzed for U and Th (U by fluorimetry and Th by X-ray fluorescence) by Skyline Labs, Inc., Wheatridge, Colorado. Results of the analyses and calculated U/Th and Th/U values are shown in table 2. The lower detection limit for U was 2 ppm, and ranged from 13 to 50 ppm for Th. To avoid statistical calculations involving 0, values of 0.5 ppm and 10.0 ppm were arbitrarily assigned to samples with non-detectable U and Th, respectively. These values are well below crustal averages for both elements (See Bayer and others, 1974; Pertlik and others, 1974) and should not significantly alter trend-surface results. Background and threshold values were determined using the methods recommended by Sinclair (1974). Trend surfaces 1^{o} through 5^{o} for U, U/Th, Th, and Th/U were calculated with 153 samples of Rawah rocks and Sherman Granite utilizing a trend surface program modified from Davis (1973). Samples excluded from trend surface plots are not representative plutonic phases but are predominantly dikes and migmatites.

TABLE 1--Descriptions of samples from the Rawah batholith and Boswell Creek stock, Medicine Bow Mountains, Larimer and Jackson Counties, Colorado. [* refers to intermediate granite of Streckeisen (1973), which is equivalent to quartz monzonite of older literature.]

Sample Number	Sample Description	Sample Number	Sample Description
6-11	Foliated granite*, Rawah	6-186	Foliated, porphyritic granite*, Rawah
6-12	Foliated granite*, Rawah	6-187	Gneissic granite*, Rawah
6-14	Granite*, Rawah	6-188	Gneissic, porphyritic granite*, Rawah
6-16	Granite*, Rawah	6-191	Foliated, porphyritic granite*, Rawah
6-28	Foliated, porphyritic granite*, Rawah	6-192	Foliated granite*, Rawah
6-34	Gneissic granite, Rawah	6-203	Foliated granite*, Rawah
6-52	Foliated, porphyritic granite, Rawah	6-204	Foliated granite*, Rawah
6-69	Foliated granite*, Rawah	6-210A	Foliated granite*, Rawah
6-74A	Foliated granite, Rawah	6-215	Gneissic granite*, Rawah
6-75	Foliated granite*, Rawah	6-217	Gneissic granite*, Rawah
6-77	Granite*, Rawah	6-222	Foliated, porphyritic granite*, Rawah
6-78	Granite*, Rawah	6-227	Foliated, porphyritic granite*, Rawah
6-80	Foliated granite*, Rawah	6-245F	Granite*, Rawah
6-82	Foliated granite*, Rawah	18-27	Granite*, Rawah
6-86	Granite*, Rawah	18-52A	Granite*, Rawah
6-89	Foliated granite*, Rawah	18-57	Biotite-sillimanite-garnet gneiss
6-106	Granite*, Rawah	18-77	Granite*, Rawah
6-109	Foliated granite*, Rawah	18-123	Granite, Rawah
6-110	Foliated, porphyritic granite*, Rawah	18-138	Granite, Rawah
6-119	Gneissic granite*, Rawah	18-143	Granite, Rawah
6-142	Foliated, gneissic granite*, Rawah	20-2	Foliated, porphyritic granite*,Rawah
6-147	Foliated, porphyritic granite*, Rawah	20-12E	Granite*, Rawah
6-168	Foliated granite*, Rawah	20-17	Granite*, Rawah
6-171	Foliated granite*, Rawah	20-47	Monzodiorite, Rawah
6-180	Granite*, Rawah	20-55	Foliated, porphyritic granite*, Rawah
6-181	Granite*, Rawah	20-63	Foliated, porphyritic granite*, Rawah

TABLE 1--Descriptions of samples from the Rawah batholith and Boswell Creek stock, Medicine Bow Mountains, Larimer and Jackson Counties, Colorado. [* refers to intermediate granite of Streckeisen (1973), which is equivalent to quartz monzonite of older literature.]--Cont.

Sample Number	Sample Description	Sample Number	Sample Description
20-76	Tonalite, Rawah	20-232	Granodiorite, Rawah
20-81	Foliated, porphyritic granite*, Rawah	26-68	Cataclastic granite, Rawah
20-91	Granodiorite, Rawah	KC 12	Granodiorite, Rawah
20-92	Granite*, Rawah	KC 31	Sheared granite*, Rawah
20-106	Tonalite, Rawah	KC 32	Foliated granite*, Rawah
20-109	Granite*, Rawah	KC 44	Granite* dike in Sherman Granite
20-117	Foliated granodiorite, Rawah	KC 47	Felsic dike in Sherman Granite
20-130	Foliated, porphyritic granodiorite, Rawah	KC 48	Felsic dike in Sherman Granite
20-134	Granite*, Rawah	KC 50	Granite, Rawah
20-136	Granite*, Rawah	KC 52	Granite, Rawah
20-148	Granite*, Rawah	KC 59	Felsic dike in Sherman Granite
20-155	Granodiorite, Rawah	KC 66	Granite*, Rawah
20-157	Granite*, Rawah	KC 70A	Foliated granite*, Rawah
20-159	Granite*, Rawah	KC 72	Felsic biotite gneiss
20-173	Tonalite, Rawah	KC 74	Foliated granite*, Rawah
20-187	Tonalite, Rawah	KC 86A	Granite*, Rawah
20-192	Granodiorite, Rawah	KC 96	Granite*, Rawah
20-198	Foliated, porphyritic granodiorite, Rawah	KC 109	Foliated granite*, Rawah
20-202	Foliated, porphyritic granodiorite, Rawah	KC 117	Granodiorite, Rawah
20-204B	Granite*, Rawah	KC 121A	Gneissic granite*, Rawah
20-208	Foliated, porphyritic granodiorite, Rawah	KC 128C	Granite*, Rawah
20-213	Foliated, porphyritic granite*, Rawah	KC 130	Granite*, Rawah
20-216	Granodiorite, Rawah	KC 132	Granite*, Rawah
20-220	Granodiorite, Rawah	KC 135	Quartz diorite, Rawah
20-223A	Granodiorite, Rawah	KC 139A	Granite*, Rawah
20-228	Tonalite, Rawah	KC 151	Granite*, Rawah

TABLE 1--Descriptions of samples from the Rawah batholith and Boswell Creek stock, Medicine Bow Mountains, Larimer and Jackson Counties, Colorado. [* refers to intermediate granite of Streckeisen (1973), which is equivalent to quartz monzonite of older literature.]-- Cont.

