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Cottontail Rabbit Scat as a Biogeochemical Prospecting Tool in Arid Desert Environments

by

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COTTONTAIL RABBIT SCAT AS A BIOGEOCHEMICAL PROSPECTING TOOL IN ARID DESERT ENVIRONMENTS

By KEITH ROBINSON

ABSTRACT

A study was made of the uranium content in cottontail rabbit (Sylvilagus audubonl arizonae) feces (scat) from an arid desert environment. The cottontail rabbit was selected because it is the most prolific mammal in numbers in the region. This study is part of an ongoing investigation into the potential of herbivorous mammalian scat as a viable geochemical exploration prospecting tool. A known uranium deposit, the Anderson mine in the Basin and Range physiographic province northwest of Wickenburg, Arizona, was chosen as a pilot area for sampling. Samples of indigenous cottontail rabbit and mule deer scat were collected along a road traverse approximately 25 miles long, beginning at a point 20 miles northwest of Wickenburg, and ending in the vicinity of the former mine workings. The scat samples strongly reflect uranium mineralization and pinpoint the Anderson mine as a locality of highly anomalous uranium content. Sample localities and uranium concentrations in the ash of the rabbit and deer scat samples are shown. The scat of these animals appears to reflect a concentration of the excess, or digestively-rejected, elements contained in vegetation browsed, composited, and consumed from geographically small areas. The potential of scat as a geochemical exploration tool is still experimental, but extremely promising. The use of deer scat in detecting uranium mineralization has been demonstrated in an earlier report.

INTRODUCTION

The use of vegetation as a sample medium in the search for concealed or buried mineral deposits, and its response to mineralization, has been amply demonstrated by past research. The potential value of vegetation as a prospecting medium is well established. Dunn, Ek, and Byman (1985), in a bibliography and state of the art report on uranium biogeochemistry list many references. Cannon (1952), Shacklette (1962), Brooks (1972 and 1983), Lakin (1979), and Erdman and Harrach (1981) are among the many scientists who have proposed and convincingly demonstrated the value of vegetation in uranium prospecting. They have variously referred to vegetation as a "mining corporation of unbelievable dimensions", "pioneer miners", and A. L. Kovalevskii of the Soviet Union, called plants with deep root systems "living drill cores" (personal commun., 1978, in Erdman and Harrach, 1981). Robinson (in press), in a study of the potential of herbivorous mammalian feces (scat) as a viable geochemical prospecting method, takes their conclusions one step further in the biogeochemical chain. He suggested that if vegetation can validly be described in such categorical terms, then the herbivorous animals that feed on plants may be likened to "super-prospectors."

With respect to the diet of herbivorous mammals and ingested metallic elements contained in water and vegetation, specifically uranium, Kennington (1981), after a five year study of animals in the Shirley Basin area uranium mining district of Wyoming, reported that indigenous wild mammals seem to eliminate most radioactive material from their bodies. Kennington suggested that the radioactive material might be discarded through the digestive system because it has no nutritional value. Koval'skii (1976) reported that in studies of sheep in Russia, 96.1 to 98.4 percent of the total uptake of uranium derived from the food chain is excreted through the alimentary canal and eliminated in the fecal droppings. These conclusions were substantiated with research conducted on northern whitetail deer, by means of a simple controlled experiment, in which almost all uranium appears to have been excreted (Robinson, in press).

Thus the scat of mammals may be considered as a host carrier of various elements that are characteristic and representative of the geochemistry of a finite area. The fecal droppings (scat) may contain variable amounts of certain elements in much the same way as stream sediments. The scat of herbivorous animals should reflect a concentration of the excess or rejected elements contained in vegetation browsed and composited from a small geographic area. The consumed vegetation also should reflect the geochemistry and elemental composition of the soils and shallowly concealed rocks upon which the plants grow. The herbivorous mammals thus inadvertently act as mobile collectors of composite geochemical samples and concentrators of metals over their relatively small territorial ranges.

Pilot studies in the use of scat as a sample medium in the exploration for mineralized areas have been conducted by the author to ascertain that herbivorous mammalian scat reflects the geochemistry of the bedrock upon which it is found. Analyses of uranium and other element contents in scat from diverse climatic and physiological environments have been made. The author has collected and has analyzed scat samples of moose from alpine glaciated areas, deer scat from northern temperate and arid desert environments, and cottontail rabbit scat from arid desert regions. The initial results are promising. A report by the author on the potential of northern whitetail deer scat as a biogeochemical prospecting tool is in press. The current report, however, deals only with the analyses of cottontail scat collected from the vicinity of the Anderson uranium mine northwest of Wickenburg, in Yavapai County, Arizona, together with two samples of mule deer scat from the same locality.

