U.S. Department of the Interior

Geological Survey

Oligocene volcanic rocks: possible source of uranium in epigenetic deposits in parts of Chaffee, Park, and Fremont Counties, Colorado

By

Kendell A. Dickinson

and

Francis Allan Hills

Open-File Report 82-403

1982

This report has not been reviewed for conformity with U.S. Geological Survey editorial standards.

CONTENTS

Illustrations

Tables

Oligocene volcanic rocks--Possible source of uranium in epigenetic deposits in parts of Chaffee, Park, and Fremont Counties, Colorado

by

Kendell A. Dickinson and Francis Allan Hills

INTRODUCTION

Uranium deposits of commercial interest have been discovered in the Tallahassee Creek uranium district about 30 km northwest of Canon City, in Fremont County, Colorado, in the High Park area about 8 km west of Cripple Creek, Colorado, and in the Chase Gulch area about 10 km northeast of Hartsel in Park County, Colorado (fig. 1). The deposits in the Tallahassee Creek district are found in the upper Eocene Echo Park Alluvium and in the lower Oligocene Tallahassee Creek Conglomerate. The deposits in the High Park area are mostly in the Tallahassee Creek Conglomerate and the deposits in the Chase Gulch area are mostly in the Oligocene Antero Formation. The Tallahassee Creek deposits were discussed by MacPherson (1959), and Shappirio and Heinrich (1961), the deposits at High Park were described by Hon and Dickinson (1980), and the Chase Gulch deposits were described by Dickinson and Crandall (1980). There has been much uranium exploration in and around these areas, especially in the Antero basin.

The purpose of this report is to analyze uranium and thorium data on volcanic source rocks collected during the National Uranium Resource Evaluation (NURE) studies of the Pueblo 1 by 2 degree NTMS quadrangle (Dickinson and Hills, 1980). A discussion of the potential of the Precambrian crystalline rocks as uranium source rocks is covered in a companion report (Hills and Dickinson, 1982).

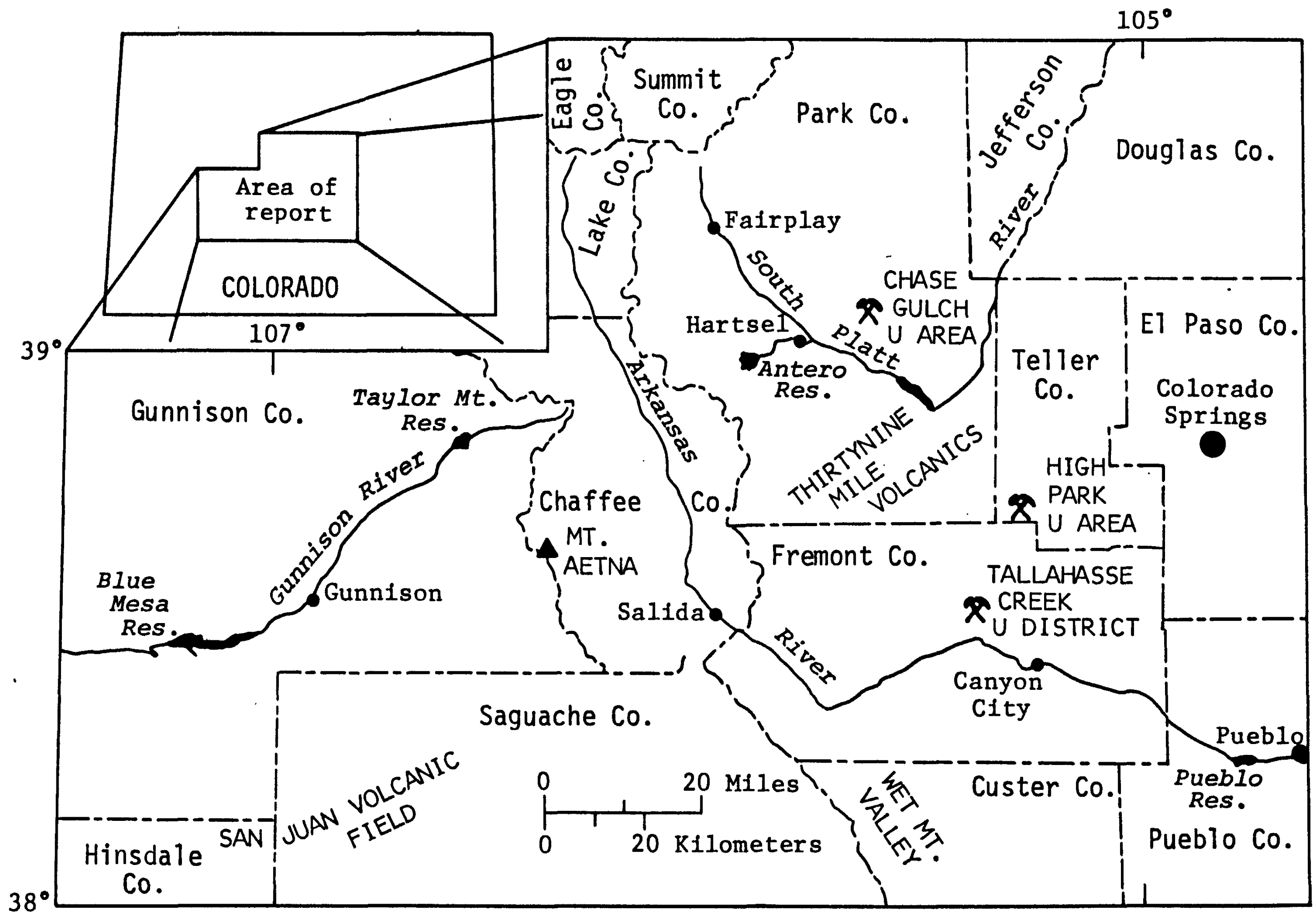

Figure 1.--Map showing locations of uranium deposits in central Colorado.

Oligocene rocks under consideration here are the Wall Mountain Tuff, the Thirtynine Mile Andesite, the tuff of Stirrup Ranch, the Badger Creek Tuff, the Antero Formation, the Thorn Ranch Tuff, and the Gribbles Park Tuff (Scott and others, 1978). Uranium and thorium analyses were made by the delayed-neutron method (Millard, 1976). All analyses were done in the analytical laboratories of the U.S. Geological Survey. For a few samples that contain a high uranium relative to thorium, the uranium interferes with the thorium determination and for these samples only an upper limit for the thorium is given. In general these samples are enriched in uranium and they are not included in the calculation of Th/U or other statistics. At some sites, samples of both apparently-weathered rock and of apparently-fresh rock were obtained. At other sites the degree of weathering was not recorded during sample collection.

Most of the samples for this report were collected by Kenneth A. Hon of the U.S. Geological Survey, and by Larry Smith of Gulf Resources Inc.

DISCUSSION

Uranium and thorium react in a similar fashion in magmatic environments but become separated in oxidizing near-surface environments because uranium has a hexavalent state and thorium does not. The hexavalent state allows uranium to become mobile as the uranyl ion, $UO_2^{=}$, in oxidizing conditions such as surface weathering environments. Volcanic rocks, especially felsic tuffs, commonly have lost uranium by leaching during weathering and are believed to be the source of uranium for many ore bodies. Thorium, on the other hand, generally is believed to remain nearly constant during the leaching process and if the original Th/U is known or can be approximated, the original uranium content of a leached rock can be estimated. In general, a volcanic rock with a higher than normal Th/U has probably lost uranium and may have served as a uranium source rock.

The greatest source of uncertainty in estimating uranium loss from leached volcanic rocks is in estimating the average Th/U in the original unleached material. In order to estimate probable uranium loss an original average Th/U of 2.9 has been assumed in this report. This ratio is used because R. A. Zielinski (unpub. data) found an average Th/U ratio of 2.9 in 28 glass separates and glassy air-fall ash samples from the Oligocene White River Formation in Wyoming (table 1). The glassy samples are believed to be unleached and they are approximtely the same age as samples evaluated in this report. Other analyses of unleached volcanic rocks (cited below) support this choice of original Th/U. The average uranium content of 88 samples of Oligocene volcanic rock from this report area is 5.8 ppm and the average thorium content is 29.4 ppm. Based on these figures and an assumed original average Th/U of 2.9, the calculated average uranium loss is about 4 μg/g. Not all the units, however, have lost uranium equally as discussed below.

R. A. Zielinski (unpub. data) also reported Th/U ranging from 3.1 to 3.5 from other groups of Cenozoic vitreous samples. K. J. Wenrich (unpub. data) reported an average Th/U of 2.8 for 32 rhyolitic samples and 2.9 for 51 andesitic samples from the 2-million year old San Francisco volcanic field located on the southern margin of the Colorado Plateau. The weathered condition of these samples, however, was not reported. The average Th/U for the continental crust reported by Rogers and Adams (1978) is 3 to 4. One vitrophyric sample of Oligocene Wall Mountain Tuff from the Tallahassee Creek area has a Th/U of 4 (table 2). There is a considerable range in Th/U of individual samples, and one sample is insufficient as the basis for a reliable estimate for a rock formation. R. A. Zielinski (unpub. data) for instance, reported a range of 1.9 to 4.2 in the White River samples (table 1). In 7 samples of tuff deposited within the lacustrine Antero Formation, the average Th/U is 2.5 (table 5). These samples are probably not leached because they were deposited in a chemically reducing lake sediment environment. This ratio is not used, however, as the basis for uranium loss calculations because of the possibility that some of these samples were slightly enriched in uranium.