Sample Number	Sample Description	Sample Number	Sample Description
KC 162	Granite*, Rawah	KC 307	Quartz diorite, Rawah
KC 168	Granite*, Rawah	KC 327	Quartz diorite inclusion in granite*,Rawah
KC 169A	Granite*, Rawah	KC 331	Quartz diorite inclusion in granite*,Rawah
KC 174B	Sheared granite*, Rawah	KC 335	Granite*, Rawah
KC 184B	Granite*, Rawah	KC 336	Granite*, Rawah
KC 189	Granite*, Rawah	KC 337	Quartz diorite inclusion in granite*,Rawah
KC 204	Sherman Granite	KC 343	Granodiorite, Rawah
KC 213B	Granite*, Rawah	KC 346	Quartz diorite, Rawah
KC 221	Felsic dike in Sherman Granite	KC 348B	Granite*, Rawah
KC 223	Felsic dike in Sherman Granite	KC 351	Granodiorite, Rawah
KC 227	Granodiorite dike in Sherman Granite*	KC 360	Granite*, Rawah
KC 228	Sheared felsic dike in Sherman Granite	KC 369	Sheared granite*, Rawah
KC 233	Biotite-rich Sherman Granite	KC 372	Quartz diorite inclusion in granite*,Rawah
KC 235	Felsic dike in Sherman Granite	KC 381	Foliated, porphyritic granite*, Rawah
KC 243	Felsic dike in Sherman Granite	KC 392	Granite*, Rawah
KC 251	Granite*, Rawah	KC 393	Granodiorite dike in Sherman Granite
KC 254A	Granite*, Rawah	KC 396	Granite*, Rawah
KC 257	Granodiorite, Rawah	KC 400	Granite*, Rawah
KC 278A	Felsic dike cutting hornblende gneiss	KC 408	Foliated granite*, Rawah
KC 280	Granite*, Rawah	KC 409	Quartz diorite inclusion in granite*,Rawah
KC 284	Foliated granite, Rawah	KC 410	Granite*, Rawah
KC 289	Foliated granite*, Rawah	KC 416	Foliated, porphyritic granite*, Rawah
KC 290	Porphyroclastic granite*, Rawah	KC 423	Granite*, Rawah
KC 291A	Foliated granite*, Rawah	KC 425	Granite*, Rawah
KC 292	Porphyroclastic granite*, Rawah	KC 433	Granite*, Rawah
KC 306	Granite*, Rawah	KC 436	Granite, Rawah

TABLE 1--Descriptions of samples from the Rawah batholith and Boswell Creek stock, Medicine Bow Mountains, Larimer and Jackson Counties, Colorado. [* refers to intermediate granite of Streckeisen (1973), which is equivalent to quartz monzonite of older literature.]--Cont.

Sample Number	Sample Description	Sample Number	Sample Description
KC 439	Granite*, Rawah	KC 518B	Sherman Granite
KC 451	Granite*, Rawah	KC 520	Biotite-rich granite*, Rawah
KC 453	Granite*, Rawah	KC 522	Gneissic granite*, Rawah
KC 463	Granite*, Rawah	KC 523	Granite*, Rawah
KC 464	Foliated granite*, Rawah	KC 525	Felsic dike in Sherman Granite
KC 465	Hornblende-magnetite-biotite gneiss	KC 528	Felsic dike in Sherman Granite
KC 467	Granite*, Rawah	KC 531	Felsic dike in Sherman Granite
KC 469B	Foliated granite*, Rawah	KC 537	Felsic dike in Sherman Granite
KC 475	Foliated granite*, Rawah	KC 539	Biotite-rich Sherman Granite
KC 476	Felsic dike in granite*, Rawah	KC 540	Granite*, Rawah
KC 479	Foliated granite*, Rawah	KC 543	Biotite-hornblende Sherman Granite*
KC 480	Foliated granite*, Rawah	KC 544	Felsic dike in Sherman Granite
KC 483	Granite*, Rawah	KC 546	Felsic dike in Sherman Granite
KC 486B	Granite*, Rawah	KC 547	Felsic dike in Sherman Granite
KC 490	Gneissic granite*, Rawah	KC 553	Felsic dike in Sherman Granite
KC 494	Felsic dike in Sherman Granite	KC 556	Felsic dike in Sherman Granite
KC 496	Sherman Granite	KC 564	Felsic dike in Sherman Granite
KC 497	Felsic dike in Sherman Granite	KC 571	Felsic dike in Sherman Granite
KC 499	Felsic dike in Sherman Granite		
KC 500	Felsic dike in Sherman Granite		
KC 502A	Felsic dike in Sherman Granite		
KC 508	Foliated granite*, Rawah		
KC 509	Foliated granite*, Rawah		
KC 512	Felsic dike in granite*, Rawah		
KC 514	Granite*, Rawah		
KC 518A	Felsic dike in Sherman Granite		

TABLE 2--U and Th Analyses of Precambrian Crystalline Rocks from the Medicine Bow Mountains of Northern Colorado.

[Analyses are reported in ppm. Lower detection limit of U is 2 ppm and ranges from 13 to 50 ppm for Th. Samples with nondetectable U and Th have been assigned values of 0.5 ppm and 10.0 ppm, respectively.

Rock Type Symbols are as follows: RGA -- Granite, Rawah; RGB -- Granite*, Rawah - equivalent to quartz monzonite of older literature; RGBF -- Foliated granite*, Rawah; RGBFP -- Porphyritic, foliated granite*, Rawah; RGBG -- Gneissic granite*, Rawah; RGBGP -- Porphyritic, gneissic granite*, Rawah; RGD -- Granodiorite, Rawah; RGDF -- Foliated granodiorite, Rawah; RGDFP -- Porphyritic, foliated granodiorite, Rawah; RMD -- Monzodiorite, Rawah; RQD -- Quartz diorite, Rawah; RQDT -- Rawah quartz diorite inclusion; RT -- Rawah tonalite; RGC -- Cataclastic Rawah granitoid rocks; SGA -- Sherman Granite; SGB -- Sherman Granite* - equivalent to quartz monzonite of older literature; BSG -- Biotite-Rich Sherman granitoid rocks; SGBD -- Granite* Dike in Sherman granitoid rocks; FD -- Felsic dike rocks; FDC -- Cataclastic felsic dike rocks; BG -- Biotite gneiss to biotite-sillimanite gneiss; M -- Metamorphic rock inclusions, undivided.

* refers to intermediate granite of Streckeisen (1973), which is equivalent to quartz monzonite of older literature.

U was determined by fluorimentry and Th by X-ray fluorescence by Skyline Labs, Inc., Wheatridge, Colorado]