BIOLOGY AND ECOLOGY

Biological research indicates that many different families, genera, and species of herbivorous mammals routinely eat and therefore composite, certain plant species. Such feeding is commonly done in a highly selective manner over a relatively small area. The best or most preferred plants are eaten first, if available. This was demonstrated for northern whitetail deer in an earlier study by Robinson (in press) on the potential use of deer scat in detecting mineralization. A similar situation exists for cottontail rabbits (Sylvilagus), except that the species of plants acceptable as food are much greater than those selected by deer and are eaten in a preferential order depending on availability.

DeCalesta (1971a) concludes that cottontail rabbits exhibit definite food preferences and, regardless of geographic area, their diets appear similar. When succulent and accessible, forbs and grasses are the preferred food, but if these plants are unavailable or reduced in palatability, then cottontails will eat bark, buds, and twigs of the indigenous trees. This selectivity is an important consideration because many different species of cottontails exist. Although exhibiting definite preferences they eat a great variety of plants. DeCalesta (1971b), in a study of the stomach contents of Colorado cottontails, identified fifty-eight plant species, with no apparent food differences attributable to rabbit sex or age or to the season or area of study. He considers the plants identified as only representative of the total plant species actually consumed. Other researchers have identified over 100 plant species in cottontail stomach contents. Palmer (1954, p. 277) states that in summer, cottontails eat herbaceous plants and that in winter, food consists of bark and twigs. He also notes that the list of plants eaten is nearly endless, however. Seton (1937) suggests that a catalogue of the flora of the United States would be required to make a complete list of the plants that serve as food for cottontails, Hamilton and Whitaker (1979) state that in summer, rabbits eat a wide variety of grasses and broad-leafed weeds, including commercial crops. Winter foods consist of the buds and twigs of small trees and bushes, sumac bark, blackberry and other thorn bush stalks, and sapling sprouts. There have been other reported instances of cottontails eating anything from commercial crops, to spiny plants such as the prickly pear, buffalo bur, Russian thistle, Yucca cactus, and wooly plantain. However, there is an ordered preference of foods. Thompson and Worden (1956) state that food is always carefully selected by rabbits when they have a choice. They show great preference for delicacies such as young shoots of various food plants and pasture. But although rabbits are in many respects highly selective feeders, their range of foods is wide. Marsden and Holler (1964) observed that as various preferred foods became available it was reflected in the feeding behavior of cottontails. If seed heads were present the rabbits would bite off the stem and slide it along the ground until they could reach the seeds.

The home range of cottontail rabbits is generally quite small and restricted. Hamilton and Whitaker (1979) state that cottontails in the eastern United States seldom occupy an area greater than a few acres in extent. Janes (1959) studied the home range and movements of cottontails in Kansas. From his observations he concluded that from birth they establish a definite home range and probably live their entire life within this area. He states that home ranges vary in size up to 12 acres, with the average size home range for both male and females being 8.34 acres. In arid regions, with a dearth of available food and water, this range may be considerably larger although it is unlikely to be over 50 acres. Thompson and Worden (1956) note that in the more arid parts of Australia, cottontails are said to travel up to four miles from feeding grounds to a water-hole. Cottontail rabbits have overlapping home ranges and are not particularly territorial in this respect, except during the rutting season.

The native cottontail rabbits of the United States, genus Sylvilagus, do not have the extensive burrowing habit of the European rabbit and do not make their own burrows. Nelson (1909, p. 21-22), states that "Most members of the genus Sylvilagus use both forms and the deserted burrows of other mammals, or find shelter under rocks, roots of trees, and similar places. Forms are in common use in summer and in regions which have a warm winter climate, but some species habitually use old burrows, which they sometimes enlarge. The forms are usually made under the shelter of dense herbage or under low brushy growths, and the owner spends the day in them regularly for considerable periods." The nests or forms of cottontails are usually placed in a bowlshaped depression in the ground in some sheltered spot, and during the absence of the parent the young are covered and completely concealed by the material of the nest. At such times the top of the nest is so like the surrounding surface of the ground, on which lie dead leaves and grasses, that its presence can be detected only by chance. Various subspecies of Sylvilagus auduboni, a group living mainly on more or less open plains of the arid regions, commonly need more secure shelter than is afforded by a form in the scanty herbage of their home and, "---they occupy the deserted burrows of other mammals or the secure refuge of holes under rocks, or crevices among stone walls and in rocky ledges. They even take possession of the space under floors of outbuildings about ranches." In some cases they enlarge burrows or dig the dirt from between rocks or under boards to make an entrance under a house, but appear never to make entirely new burrows."

Lockley (1966, p. 103-106) in a detailed study of wild rabbits states that "---We observed that when the wild rabbit first goes forth to graze in the late afternoon it eats voraciously, nibbling down grass and vegetation in scythe-like movements of the jaws from one side to another,---. Perhaps after half an hour of grazing a rabbit will eat less indiscriminately, will cast about for plants which it finds more palatable. During this first hour, as the new green food accumulates in the stomach, the rabbit voids numbers of hard faecal pellets, probably as a result of the exercise as well as the increasing pressure of ingested food upon the intestines. (On an average an adult rabbit will evacuate 360 hard pellets--total weight about four ounces--above ground each twenty-four hours.) --- The hard pellets are composed of hay-like fragments of plant cuticle and stalk. --- Soft pellets (it is commonly believed) may be voided at intervals out of doors but are usually, if not invariably, collected as they cling to the anus, which is slightly everted to project them by muscular action; and swallowed without falling to the ground.