Uranium enrichment in some of the volcanic rocks is an additional problem. These enriched rocks can generally be recognized by their low Th/U, commonly less than one, or by their mineralogy. They may contain iron oxides or opal deposited in association with uranium enrichment. In addition, their high uranium content may be a clue.

Table 1.--Uranium and thorium contents of Oligocene volcanic materials.

		No. of Samples	Uranium (ppm) Min.	Uranium (ppm) Max.	Uranium (ppm) Avg.	Uranium (ppm) Std. Dev.	Thorium (ppm) Min.	Thorium (ppm) Max.	Thorium (ppm) Avg.	Thorium (ppm) Std. Dev.	Th/U Min.	Th/U Max.	Th/U Avg.	Th/U Std. Dev.
White River Fm. (R.A. Zielinski, unpub. data)	Glass separates and glassy air-fall ash	28	4.0	18.6	8.0	3.3	12.2	43.3	22.4	8.2	1.9	4.2	2.9	0.6
Samples from parts of Chaffee, Park, and Fremont Counties, Colorado														
	All samples from parts of Chaffee, Park and Fremont Counties, Colorado	88	1.0	12.4	5.8	2.8	4.3	57.8	29.4	15.2	1.8	10.9	5.3	2.0
	Samples of Wall Mountain Tuff	27	3.6	11.5	7.6	2.3	16.2	54.1	41.9	8.9	2.6	8.9	5.8	1.7
	Samples of the lower member of the Thirtynine Mile Andesite	9	1.0	2.5	1.8	0.5	4.3	14.0	10.3	3.0	3.5	10.9	6.0	2.2
	Samples of the tuff of Stirrup Ranch	14	2.6	12.4	5.8	2.9	16.8	43.2	30.8	10.2	2.5	8.2	6.0	1.7
	Samples of Badger Creek Tuff	23	2.1	11.8	5.2	2.5	6.9	23.1	16.3	4.5	1.8	6.7	3.6	1.5
	Samples of Thorn Ranch Tuff	9	2.4	9.1	5.3	2.3	18.3	56.0	28.3	15.3	3.6	10.7	5.6	2.2
	Samples of Gribbles Park Tuff	6	6.7	9.1	7.5	0.9	40.4	57.8	49.9	7.7	5.7	8.7	6.8	1.1

WALL MOUNTAIN TUFF

The Wall Mountain Tuff is a reddish-brown to yellowish-gray rhyolitic ash-flow tuff that is moderately to strongly welded and contains crystals of glassy sanidine and argillized plagioclase. It originated during the early Oligocene somewhere west of the Tallahassee Creek uranium district, perhaps near Salida or Mt. Aetna (Epis and others, 1976), and it flowed widely over a late Eocene, low-relief, erosion surface. The tuff extended as far northward as Castle Rock, Colorado, and as far southward as the north end of the Wet Mountain Valley (Scott and others, 1978; Bryant and others, 1978).

The Wall Mountain Tuff was apparently a major source of uranium found in the deposits in the Tallahassee Creek uranium district and in the Antero basin and Chase Gulch areas in central Colorado. This conclusion is based on three lines of evidence:

(1) The Wall Mountain Tuff lies beneath the Tallahassee Creek Conglomerate and above the Echo Park Alluvium, the two primary uranium host rocks in the Tallahassee Creek district.

(2) Several potential uranium host rocks contain uranium occurrences where they were overlain by or probably were overlain by the Wall Mountain Tuff. These occurrences are found along the foothills in the area from Canon City to Morrison in Colorado (fig. 1), along the west side of the Denver basin in the up-turned edges of Paleozoic and Mesozoic host rocks, and in Paleocene rocks to the east in the central part of the basin (Hills and others, 1980; and Dickinson and Hills, 1980). All of these rocks cropped out along the late Eocene erosion surface (Granger, and Dickinson, 1980).

(3) Based on the average thorium content (41.9 ppm, tables 1 and 2) of the Wall Mountain Tuff and an assumed original Th/U of 2.9, the original uranium content was about 15 ppm. The present average uranium content of the tuff is

7.6 ppm, suggesting a uranium loss by leaching of about 7 μg/g.

Disregarding the sample numbered 425, which was probably enriched in uranium only sample 407 has lost no uranium if its original Th/U is assumed to be 2.9 (figs. 2 and 3). Three additional samples, however, (numbers 350, 428, and 500) fall within the range of Th/U of the White River glassy samples reported by R. A. Zielinski (unpub. data) (table 1). These data suggest that only 4 of 27 samples may have remained unleached. Some of the samples that have a fresh appearance, such as samples 378 and 422 apparently lost considerable uranium.

The Wall Mountain Tuff, based on its probable original uranium content, its degree of leaching, and its widespread occurrence, was probably the most important volcanic uranium source in the report area.

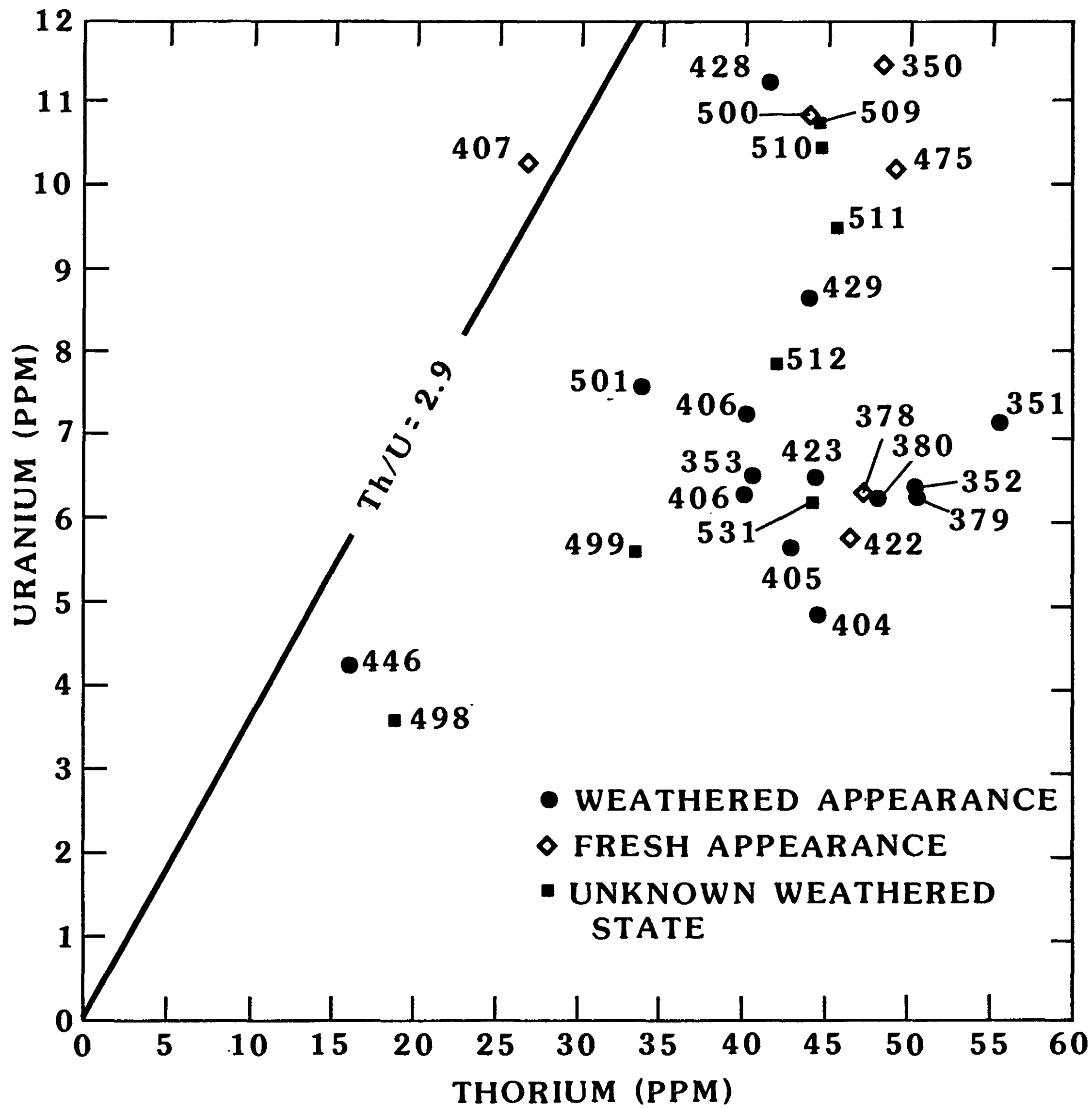

Figure 2.--Graph of uranium versus thorium in the Wall Mountain Tuff.