Sample Number	Rock Type	U	Th	U/Th	Th/U	Sample Number	Rock Type	U	Th	U/Th	Th/U	Sample Number	Rock Type	U	Th	U/Th	Th/U
6-11	RGBF	0.50	10.0	0.05	20.0	6-181	RGB	2.0	10.0	0.20	5.0	20-47	RMD	5.0	10.0	0.50	2.0
6-12	RGBF	3.0	90.0	0.03	30.0	6-186	RGBFP	0.50	10.0	0.05	20.0	20-55	RGBFP	0.50	40.0	0.01	80.0
6-14	RGB	5.0	10.0	0.50	2.0	6-187	RGBG	0.50	10.0	0.05	20.0	20-63	RGBFP	0.50	40.0	0.01	80.0
6-16	RGB	0.50	40.0	0.01	80.0	6-188	RGBGP	0.50	10.0	0.05	20.0	20-76	RT	7.0	40.0	0.17	5.71
6-28	RGBFP	0.50	65.0	0.01	130.0	6-191	RGBFP	0.50	10.0	0.05	20.0	20-81	RGBFP	6.0	10.0	0.60	1.67
6-34	RGAG	0.50	10.0	0.05	20.0	6-192	RGBF	0.50	10.0	0.05	20.0	20-91	RGD	0.50	10.0	0.05	20.0
6-52	RGBFP	0.50	10.0	0.05	20.0	6-203	RGBF	3.0	10.0	0.30	3.33	20-92	RGB	0.50	35.0	0.01	70.0
6-69	RGBF	0.50	10.0	0.05	20.0	6-204	RGBF	0.50	10.0	0.05	20.0	20-106	RT	0.50	10.0	0.05	20.0
6-74A	RGBF	0.50	55.0	0.01	110.0	6-210A	RGBF	0.50	50.0	0.01	100.0	20-109	RGB	3.0	30.0	0.10	10.0
6-75	RGBF	3.0	30.0	0.1	10.0	6-215	RGBG	0.50	10.0	0.05	20.0	20-117	RGDF	0.50	10.0	0.05	20.0
6-77	RGB	0.50	10.0	0.05	20.0	6-217	RGB	3.0	10.0	0.30	3.33	20-130	RGDFP	0.50	40.0	0.01	80.0
6-78	RGB	0.50	110.0	0.00	220.0	6-222	RGBFP	0.50	10.0	0.05	20.0	20-134	RGB	0.50	35.0	0.01	70.0
6-80	RGBF	0.50	10.0	0.05	20.0	6-227	RGBFP	0.50	35.0	0.01	70.0	20-136	RGB	3.0	10.0	0.30	3.33
6-82	RGBF	4.0	10.0	0.40	2.50	6-245F	RGB	0.50	10.0	0.05	20.0	20-148	RGB	0.50	10.0	0.05	20.0
6-86	RGB	0.50	10.0	0.50	20.0	18-27	RGB	5.0	10.0	0.50	2.0	20-155	RGD	3.0	10.0	0.30	3.33
6-89	RGBF	0.50	10.0	0.50	20.0	18-52A	RGB	5.0	110.0	0.04	22.0	20-157	RGB	0.50	10.0	0.05	20.0
6-106	RGB	3.0	40.0	0.08	13.30	18-57	M	0.50	10.0	0.05	20.0	20-159	RGB	0.50	10.0	0.05	20.0
6-109	RGBF	0.50	10.0	0.05	20.0	18-77	RGB	0.50	65.0	0.01	130.0	20-173	RT	0.50	10.0	0.05	20.0
6-110	RGBFP	0.50	10.0	0.05	20.0	18-123	RGA	4.0	10.0	0.40	2.50	20-187	RT	0.50	10.0	0.05	20.0
6-119	RGBG	0.50	10.0	0.05	20.0	18-138	RGA	4.0	60.0	0.07	15.0	20-192	RGD	0.50	10.0	0.05	20.0
6-142	RGBGF	0.50	10.0	0.05	20.0	18-143	RGA	0.50	10.0	0.05	20.0	20-198	RGDFP	0.50	110.0	0.01	220.0
6-147	RGBFP	0.50	10.0	0.05	20.0	20-2	RGBFP	0.50	10.0	0.05	20.0	20-202	RGDFP	7.0	10.0	0.70	1.43
6-168	RGBF	4.0	10.0	0.40	2.50	20-12E	RGB	0.50	10.0	0.05	20.0	20-204B	RGB	3.0	110.0	0.03	36.70
6-171	RGBF	5.0	10.0	0.50	2.0	20-17	RGB	0.50	10.0	0.05	20.0	20-208	RGDFP	0.50	10.0	0.05	20.0
6-180	RGB	0.50	10.0	0.05	20.0	20-213	RGBFP	0.50	10.0	0.05	20.0	20-216	RGD	3.0	10.0	0.30	3.33

TABLE 2--U and Th Analyses of Precambrian Crystalline Rocks from the Medicine Bow Mountains of Northern Colorado.
[Analyses are reported in ppm. Lower detection limit of U is 2 ppm and ranges from 13 to 50 ppm for Th.
Samples with nondetectable U and Th have been assigned values of 0.5 ppm and 10.0 ppm, respectively.
Rock Type Symbols are as follows: RGA -- Granite, Rawah; RGB -- Granite*, Rawah - equivalent to quartz monzonite of older literature; RGBF -- Foliated granite*, Rawah; RGBFP -- Porphyritic, foliated granite*, Rawah; RGBG -- Gneissic granite*, Rawah; RGBGP -- Porphyritic, gneissic granite*, Rawah; RGD -- Granodiorite, Rawah; RGDF -- Foliated granodiorite, Rawah; RGDFP -- Porphyritic, foliated granodiorite, Rawah; RMD -- Monzodiorite, Rawah; RQD -- Quartz diorite, Rawah; RQDT -- Rawah quartz diorite inclusion; RT -- Rawah tonalite; RGC -- Cataclastic Rawah granitoid rocks; SGA -- Sherman Granite; SGB -- Sherman Granite* - equivalent to quartz monzonite of older literature; BSG -- Biotite-Rich Sherman granitoid rocks; SGBD -- Granite* Dike in Sherman granitoid rocks; FD -- Felsic dike rocks; FDC -- Cataclastic felsic dike rocks; BG -- Biotite gneiss to biotite-sillimanite gneiss; M -- Metamorphic rock inclusions, undivided.
* refers to intermediate granite of Streckeisen (1973), which is equivalent to quartz monzonite of older literature.
U was determined by fluorimentry and Th by X-ray fluorescence by Skyline Labs, Inc., Wheatridge, Colorado]--Cont.

Sample Number	Rock Type	U	Th	U/Th	Th/U
20-220	RGD	2.0	10.0	0.20	5.0
20-223A	RGD	5.0	85.0	0.06	17.0
20-228	RT	0.50	10.0	0.05	20.0
20-232	RGD	0.50	10.0	0.05	20.0
KC 12	RGD	0.50	30.0	0.02	60.0
KC 31	RGC	5.0	60.0	0.08	12.0
KC 32	RGBF	4.0	95.0	0.04	23.80
KC 44	SGBD	3.0	10.0	0.30	3.33
KC 47	FD	3.0	10.0	0.30	3.33
KC 48	FD	4.0	25.0	0.16	6.25
KC 50	RGA	2.0	30.0	0.07	15.0
KC 52	RGA	3.0	10.0	0.30	3.33
KC 59	FD	4.0	30.0	0.13	8.50
KC 66	RGB	5.0	10.0	0.50	2.0
KC 70A	RGBF	6.0	30.0	0.20	5.0
KC 72	BG	0.50	10.0	0.05	20.0
KC 74	RGBF	6.0	10.0	0.60	1.67
KC 86A	RGB	4.0	10.0	0.40	2.50
KC 96	RGB	5.0	10.0	0.50	2.0
KC 109	RGBF	0.50	110.0	0.01	220.0
KC 117	RGD	0.50	10.0	0.05	20.0
KC 121A	RGBG	2.0	35.0	0.03	17.50
KC 128C	RGB	4.0	30.0	0.13	7.50
KC 130	RGB	7.0	10.0	0.70	1.43
KC 132	RGB	3.0	10.0	0.30	3.33
KC 135	RQD	0.50	10.0	0.05	20.0
KC 139A	RGB	0.50	30.0	0.02	60.0

Sample Number	Rock Type	U	Th	U/Th	Th/U
KC 151	RGB	0.50	45.0	0.01	90.0
KC 162	RGB	0.50	35.0	0.01	70.0
KC 168	RGB	2.0	25.0	0.08	12.50
KC 169A	RGB	3.0	10.0	0.30	3.33
KC 174B	RGC	0.50	10.0	0.05	20.0
KC 184B	RGB	4.0	10.0	0.40	2.50
KC 189	RGB	2.0	30.0	0.07	15.0
KC 204	SGA	7.0	30.0	0.20	4.29
KC 213B	RGB	7.0	10.0	0.70	1.43
KC 221	FD	0.50	30.0	0.02	60.0
KC 223	FD	2.0	10.0	0.20	5.0
KC 227	SGBD	3.0	10.0	0.30	3.33
KC 228	FDC	3.0	10.0	0.30	3.33
KC 233	BSG	0.50	35.0	0.01	70.0
KC 235	FD	3.0	10.0	0.30	3.33
KC 243	FD	3.0	10.0	0.30	3.33
KC 251	RGB	2.0	25.0	0.08	12.50
KC 254A	RGB	3.0	10.0	0.30	3.33
KC 257	RGD	0.50	30.0	0.02	60.0
KC 278A	FD	5.0	30.0	0.17	6.0
KC 280	RGB	3.0	25.0	0.12	8.33
KC 284	RGAF	0.50	60.0	0.01	120.0
KC 289	RGBF	0.50	10.0	0.05	20.0
KC 290	RGC	0.50	10.0	0.05	20.0
KC 291A	RGBF	3.0	10.0	0.30	3.33
KC 292	RGC	0.50	10.0	0.05	20.0
KC 306	RGB	3.0	35.00	0.09	11.70