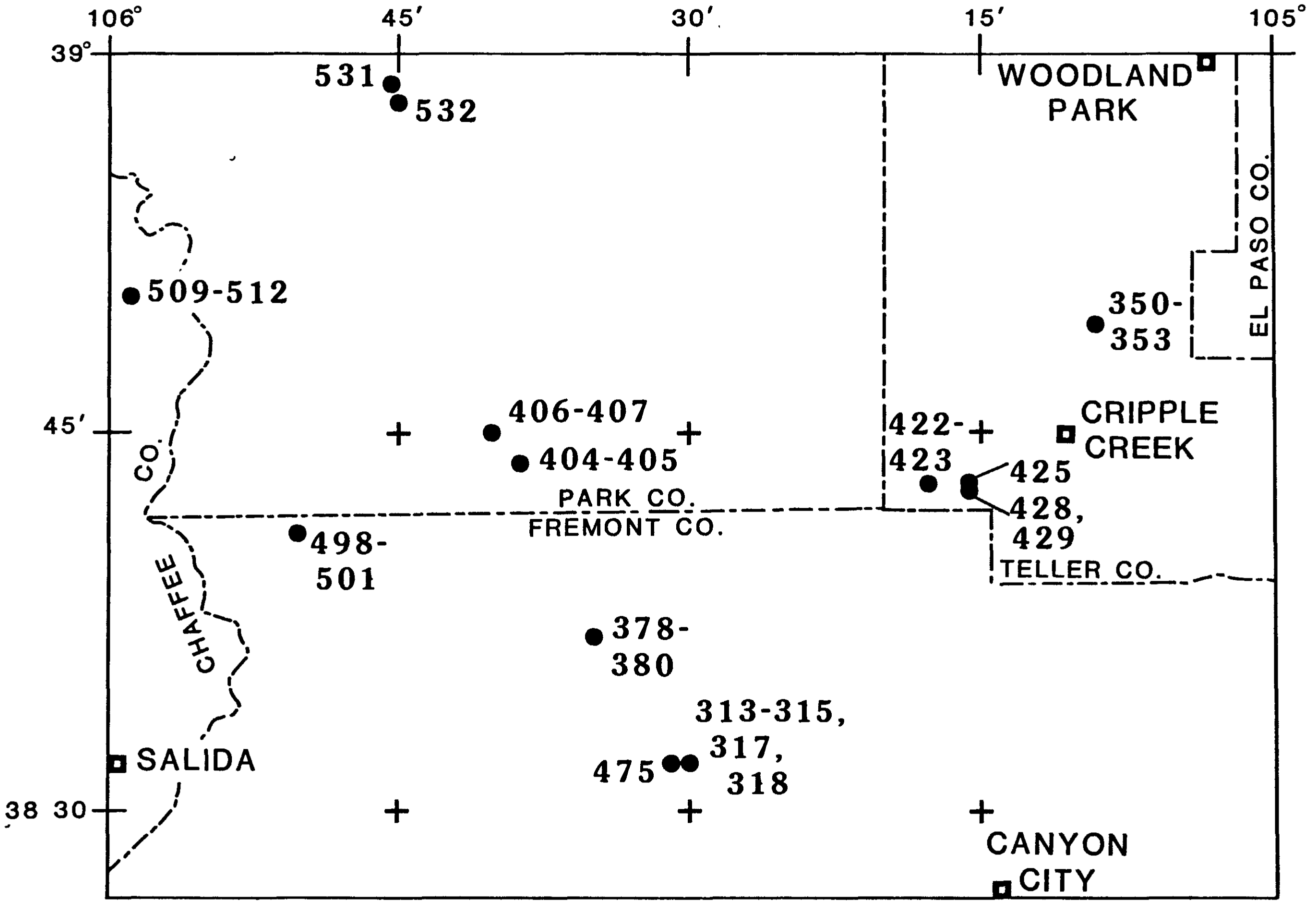

Figure 3.--Sample localities of Wall Mountain Tuff.

Table 2.--Uranium and Thorium data for samples of the Wall Mountain Tuff

Sample Number	Uranium (ppm)	Thorium (ppm)	Th/U	Field comments
		Fresh appearance		
350	11.5	48.5	4.2	Moderate to densely welded tuff
378	6.4	47.3	7.4	Fresh tuff, limonite on fractures
407	10.3	27.0	2.6	Fresh tuff
422	5.8	45.3	7.8	Fresh unweathered tuff
475	10.2	49.2	4.8	Boulder of Wall Mountain Tuff in Tallahassee Creek Conglomerate, fresh
500	10.9	43.8	4.0	Vitrophyre
		Weathered appearance		
351	7.2	54.1	7.5	Partially weathered, moderately welded
352	6.4	50.5	7.9	Weathered tuff
353	6.6	40.7	6.2	Bleached weathered tuff
379	6.3	50.6	8.0	Bleached weathered altered tuff
380	6.3	48.2	7.7	(replicate sample of above)
404	5.0	44.6	8.9	Weathered tuff in float
405	5.7	43.0	7.5	Partially weathered tuff
406	7.3	40.2	5.5	Weathered tuff
423	6.6	44.4	6.7	Weathered tuff
425	49.9[1/]	<15.0[1/]	<0.3[1/]	Brecciated silicified tuff
429	8.7	43.8	5.0	Weathered tuff
446	4.3	16.2	3.8	Highly weathered tuff
501	7.6	34.0	4.5	Devitrified tuff
		Weathered appearance unknown		
428	11.3	41.5	3.7	
498	3.6	19.0	5.3	Distal tuff capping mesa
499	5.6	33.6	6.0	Distal tuff capping mesa
509	10.8	44.5	4.1	
510	10.5	44.6	4.3	
511	9.5	45.6	4.8	
512	7.9	42.0	5.3	
531	6.3	44.2	7.0	
532	6.5	44.3	6.8	
Overall Average	7.6	41.9	5.8	

[1/]Not included in average

LOWER MEMBER OF THE THIRTYNINE MILE ANDESITE

The lower member of the Thirtynine Mile Andesite consists mostly of dark-colored laharic breccias and lava flows derived from local vents marked by small breccia cones. Non-vescicular pyroxene andesite is the most common petrographic type (Epis and Chapin, 1974). The unit covers much of northwestern Fremont County and southwestern Park County.

The lower member of the Thirtynine Mile Andesite was probably not a major source of uranium for the deposits in Park and Fremont Counties because the unit apparently had a low original uranium content. Nine samples averaged 10.3 ppm thorium and 1.8 ppm uranium giving an average Th/U of about 6.0 (tables 1 and 3). Based on its average thorium content of 10.3 ppm and using an assumed original Th/U of 2.9, the original uranium content would have been about 3.6 ppm (tables 1 and 3). The average uranium content of the samples collected for this report is 1.8 ppm suggesting a uranium loss of a little less than 2 µg/g. If, however, the Th/U is considered on an areal basis, it can be seen that the Th/U is higher in the vicinity of the Tallahassee Creek uranium area and more extensive leaching may have occurred at that locality (table 3, fig. 5). None of the samples of the andesite had a Th/U of 2.9 or less, and only one sample, number 395 fell below R. A. Zielinski's (unpub. data) upper limit of 4.2 for the Oligocene glassy samples (fig. 4).

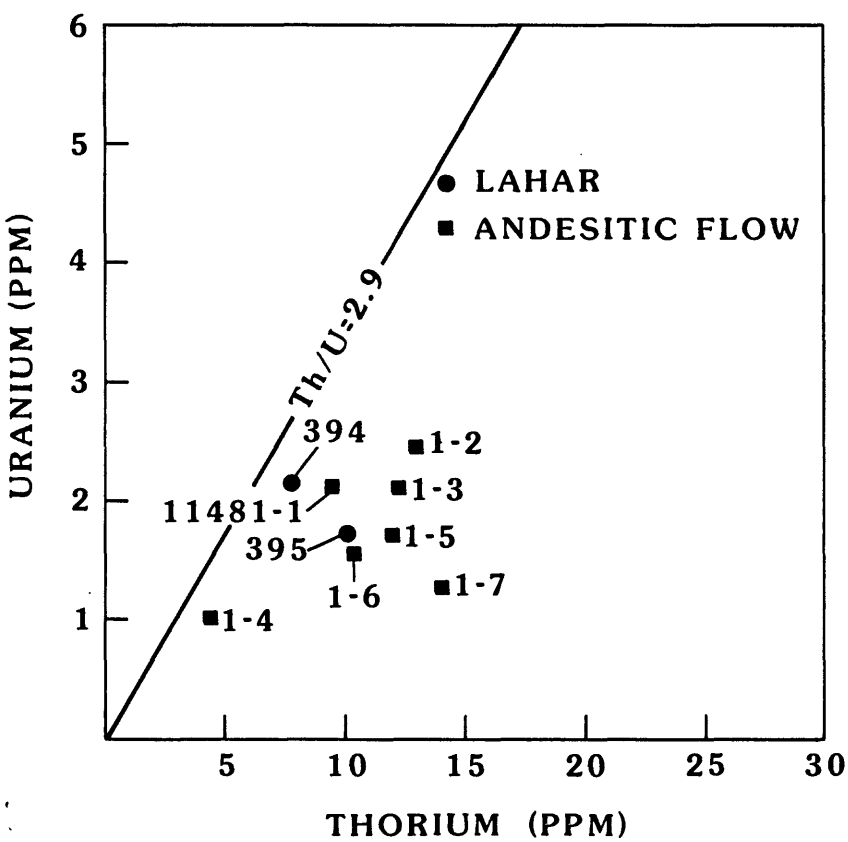

Figure 4.--Graph of uranium versus thorium contents of samples of the lower member of the Thirtynine Mile Andesite.