Sample Number	Rock Type	U	Th	U/Th	Th/U
KC 307	RQD	0.50	10.0	0.05	20.0
KC 327	RQDI	0.50	10.0	0.05	20.0
KC 331	RQDI	0.50	10.0	0.05	20.0
KC 335	RGB	0.50	30.0	0.02	60.0
KC 336	RGB	4.0	60.0	0.07	15.0
KC 337	RQDI	0.50	10.0	0.05	20.0
KC 343	RGD	0.50	10.0	0.05	20.0
KC 346	RQD	0.50	10.0	0.02	50.0
KC 348B	RGB	0.50	10.0	0.05	20.0
KC 351	RGD	0.50	10.0	0.05	20.0
KC 360	RGB	3.0	30.0	0.10	10.0
KC 369	RGC	3.0	35.0	0.09	11.70
KC 372	RQDI	2.0	40.0	0.05	20.0
KC 381	RGBFP	2.0	10.0	0.20	5.0
KC 392	RGB	0.50	10.0	0.05	20.0
KC 393	SGBD	5.0	35.0	0.17	7.0
KC 396	RGB	3.0	10.0	0.30	3.33
KC 400	RGB	2.0	35.0	0.05	17.50
KC 408	RGBF	0.50	10.0	0.05	20.0
KC 409	RQDI	0.50	10.0	0.05	20.0
KC 410	RGB	0.50	10.0	0.05	20.0
KC 416	RGBFP	0.50	10.0	0.05	20.0
KC 423	RGB	4.0	10.0	0.40	2.50
KC 425	RGB	0.50	10.0	0.05	20.0
KC 433	RGB	4.0	10.0	0.40	2.50
KC 436	RGA	0.50	10.0	0.05	20.0
KC 439	RGB	0.50	10.0	0.05	20.0

TABLE 2--U and Th Analyses of Precambrian Crystalline Rocks from the Medicine Bow Mountains of Northern Colorado.
[Analyses are reported in ppm. Lower detection limit of U is 2 ppm and ranges from 13 to 50 ppm for Th.
Samples with nondetectable U and Th have been assigned values of 0.5 ppm and 10.0 ppm, respectively.
Rock Type Symbols are as follows: RGA -- Granite, Rawah; RGB -- Granite*, Rawah - equivalent to quartz monzonite of older literature; RGBF -- Foliated granite*, Rawah; RGBFP -- Porphyritic, foliated granite*, Rawah; RGBG -- Gneissic granite*, Rawah; RGBGP -- Porphyritic, gneissic granite*, Rawah; RGD -- Granodiorite, Rawah; RGDF -- Foliated granodiorite, Rawah; RGDFP -- Porphyritic, foliated granodiorite, Rawah; RMD -- Monzodiorite, Rawah; RQD -- Quartz diorite, Rawah; RQDT -- Rawah quartz diorite inclusion; RT -- Rawah tonalite; RGC -- Cataclastic Rawah granitoid rocks; SGA -- Sherman Granite; SGB -- Sherman Granite* - equivalent to quartz monzonite of older literature; BSG -- Biotite-Rich Sherman granitoid rocks; SGBD -- Granite* Dike in Sherman granitoid rocks; FD -- Felsic dike rocks; FDC -- Cataclastic felsic dike rocks; BG -- Biotite gneiss to biotite-sillimanite gneiss; M -- Metamorphic rock inclusions, undivided.
* refers to intermediate granite of Streckeisen (1973), which is equivalent to quartz monzonite of older literature.
U was determined by fluorimentry and Th by X-ray fluorescence by Skyline Labs, Inc., Wheatridge, Colorado]—Cont.

Sample Number	Rock Type	U	Th	U/Th	Th/U	Sample Number	Rock Type	U	Th	U/Th	Th/U
KC 451	RGB	3.0	10.0	0.30	3.33	KC 522	RGBG	2.0	30.0	0.07	15.0
KC 453	RGB	4.0	35.0	0.11	8.75	KC 523	RGB	2.0	10.0	0.20	5.0
KC 463	RGB	3.0	70.0	0.04	23.30	KC 525	FD	3.0	10.0	0.30	3.33
KC 464	RGBF	4.0	40.0	0.10	10.0	KC 528	FD	2.0	35.0	0.06	17.50
KC 465	M	5.0	10.00	0.50	2.0	KC 531	FD	2.0	30.0	0.07	15.0
KC 467	RGB	2.0	10.0	0.05	5.0	KC 537	FD	0.50	10.0	0.05	20.0
KC 469B	RGBF	3.0	10.0	0.30	3.33	KC 539	BSG	2.0	10.0	0.20	5.0
KC 475	RGBF	7.0	30.0	0.20	5.0	KC 540	RGB	2.0	10.0	0.20	5.0
KC 476	FD	5.0	10.0	0.50	2.0	KC 543	BSG	0.50	10.0	0.05	20.0
KC 479	RGBF	0.50	10.0	0.05	20.0	KC 544	FD	0.50	10.0	0.05	20.0
KC 480	RGBF	2.0	10.0	0.20	5.0	KC 546	FD	0.50	10.0	0.05	20.0
KC 483	RGB	5.0	35.0	0.14	7.0	KC 547	FD	3.0	10.0	0.30	3.33
KC 486B	RGB	0.50	10.0	0.05	20.0	KC 553	FD	3.0	10.0	0.30	3.33
KC 490	RGBG	0.50	40.0	0.01	80.0	KC 556	FD	6.0	60.0	0.10	10.0
KC 494	FD	5.0	10.0	0.50	2.0	KC 564	FD	4.0	25.0	0.16	6.25
KC 496	BSG	0.50	25.0	0.02	50.0	KC 571	FD	3.0	65.0	0.05	21.70
KC 497	FD	7.0	10.0	0.70	1.43						
KC 499	FD	o.50	40.0	0.01	80.0						
KC 500	FD	3.0	10.1	0.30	3.33						
KC 502A	FD	2.0	10.0	0.20	5.0						
KC 508	RGBF	5.0	10.0	0.50	2.0						
KC 509	RGBF	4.0	10.0	0.40	2.50						
KC 512	FD	3.0	10.0	0.30	3.33						
KC 514	RGB	3.0	10.0	0.30	3.33						
KC 518A	FD	6.0	10.0	0.50	1.67						
KC 518B	BSG	0.50	35.0	0.01	70.0						
KC 520	RGB	4.0	30.0	0.13	7.50						

RESULTS

No U was detected in approximately 60 percent of the samples analyzed from the Colorado Medicine Bow Mountains, and Th was not detected in nearly 75 percent of the samples. Consequently, precise U and Th background values could not be determined. Background and threshold values listed in table 3 must therefore be considered statistical maximums and trend surfaces represent qualitative estimates only.

The calculated background value for U in granitoid rocks of the Rawah batholith is slightly more than the arbitrarily assigned value of 0.5 ppm. However, although the exact background value is unknown, it is considerably less than the 5.0 ppm average reported by Phair and Gottfried (1964) for Precambrian granites in the Front Range of Colorado. Despite efforts to collect unweathered material, this difference may in part be attributed to leaching of U through weathering of the Rawah batholith rocks. These data indicate that at least the Medicine Bow portion of the syntectonic Rawah batholith is depleted in U relative to Precambrian plutons of the Front Range. Samples that contain more than 6 ppm U (calculated threshold) are plotted on figure 3.