Table 3.--Uranium and thorium data for samples of the lower member of the Thirtynine Mile Andesite

Sample Number	Uranium (ppm)	Thorium (ppm)	Th/U	Field Comments
111481-1	2.1	9.4	4.5	Andesite, gray, mottled, ash-flow tuff
-2	2.5	12.9	5.2	Andesite, gray, volcaniclastic
-3	2.1	12.1	5.8	Andesite, light yellow-brown weathered
-4	1.0	4.3	4.2	Andesite, gray, hard, tuffaceous
-5	1.7	11.9	7.0	Andesite, mottled brown, hard
-6	1.5	10.3	6.7	Andesite, gray, porphyritic, altered phenocrysts
-7	1.3	14.0	10.9	Andesite, gray, amygdaloidal, clay and iron oxide
394	1.7	10.3	6.1	Lahar at base of unit
395	2.2	7.7	3.5	Lahar at base of unit
Averages	1.8	10.3	6.0	

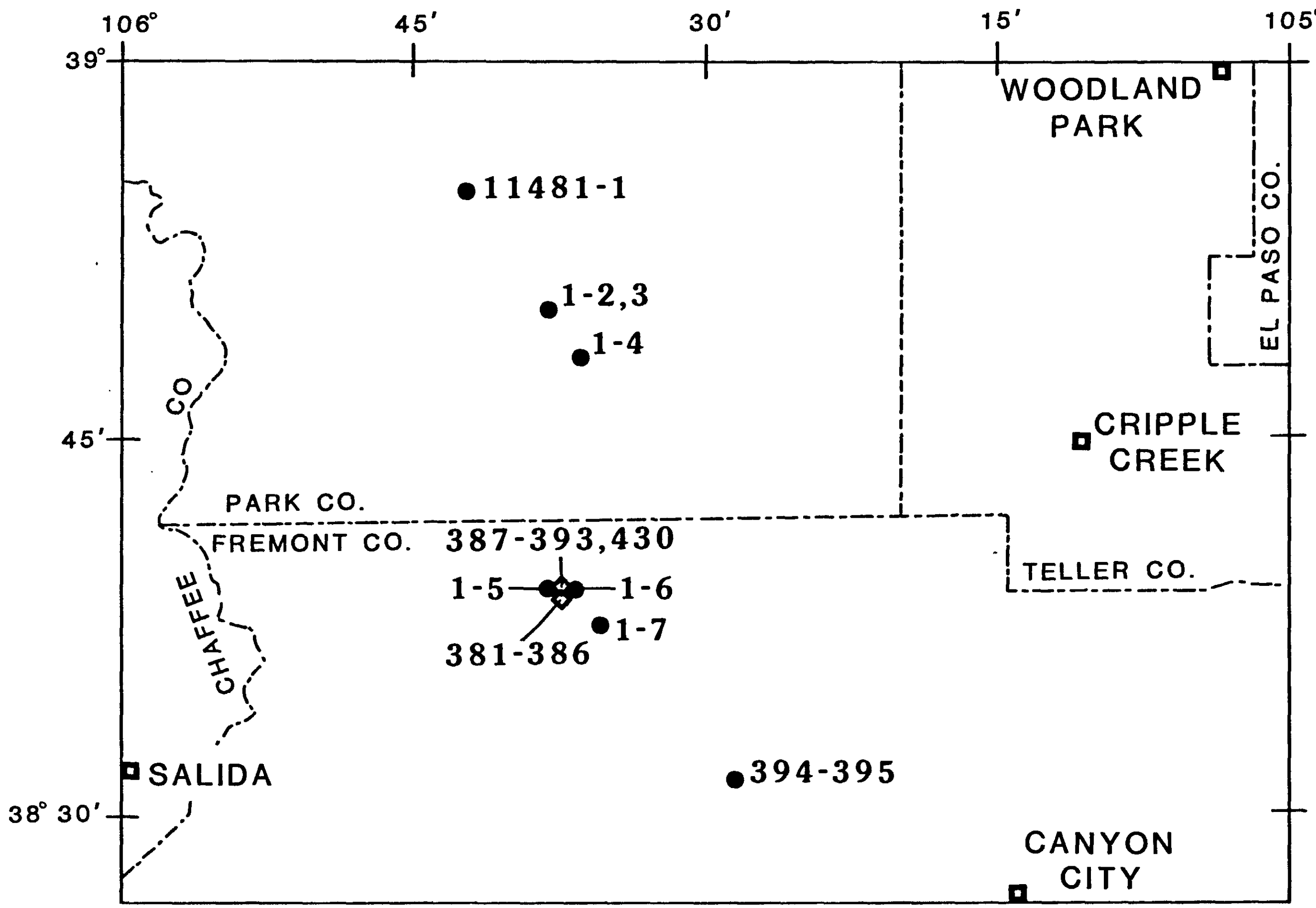

Figure 5.--Sample localities of the Tuff of Stirrup Ranch (●) and the lower member of the Thirtynine Mile Andesite (□).

TUFF OF STIRRUP RANCH

The tuff of Stirrup Ranch is a rhyolitic ash-flow that is interbedded with the lower member of the Thirtynine Mile Andesite and that at one locality in the Tallahassee Creek area lies directly on the Tallahassee Creek Conglomerate. Lithologically and chemically the unit is indistinguishable from the Wall Mountain Tuff (Epis and Chapin, 1974).

The average thorium content of the samples from the tuff of Stirrup Ranch is 30.8 ppm (tables 1 and 4). Using this thorium content and an assumed average original Th/U of 2.9 the average original uranium content should have been about 10.6. The average present uranium content of the samples is 5.8, suggesting a uranium loss of about 5 μg/g. One sample, number 430, has a Th/U of 2.5 and probably is not leached. The Th/U of two other samples is below 4.2 and also may not have been leached (figs. 5 and 6).

The tuff of Stirrup Ranch samples were collected from two localities that differ in their uranium and thorium contents (fig. 6). In the samples from locality 2, the thorium content averages about 40 ppm, about twice that from locality 1. Uranium in samples from locality 2 is also about twice that for samples from locality 1. The Th/U are nearly equal for the two groups, suggesting that the degree of leaching is also nearly equal. Rocks at the two localities may not have been derived from the same eruption or from the same cooling unit.

The limited geographic extent of the tuff of Stirrup Ranch is the greatest limitation to its potential as a source rock. In the Tallahassee Creek district, however, it is present in a small belt of outcrops that extends from the junction of North and Middle Tallahassee Creeks northward along the west margin of the Echo Park graben for about 17 km. The tuff may have been a substantial source in this area, especially where it was in direct contact with the underlying Tallahassee Creek Conglomerate.

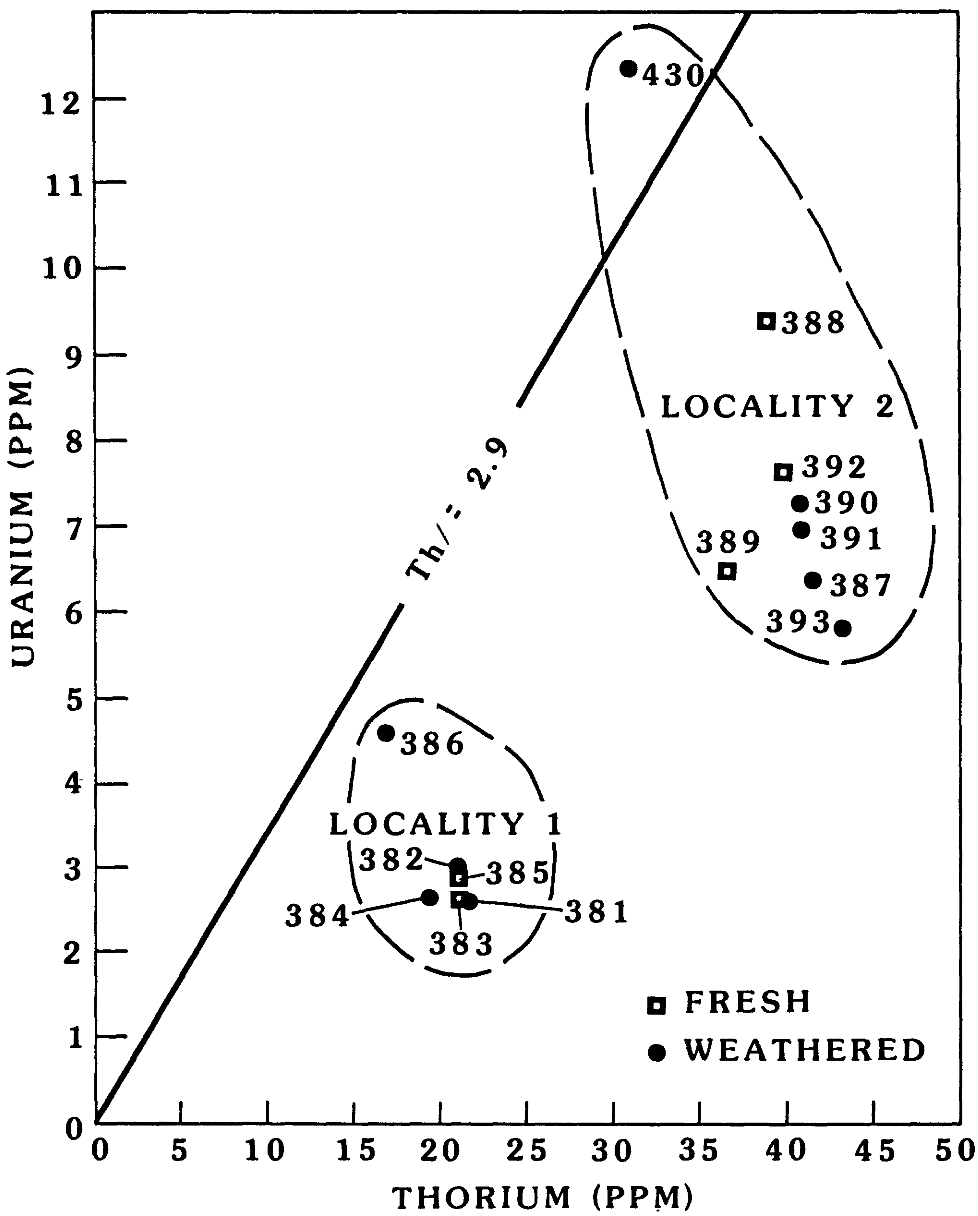

Figure 6.--Graph showing uranium and thorum in tuff of Stirrup Ranch.

Table 4.--Uranium and thorium data for samples of the tuff of Stirrup Ranch

Sample Number	Uranium (ppm)	Thorium (ppm)	Th/U	Field Comments
		Fresh appearance		
383	2.6	21.1	8.0	Densely welded
385	2.9	21.0	7.3	Densely welded
388	9.4	38.8	4.1	Densely welded
389	6.6	36.1	5.5	
392	7.6	39.8	5.2	Densely welded tuff
		Weathered appearance		
381	2.6	21.5	8.2	Bleached
382	3.0	21.1	7.1	Bleached
384	2.7	18.4	6.9	Bleached, altered, breccia in tuff
386	4.6	16.8	3.7	Fault breccia in tuff
387	6.4	41.5	6.5	Partially altered, vapor phase to zeolites
390	7.3	40.7	5.6	
391	7.0	40.8	5.9	Partially weathered tuff
393	5.8	43.2	7.4	Partially weathered, vapor phase alteration
430	12.4	31.0	2.5	Weathered tuff
Overall Average	5.8	30.8	6.0	

BADGER CREEK TUFF AND ANTERO FORMATION

The Badger Creek Tuff is dominantly a latite that contains abundant biotite, andesine, and hornblende crystals mixed with light-colored pumice lapilli. The Antero Formation is predominantly lacustrine sediment, but it also contains ash-flow tuff that flowed into the lake basin. This tuff is equivalent in age and lithology to the Badger Creek Tuff (Epis and Chapin, 1974) or the lower member of the Thirtynine Mile Andesite (Scott and others, 1978). The Antero samples included in this study are samples of the ash-flow tuff.

The Badger Creek Tuff is a compound cooling unit consisting of several ash flows that locally contain densely welded vitrophyre (Epis and Chapin, 1974). In the Castle Rock Gulch paleovalley, which extends northeastward from Castle Rock Gulch (fig. 8), the Badger Creek Tuff is described by L. B. Smith (unpub. data) as a nonwelded andesitic ash-flow tuff. He describes the Badger Creek Tuff in the Salida-Waugh Mountain paleovalley as a welded to nonwelded dacitic ash-flow tuff. Different uranium and thorium contents in the Castle Rock Gulch and Salida-Waugh Mountain areas (fig. 7, table 5) probably reflect the different lithologic compositions and different degrees of leaching. Samples from Castle Rock Gulch average 2.3 ppm uranium and 13.4 thorium. For the Salida-Waugh Mountain area, uranium averages 6.4 ppm, more than twice as much as samples from Castle Rock Gulch, and thorium averages 19.2 ppm U. The difference apparently results from the higher original uranium content of the Salida-Waugh Mountain samples and the greater leaching of the Castle Rock Gulch samples (Dickinson, 1980). Based on an assumed original average Th/U of 2.9, the Castle Rock Gulch samples have lost about 2 g/g and the Salida-Waugh Mountain samples have only lost about 0.2 g/g.

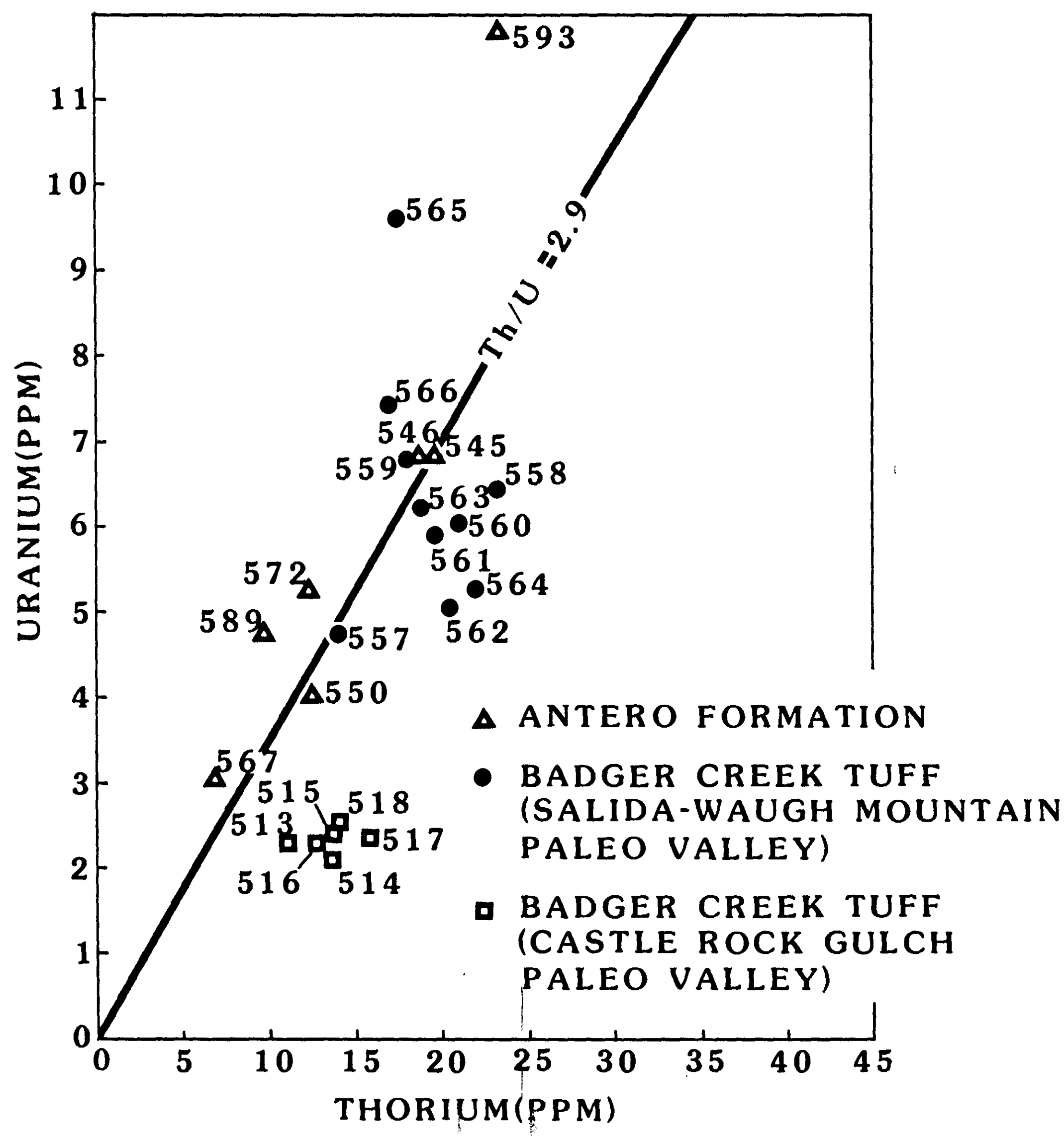

Figure 7.--Graph of uranium versus thorium in the Badger Creek Tuff and the Gribbles Park Tuff.