Background for Th in Rawah granitoid rocks is approximately 23 ppm, which is comparable to the 25 ppm average for Front Range granites reported by Phair and Gottfried (1964). This is probably a function of the presence of allanite as a significant accessory mineral in both Rawah batholith and Front Range granitic rocks (Filson, 1973; Hartman, 1973; McCallum and Hedge, 1976). The threshold value for Th is approximately 50 ppm. Locations of samples that exceed this value are plotted on figure 4.

The mean U and Th contents for 6 samples of badly weathered Sherman

TABLE 3.--Approximate background and threshold values for Precambrian crystalline rocks in the Colorado Medicine Bow Mountains. [Number of samples analyzed per rock unit given in parentheses. Leaders (---) indicate absence of statistically significant values.]

	Background	Threshold
Rawah batholith granite (153)		
U(ppm)	0.5	6
Th(ppm)	23	50
U/Th	.05	---
Th/U	16	---
Sherman Granite (6)		
U(ppm)	1.8	---
Th(ppm)	24	---
U/Th	.08	---
Th/U	37	---
Dikes in Sherman Granite (30)		
U(ppm)	3	6
Th(ppm)	12	47
U/Th	.20	---
Th/U	6	---

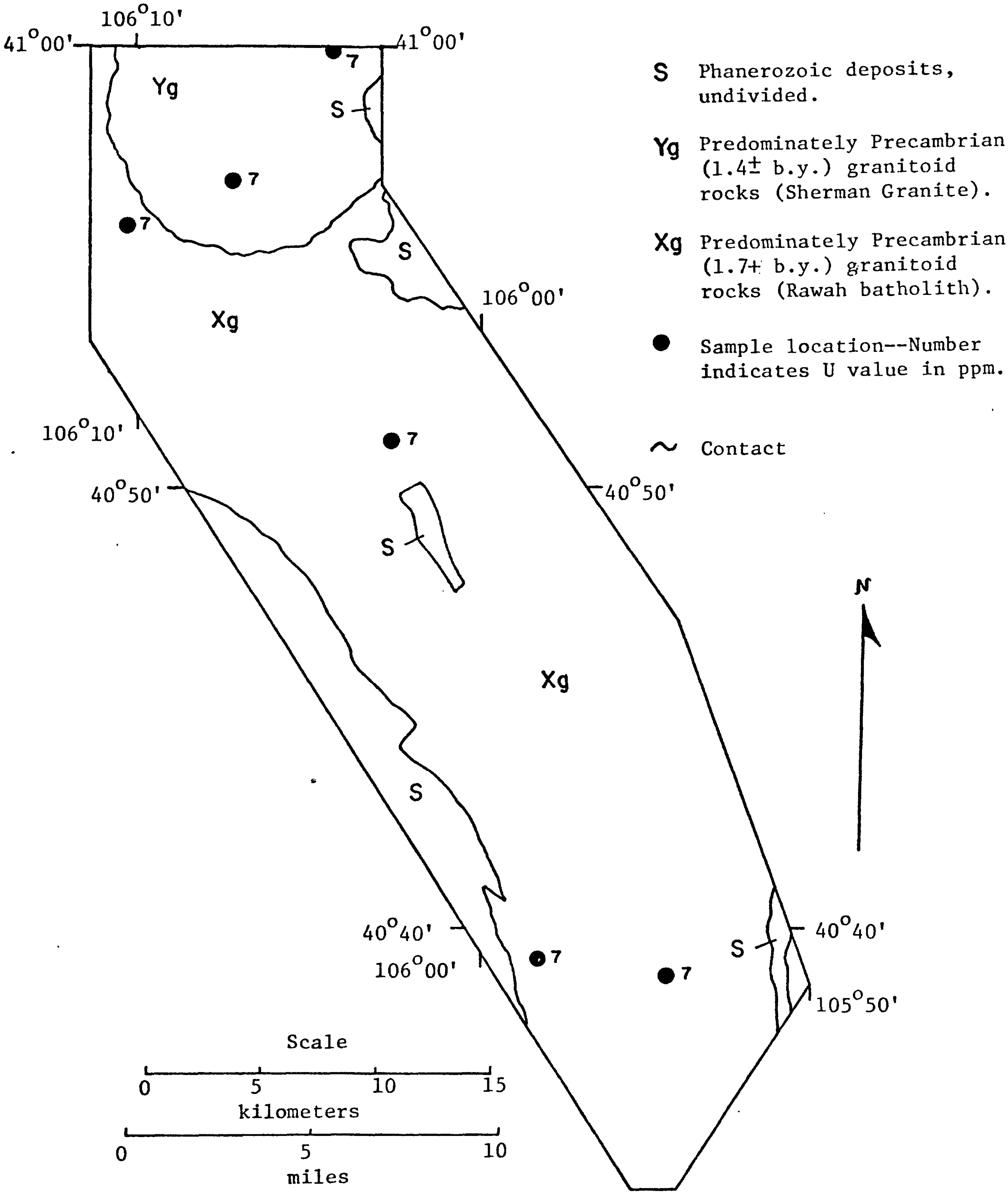

Figure 3. Locations of samples from the Medicine Bow Mountains, Colorado that contain U concentrations above threshold values.