Table 5.--Uranium and Thorium data for Badger Creek Tuff and the Antero Formation

Sample Number	Uranium (ppm)	Thorium (ppm)	Th/U	Field Comments
Castle Rock Gulch, [low silica dacites (personal communication, L. B. Smith, 1981)]				
513	2.3	11.0	4.8	Light-gray to reddish-gray, moderate to densely welded rhyolite ash-flow tuff
514	2.1	13.6	6.4	Light-gray, soft, non-welded andesite(?) ash-flow tuff
515	2.4	13.6	5.7	
516	2.3	12.9	5.7	
517	2.4	15.9	6.7	
518	2.4	13.5	5.5	
Salida-Waugh Mountain paleovalley [high silica dacites (personal communication, L. B. Smith, 1981)]				
557	4.8	14.0	2.9	Light-gray, pumaceous, slightly welded ash-flow tuff
558	6.4	23.1	3.6	Light-gray, soft, nonwelded ash-flow tuff
559	6.8	18.2	2.7	Light-yellow brown, massive, nonwelded pumaceous, ash-flow tuff
560	6.1	21.1	3.5	Pinkish gray massive non-welded pumaceous, ash-flow tuff
561	5.9	19.7	3.3	Gray to brown moderately welded eutaxitic ash-flow tuff
562	5.0	20.6	4.1	Moderate welded slightly eutaxitic ash-flow tuff
563	6.3	18.8	3.0	Medium gray, moderately welded eutaxitic ash-flow tuff
564	5.3	22.0	4.2	Medium gray, densely welded eutaxitic ash-flow tuff
565	9.6	17.6	1.8	White massive nonwelded pumaceous ash-flow tuff
566	7.4	17.0	2.3	Light-gray nonwelded pumaceous ash-flow tuff
Antero Formation (tuffaceous rock equivalent to the Badger Creek Tuff)				
545	6.8	19.8	2.9	
546	6.8	18.7	2.8	
550	4.0	12.4	3.1	Non welded, pumaceous andesitic(?) ash-flow tuff
567	3.1	6.9	2.3	Brown to gray silicified, nonwelded pumaceous andesitic ash-flow tuff
568	12.8[1/]	<6.5[1/]	<0.5[1/]	White, massive, pumaceous andesitic ash-flow tuff
572	5.3	12.4	2.4	White, massive, highly pumaceous, nonwelded andesitic ash-flow tuff
589	4.7	9.8	2.1	Gray, brown, moderately welded eutaxitic andesitic(?) ash-flow tuff
593	11.8	23.1	2.0	Nonwelded pumaceous andesitic ash flow tuff
Overall Average	5.2	16.3	3.6	

1/Samples not included in averages

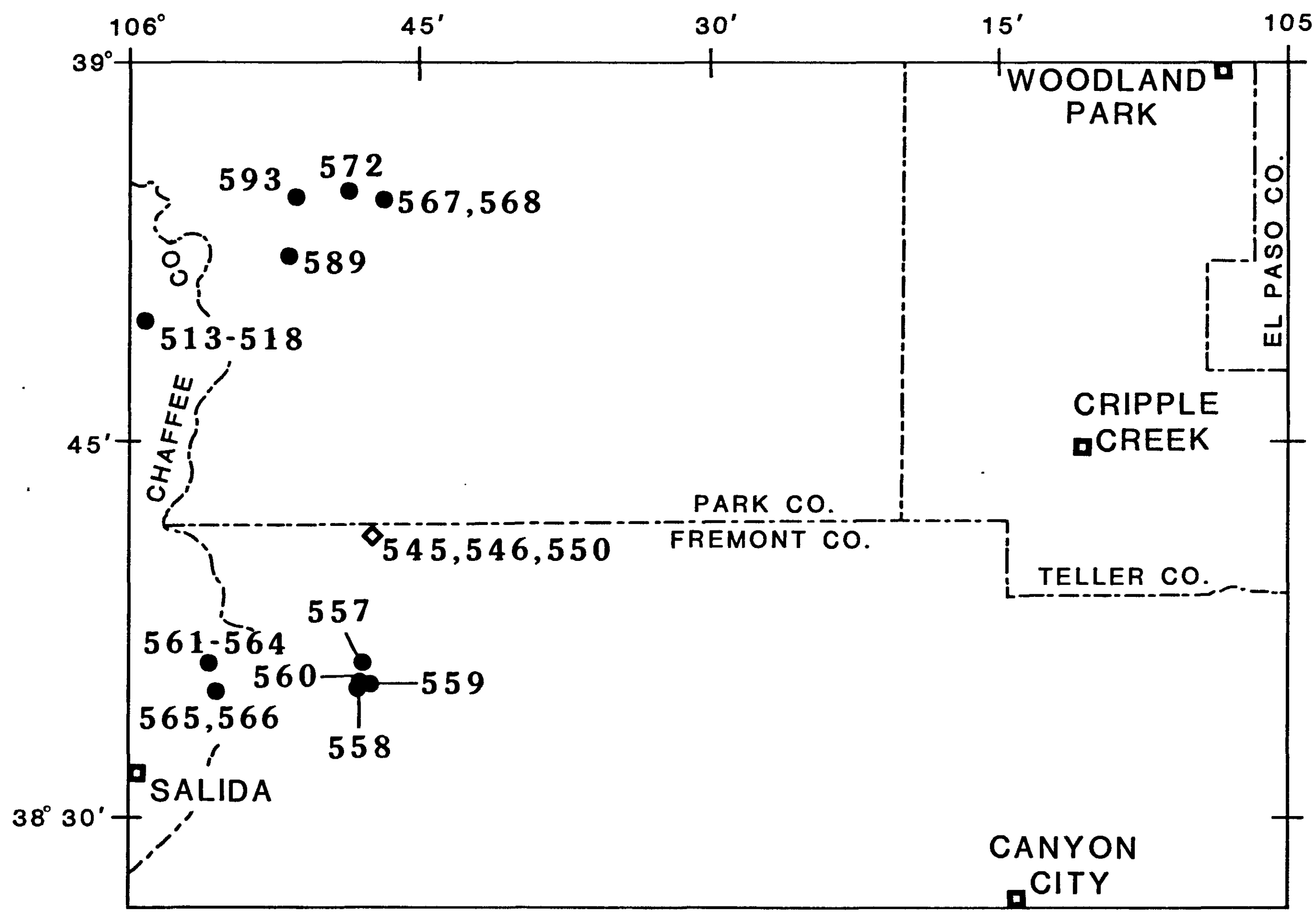

Figure 8.--Sample localities for Badger Creek Tuff (●), and Antero Formation (◘).

The uranium and thorium contents of the Antero Formation samples (fig. 7, table 5) vary widely, but based on an assumed average Th/U of 2.9, none of the samples has been leached of uranium. Excluding sample 568 (table 5) which appears to be slightly enriched in uranium, the average Th/U is 2.2. The thorium content, again excluding the enriched sample, averages 13.1 ppm suggesting that the Antero samples are more closely related to the Badger Creek Tuff of Castle Rock Gulch, which averages 13.4 ppm thorium, than to the Badger Creek Tuff from the Salida-Waugh Mountain paleovalley which averages 19.2 ppm thorium. The unleached condition of the tuff deposited in the lake basin suggests that the geochemical conditions in the lake, probably a chemically reducing environment, were not conducive to leaching and that the source for uranium deposits in the lake sediment was external to the lake.

GRIBBLES PARK TUFF, THORN RANCH TUFF, AND EAST GULCH TUFF

The Gribbles Park Tuff, the Thorn Ranch Tuff and the East Gulch Tuff are associated in age and geographical distribution and they have not been separated in mapping (Scott and others, 1978). The East Gulch Tuff is the oldest and the Gribbles Park Tuff is youngest at 29 million years. They crop out around the southern end of the Antero basin, around Waugh Mountain, and in the vicinity of the southern end of the Echo Park graben (fig. 10). No samples were collected from the East Gulch Tuff.

Gribbles Park Tuff.--According to Wobus, Epis, and Scott (1979) the Gribbles Park Tuff consists of "gray, brown, red, or orange welded to nonwelded rhyolitic ash-flow tuff characterized by chatoyant sanidine, bronze-colored biotite, and dark-brown or gray lithic fragments." The source of the flow is unknown but the Bonanza volcanic field, to the west, has been suggested as a possibility.

The average uranium content of the Gribbles Park Tuff based on 6 samples is 7.5 ppm and the average thorium content is 49.9 ppm (tables 1 and 6). Based on

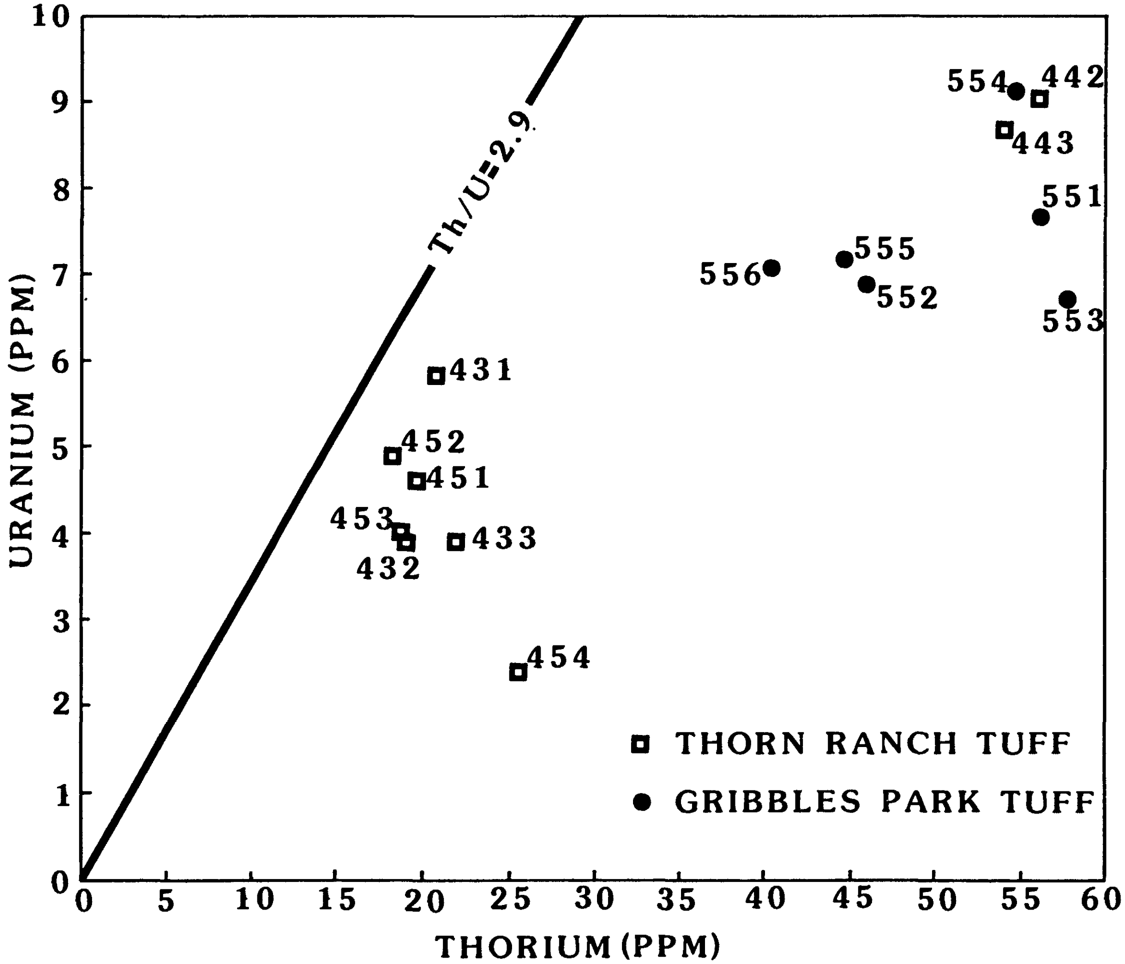

Figure 9.--Graph of uranium versus thorium in the Thorn Ranch Tuff and Gribbles Park Tuff.

an assumed average original Th/U of 2.9, these data suggest that the original uranium content of Gribbles Park Tuff was about 17 ppm and that it has lost about 9 µg/g of rock. The unit appears to have been an important local source for that element. The greatest limitation on the Gribbles Park Tuff as an important uranium source may be its restricted areal distribution.

Thorn Ranch Tuff.--The Thorn Ranch Tuff is a reddish-brown to pinkish-white, welded to non-welded ash-flow tuff of rhyolitic composition. The tuff contains pink and white pumice, igneous and metamorphic rock fragments, and phenocrysts of sanidine, plagioclase, quartz, and biotite (Epis and Chapin, 1974). According to Wobus, Epis, and Scott (1979) the source of the Thorn Ranch Tuff may have been the San Juan volcanic field (fig. 1).

Thorn Ranch Tuff samples fall into two groups based on the thorium and uranium contents and on locality (fig. 9, 10). The first group of samples was collected near the confluence of North, Middle, and South Tallahassee Creeks, and the second group was collected 6 to 9 km north of the first group along Cottonwood Creek (fig. 10). The first group consisted of 7 samples; numbers 431, 432, 433, 451, 452, 453, and 454; and the second group consisted of only 2 samples; numbers 442 and 443 (table 6). The first group of samples averaged 20.6 ppm thorium, and assuming an average original Th/U of 2.9 it had an original uranium content of about 7 ppm. The present uranium content averages about 4 ppm, suggesting a loss of about 3 µg/g. The second group, of only two samples, averages 55 ppm thorium, suggesting an original uranium content of 19 ppm. These two samples average about 9 ppm uranium, suggesting a loss of about 10 µg/g.

Table 6.--Uranium and Thorium data for the Thorn Ranch Tuff and Gribbles Park Tuff

Sample Number	Uranium (ppm)	Thorium (ppm)	Th/U	Comments
		Thorn Ranch Tuff		
MDE 431	5.8	20.8	3.6	Medium-brown, spherulitic tuff, contains pumice fragments
MDE 432	3.9	19.0	4.9	Moderately to poorly welded tuff, contains pumic fragments
MDE 433	3.9	22.0	5.7	Moderately welded tuff, containing pumice fragments and vapor phase minerals
MDE 442	9.1	56.0	6.2	Very weathered, densely welded, sanidine rich tuff
MDE 443	8.7	54.0	6.2	Partly weathered, welded tuff, containing pumice with altered vapor phase minerals
MDE 451	4.6	19.7	4.3	Densely welded tuff
MDE 452	4.9	18.3	3.7	Weathered tuff
MDE 453	4.0	18.9	4.7	Moderately welded tuff
MDE 454	2.4	25.7	10.7	Poorly to mderately welded tuff
Averages	5.3	28.3	5.6	
		Gribbles Park Tuff		
MDE 551	7.7	56.1	7.3	Pink to gray, densely welded rhyolitic ash-flow tuff (middle part)
MDE 552	6.9	45.8	6.7	Purple densely welded, slightly devitrified rhyolitic ash-flow tuff (middle part)
MDE 553	6.7	57.8	8.7	Tan, densely welded vitroclastic rhyolitic ash-flow tuff (lower part)
MDE 554	9.1	54.6	6.0	Dark-red densely welded, devitrified, vitro-clastic rhyolitic ash-flow tuff
MDE 555	7.2	44.7	6.2	Medium-gray densely welded rhyolitic ash flow tuff (upper part)
MDE 556	7.1	40.4	5.7	Medium-gray and reddish-gray, moderately to densely welded rhyolitic ash-flow tuff (upper part)
Averages	7.5	49.9	6.8	