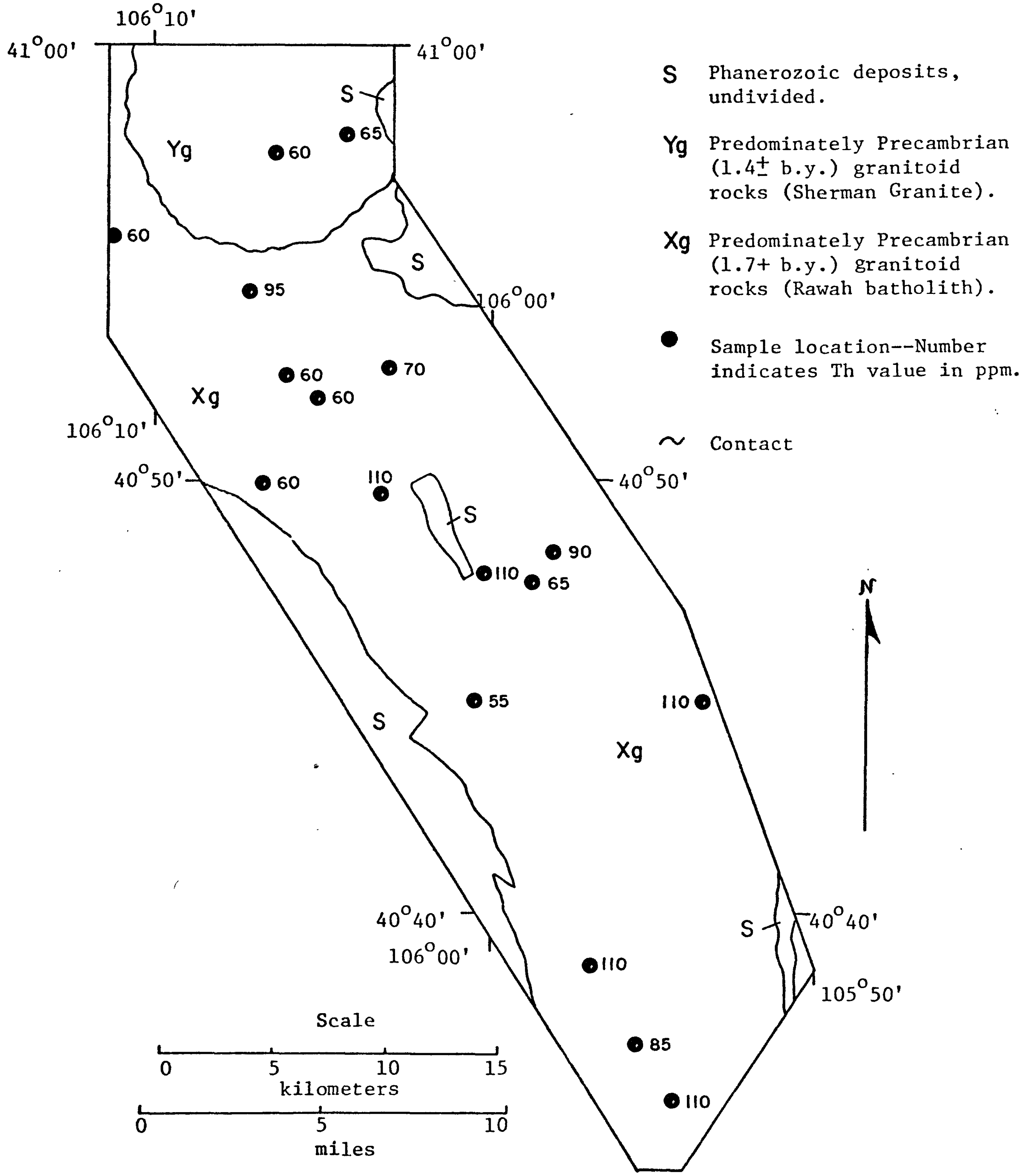

Figure 4. Locations of samples from the Medicine Bow Mountains, Colorado that contain Th concentrations above threshold values.

Granite are 1.8 and 24 ppm, respectively (table 3). Although the values are statistically invalid, they may suggest that the Sherman Granite in this region contains slightly more U than phases of the Rawah batholith. Late-stage dikes that cut the Sherman Granite are enriched in U and contain less Th than the 1.7+ b.y. plutonic rocks. Sample sites with anomalously high values of U and Th are plotted on figures 3 and 4 respectively.

Only three metamorphic rock xenoliths (samples 18-57, KC72 and KC465; table 2) were analyzed for this study and the U and Th levels on all but sample KC465 (5.0 ppm U) were below the limits of detection. U and Th in cataclastic granitoid rocks range from nondetectable to 4.0 and 35 ppm, respectively.

Trend surfaces (figs. 5-8) illustrate the distribution of U, Th, U/Th, and Th/U in granitoid rocks of the Medicine Bow Mountains. Pertinent statistical information used to determine best-fit surfaces is compiled in table 4.

The 3^{o} trend surface for U shows marked increases at the southern and northwestern margins of the study area (fig. 5). Relative highs in the northwest coincide with contact zones of the Rawah batholith where considerable assimilation of host metamorphic rocks has occurred. The increase in U is probably related to the increase in biotite in granitoid rocks of these zones, although it may be partially attributed to migration of U in shear zones near the Sherman Granite-Rawah batholith contact. Increased U content to the south correlates reasonably well with an increase in density of post-Precambrian faults and shear zones. The U low over the Sherman Granite to the north is probably due to poor distribution of limited samples. The majority of the samples available for analysis from the Sherman Granite

TABLE 4.--Statistical Information Used to Determine Best Fit Trend Surfaces for U-Th Data, Medicine Bow Mountains, Colorado

Statistics for U trend surfaces

	Trend Surface Order		
	2°	[1]3°	4°
F-test	2.45	2.78	2.16
Sum of Squares (Regression)	42.27	81.55	98.36
Degrees of Freedom (Regression)	5	9	14
Mean Squares (Deviation)	3.44	3.26	3.26
Total Variation	152	152	152
Correlation Coefficient	.2778	.3859	.4238

Statistics for Th trend surfaces

	Trend Surface Order	
	4°	[2]5°
F-test	.8613	1.52
Sum of Squares (Regression)	6813.92	15850.87
Degrees of Freedom (Regression)	14	20
Mean Squares	565.12	522.34
Total Variation	152	152
Correlation Coefficient	.2835	.4323

TABLE 4.--Statistical Information Used to Determine Best Fit Trend Surfaces for U-Th Data, Medicine Bow Mountains, Colorado--Cont.

Statistics for U/Th trend surfaces

	Trend Surface Order		
	1^0	$\underline{3}/2^0$	3^0
F-test	1.20	2.05	1.86
Sum of Squares (Regression)	.07	.29	.47
Degrees of Freedom (Regression)	2	5	9
Mean Squares (Deviation)	.03	.03	.03
Total Variation	152	152	152
Correlation Coefficient	.1256	.2551	.3236

Statistics for U/Th trend surfaces

	Trend Surface Order		
	2^0	$\underline{4}/3^0$	4^0
F-test	.2096	1.09	1.05
Sum of Squares (Regression)	1567.71	14274.07	21320.45
Degrees of Freedom (Regression)	5	9	14
Mean Squares (Deviation)	1495.71	1448.69	1450.12
Total Variation	152	152	152
Correlation Coefficient	.0841	.2539	.3103

1/ 3^0 is the best fit surface at the 2/5 percent significance level.

2/ 5^0 is an approximate surface at the 2.5 percent significance level.

3/ 2^0 is the best fit surface at the 10 percent significance level.

4/ 3^0 is the best fit surface at the 50 percent significance level.