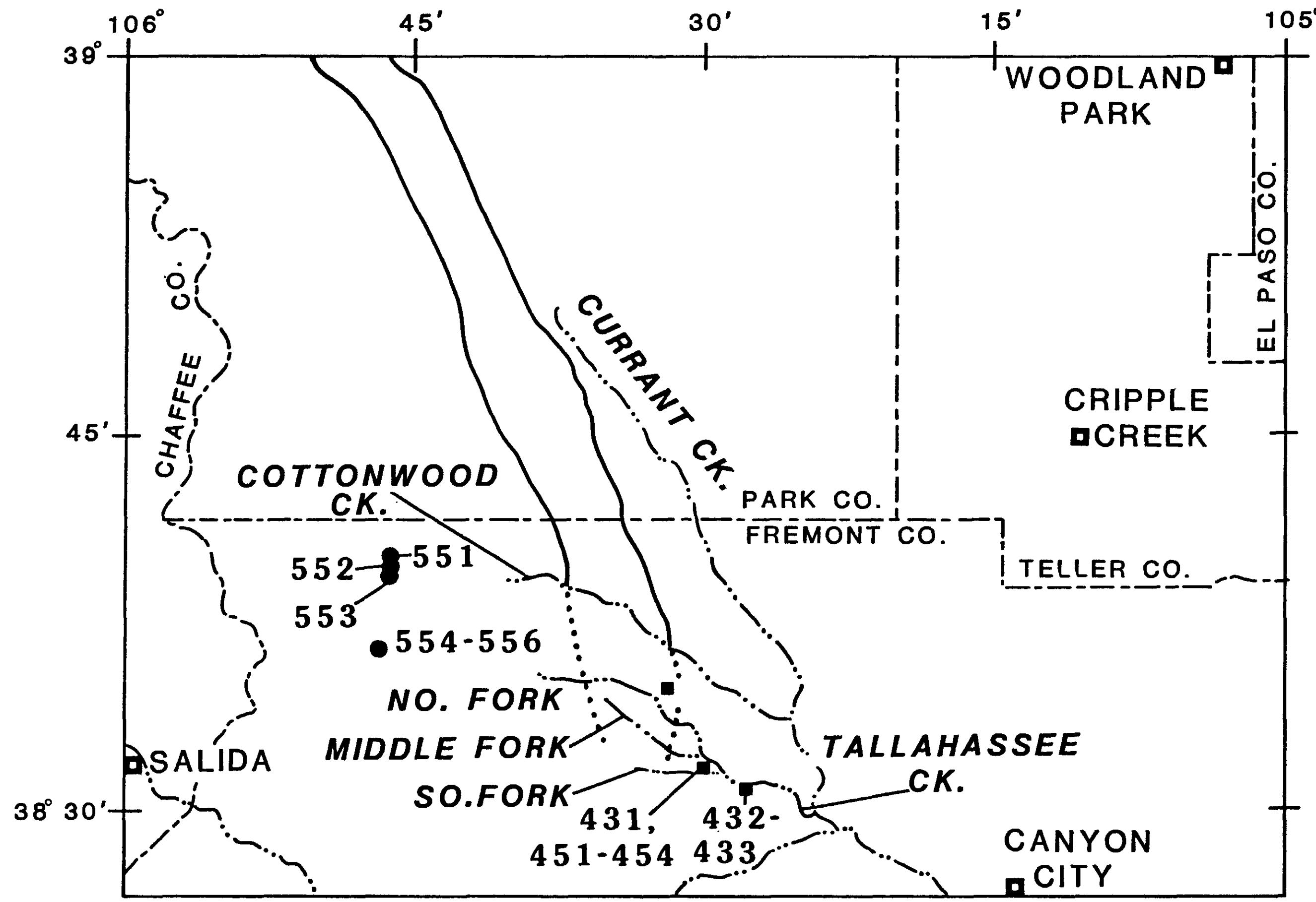

Figure 10.--Sample localitites of the Thorn Ranch Tuff (□) and the Gribbles Park Tuff (●).

As is true of other rocks evaluated in this report, Th/U of the samples do not appear to correlate well with their apparent state of weathering. The uranium content and the Th/U seem to be more related to location and perhaps to stratigraphic position.

SUMMARY AND CONCLUSIONS

1. All of the volcanic rocks in the report area probably contributed uranium to mineralizing fluids, but some of the rocks apparently were more important contributors, because (1) they originally contained more uranium, (2) they were leached to a greater degree, and (3) they were distributed over a wider area. The most important unit is thought to be the Wall Mountain Tuff, because it probably had an original uranium content of about twice the average for silicic tuff, it was strongly leached, and it is widespread. Other units that could have contributed significant uranium are the Gribbles Park Tuff, the Thorn Ranch Tuff and the tuff of Stirrup Ranch, although these units have a very limited distribution. The lower member of the Thirtynine Mile Andesite probably was not a significant uranium source because of its low original uranium content. The Badger Creek Tuff seems to have been a significant source of uranium only in the Castle Rock Gulch paleovalley, where it is strongly leached even though its original uranium content there was probably low. In the Salida-Waugh Mountain paleovalley and in the Antero basin where tuff equivalent to the Badger Creek forms part of the Antero Formation, the tuff was apparently not leached. A companion report (Hills and Dickinson, 1982), concludes that 1400 m.y. old Silver Plume Granite adjoining the Tallahassee Creek area contains leachable uranium and may have contributed uranium to deposits in that area.
2. The data in this report, although somewhat limited, suggest that the degree of leaching of a given volcanic unit varies geographically. These variations

may result from the variable chemical character of the leaching fluid and from the variable quantities of water that flowed through each volume of rock. The quantity of water moving through the rock varies with paleo-hydrostatic head and with permeability, which depends mainly on the texture of the rock, and on its degree of welding. These characteristics may vary with stratigraphic position in the unit. Paleo-variations in leachate chemistry are impossible to determine.

3. The weathered appearance of the rock does not seem to be a good indicator of its leached state with regard to uranium. The Th/U ratio appears to be a better indicator. If samples are divided into leached and non leached on the basis of weathered appearance, the weathered group may have only slightly less uranium and a slightly higher Th/U. If, on the other hand, the leached group is determined on the basis of its high Th/U it will also contain significantly less uranium.
4. Vertical trends on the uranium-thorium graphs (figs. 2, 4, 6, 7, 9) result from greater variability in the uranium contents than in the thorium contents. This variation probably results uranium loss by varying degrees of leaching.

References Cited

Bryant, B., McGrew, L. W., and Wobus, R. R., 1978, Preliminary Geologic Map of the Denver 1^{o} x 2^{o} Quadrangle, North-Central Colorado: U.S. Geol. Survey Open-File Report 78-397.

Dickinson, K. A., 1980, Environments favorable for uranium: Area H, Castle Rock Gulch, _in_ Dickinson, K. A., and Hills, F. A., _eds._, Uranium resource evaluation, Pueblo Quadrangle, Colorado: U.S. Dept. of Energy Open-File Report PGJ-075(81).

Dickinson, K. A., and Crandall, T. M., 1980, South Park favorable area, _in_ Hills, F. A., and Dickinson, K. A., _eds._ Uranium Resource Evaluation, Denver Quadrangle, Colorado: U.S. Dept. of Energy, Open-File Report PGJ-078(81), p. 73-80.

Dickinson, K. A., and Hills, F. A., 1980, Uranium resource evaluation, Pueblo Quadrangle, Colorado: U.S. Dept. of Energy Open-File Report, PGJ-075(81) 4 tables, 16 figs., 10 plates, 197 p.

Epis, R. C., and Chapin, C. E., 1974, Stratigraphic nomenclature of the Thirtynine Mile volcanic field, Central Colorado: U.S. Geological Survey Bulletin 1395-C, 23 p.

Epis, R. C., Scott, G. R., Taylor, R. B., and Chapin, C. E., 1976, Cenozoic volcanic, tectonic, and geomorphic features of central Colorado, _in_ Epis, R. C., and Weimer, R. J., Professional Contributions of Colorado School of Mines; Studies in Colorado Field Geology, no. 8, p. 323-338.

Granger, H. C., and Dickinson, K. A., 1980, Environments favorable for uranium deposits, additional criteria for favorability, in Dickinson, K. A., and Hills, F. A., eds.: Uranium resource evaluation, Pueblo Quadrangle, Colorado, U.S. Dept. of Energy Open-File Report, PGJ-075(81).

Hills, F. A., Dickinson, K. A., Nash, J. T., Otton, J. K., Dodge, H. W., and Granger, H. C., 1980, Uranium resource evaluation, Denver 1^{o} x 2^{o} Quadrangle: U.S. Geological Survey NURE Folio: U.S. Department of Energy Open-File PGJ-078(81), 159 p. text, 1209 p. appendices, 27 pl.

Hills, F. A., and Dickinson, K. A., 1982, Silver Plume Granite: possible source of uranium in sandstone uranium deposits, Tallahassee Creek and High Park areas Fremont and Teller Counties, Colorado: U.S. Geol. Survey Open File Report 82-404, 23 p.

Hon, K. A., Dickinson, K. A., 1980, Area A, Echo Park Graben, Tallahassee Creek Uranium district in Dickinson, K. A., and Hills, F. A., eds., Uranium resource evaluation, Pueblo Quadrangle, Colorado, U.S. Department of Energy Open-File Report PGJ-075(81).

MacPherson, B. A., 1959, Geology and uranium deposits of the Tallahassee Creek district, Fremont County, Colorado: U.S. Atomic Energy Comm. RME-1083, Open-file report, 41 p.

Millard, H. T., Jr., 1976, Determinations of uranium and thorium in USGS standard rocks by the delayed neutron technique: U.S. Geol. Survey Prof. Paper 840, p. 61-65.

Rogers, J. J. W., and Adams, J. A. S., 1978, Thorium: abundances in common igneous rocks, in Wedepohl ed.: Handbook of Geochemistry vol. II/5, chapter 90, p. E-4.

Scott, G. R., Taylor, R. B., Epis, R. C., and Wobus, R. A., 1978, Geologic map of the Pueblo 1^{o} x 2^{o} Quadrangle, South-Central Colorado: U.S. Geol. Survey, Misc. Inv. Series Map I-1022.

Shappirio, J. R., and Heinrich, E. W., 1961, Uranium deposits of the Tallahassee Creek area, Fremont County, Colorado [abs.]: Econ. Geology, v. 56, no. 7, p. 1341.

Smith, L. B. (in press), Geology and geochemistry of the western margin of the Thirtynine Mile Volcanic field: Ms. thesis, Colorado School of Mines, Golden, Colorado.

Stuckless, J. S., 1979, Uranium and thorium concentrations in Precambrian granites as indicators of a uranium province in central Wyoming: University of Wyoming, Contributions to Geology, v. 17, no. 2, p. 173-178.

Wobus, R. A., Epis, R. C., and Scott, G. R., 1979, Geologic map of the Cover Mountain quadrangle, Fremont, Park, and Teller Counties, Colorado: U.S. Geol. Survey, Misc. Inv. Series Map I-1179, scale 1:62,500.