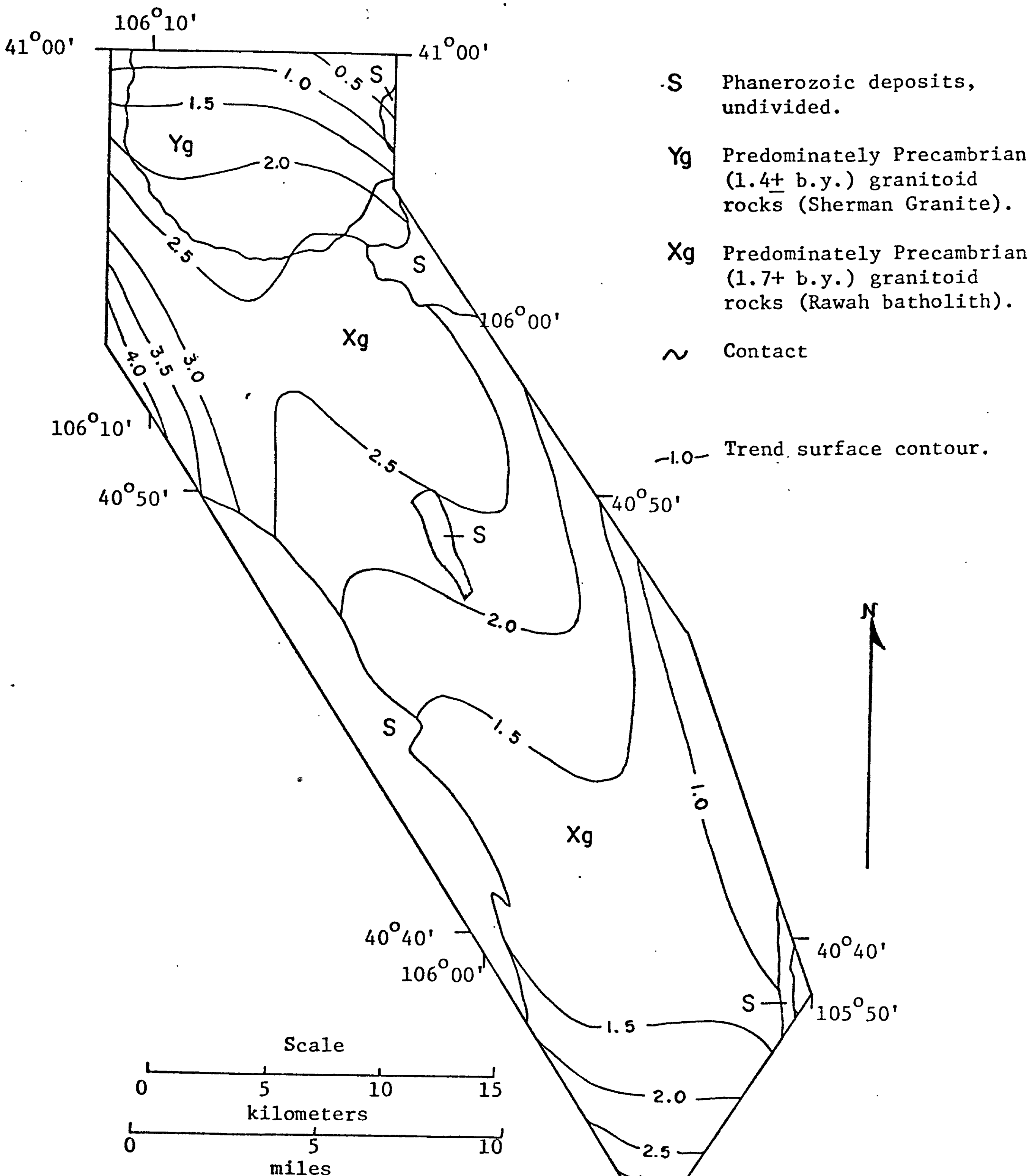

Figure 5. Third-order trend surface for uranium, Rawah batholith and Sherman Granite, Medicine Bow Mountains, Colorado. Contour interval, 0.5 ppm.

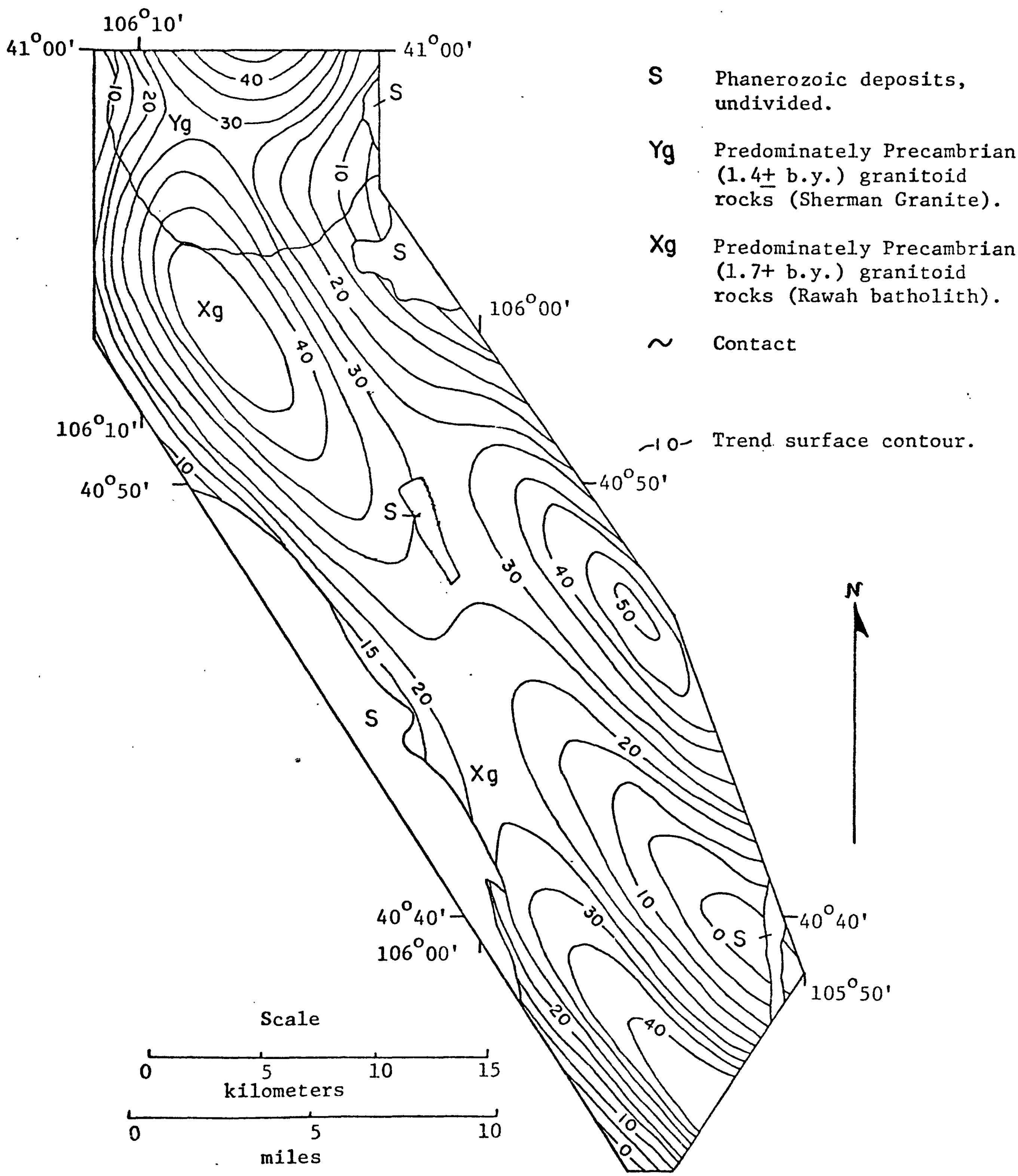

Figure 6. Fifth order trend surface for thorium, Rawah batholith and Sherman Granite, Medicine Bow Mountains, Colorado. Contour interval, 5.0 ppm.

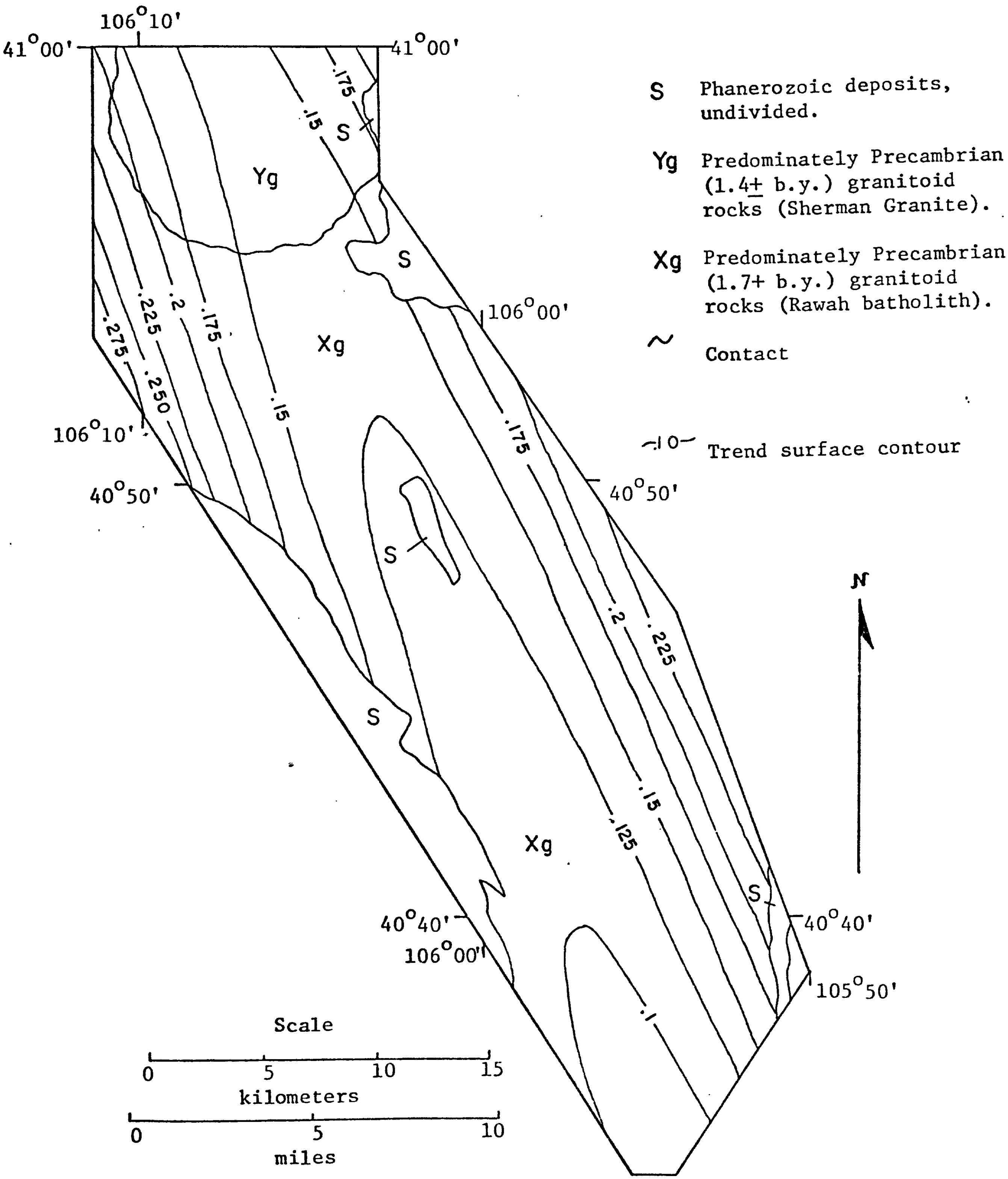

Figure 7. Second-order trend surface for U/Th ratio, Rawah batholith and Sherman Granite, Medicine Bow Mountains, Colorado. Contour interval, 0.025.

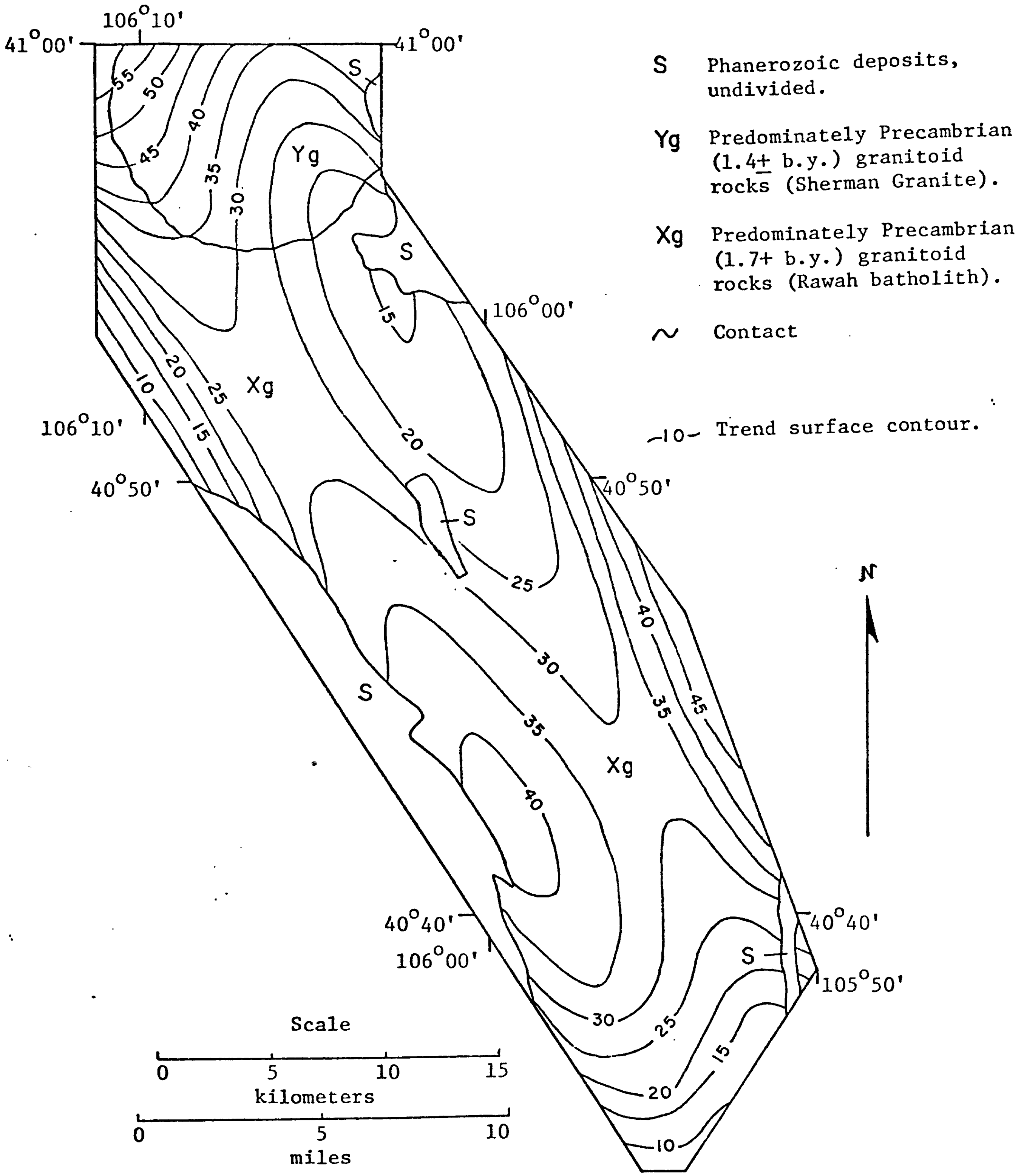

Figure 8. Third-order trend surface for Th/U ratio, Rawah batholith and Sherman Granite, Medicine Bow Mountains, Colorado. Contour interval, 5.0.

pluton were from felsic dikes, thus data derived from them were not applicable for trend surface evaluation of pluton composition.

Thorium highs exist in three different areas in the Colorado Medicine Bow Mountains (fig. 6), and these apparently reflect increases in allanite content. Hickling and others (1970) postulate that much of the allanite in the 1.7+ b.y. Boulder Creek batholith in the central Front Range is secondary and crystallized when the Boulder Creek pluton was intruded by 1.4$\pm$ b.y.old rocks. This does not appear to be the case in the Medicine Bow Mountains. A Th low exists in the Sherman pluton, and two of the three Th highs are far removed from 1.4$\pm$ b.y. intrusive rocks. The Th distribution probably relates to primary compositional variations in the Rawah batholith itself and is not a function of enrichment from outside sources.

The central axial portion of the Colorado Medicine Bow Mountains is characterized by low U (fig. 5) and moderately high to high Th (fig. 6). These trends are accentuated by plots of U/Th (fig. 7) and Th/U (fig. 8) which are low and high, respectively. Although these values may merely reflect primary chemical variations within phases of the Rawah batholith, much of this area is the site of an extensively weathered, high-level erosion surface where selective leaching of U over Th would be expected. Secondary chemical processes would, therefore, readily account for the low U levels and very high Th/U ratios of rocks from such areas.

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