Our observation of the rabbit below ground, reingesting these pellets, shows that the soft pellets are usually produced several hours after grazing, on a full stomach, long after the main mass of hard pellets has been evacuated in the open earlier in the evening. --- The fluid contents of the soft pellet from the rectum are revealed under a high-powered microscope as a rich flora of micro-organisms mingled with undigested cell walls of the plant food grazed by the rabbit. The nutrient bacteria are filamentous and rod-like, and there are cocci and cocco-bacilli. Parasitic oocysts and worm eggs can also be present. --- These pellets on analysis contained (dry weight) about 56% bacteria. The protein content of the bacteria was 36%, and that of the plant matter 11%; or an average of 24.4% protein for the pellet, exclusive of the envelope. After being swallowed whole by the rabbit the soft pellets pass into the stomach where they do not immediately mingle with the normal contents of the stomach--the greenish chewed up plant material. These reingested pellets remain intact for up to six hours and as long as they remain intact the bacteria they contain remain viable, permitting active fermentation of carbohydrate to take place. They finally dissolve, yielding their concentration of phosphorus, sodium and potassium and lactic acid, to aid digestion and nutrition."

Reingestion obviously ensures better utilization of food, by allowing internal bacteria, protozoa, and other micro-organisms in the lower alimentary tract to act twice on it.

STUDY AREA

In the early summer of 1981 a limited geochemical sampling reconnaissance survey was conducted by the author in the vicinity of the Anderson uranium mine, Yavapi County, Arizona. The mine workings are located about 40 miles northwest of Wickenburg, in the Date Creek basin of the Basin and Range province, in west-central Arizona (Fig. 1). In the mine area, along the north edge of the basin, the exposed surface rocks are Tertiary in age. To the south and east these rocks are covered by Holocene to late Miocene alluvium. The alluvial blanket ranges in thickness from a few inches to hundreds of feet. The uranium deposits at the Anderson mine occur in lacustrine sedimentary rocks of the Miocene Chapin Wash Formation, that are exposed by river erosion on the northeastern margin of the Date Creek basin. The basin is flanked on the north by Mesozoic to Precambrian crystalline basement rocks. The geology and genesis of the uranium deposit at the Anderson mine and of the Date Creek basin have been described in detail by Sherborne and others (1979), Otton (1981), and Mueller and Halbach (1983). Otton (1981) described the geology and genesis of the Anderson mine area as follows:

"Uranium deposits at the Anderson mine in western Arizona occur largely in debris flow and turbidite sediments deposited in an interfan lake on the northeastern flank of the early middle Miocene Date Creek basin. These lake sediments were deposited during a period of rapid constriction of lakes in the basin, of increasing climatic aridity, and of corresponding increased alkalinity and salinity of ground water and lake water. Alluvial fans marginal to the lake had Precambrian to early Tertiary igneous and metamorphic and older Tertiary volcanic rock sources. Precambrian granitic rocks north of the basin are exceptionally radioactive. Ash falls periodically covered the entire basin. Uraniferous topaz-bearing rhyolites and ultra-potassic rhyolites and trachytes have been found nearby. Palms, grasses, and semi-arid shrubs grew on the alluvial fans and alluvial plains adjacent to the lake, while a temperate deciduous hardwood forest grew in adjacent mountains. Clastic crystalline and tuffaceous detritus, along with entrained plant debris, washed into the lake during episodic floods. Sedimentation was dominated by debris flows. Considerable sorting of the plant debris occurred, with large branches, twigs, and logs remaining in the thick subaerial or subaqueous debris-flow beds while finely macerated plant debris was deposited in thin, laminated distal turbidites. Plant debris in the thick proximal debris-flow facies tended to be silicified, probably because of the greater porosity and permeability of the beds. Plant debris in the more distal facies was preserved and coalified probably because the beds were deposited in a quiet anoxic lake bottom and were low in porosity and permeability.

Shallow ground water from sources in adjacent mountains and within the basin itself leached uranium and silica from the adjacent granitic terrains, from arkosic alluvium, and from ash-falls. This ground water moved into the lake environment where it also dissolved humic material from degraded plant material in soil horizons or entrained in debris flows. Ground water recharged the lake in the littoral zone around the lake margin. In the quiet, anoxic portions of the lake bottom, uranium, silica, humate, and other species precipitated from solution. Precipitation may have occurred by one or more mechanisms. Increases in salinity by evaporative concentration between periods of fresh water influx may have initiated humate and silica flocculation and precipitation. Alternatively, lower Eh and pH conditions in

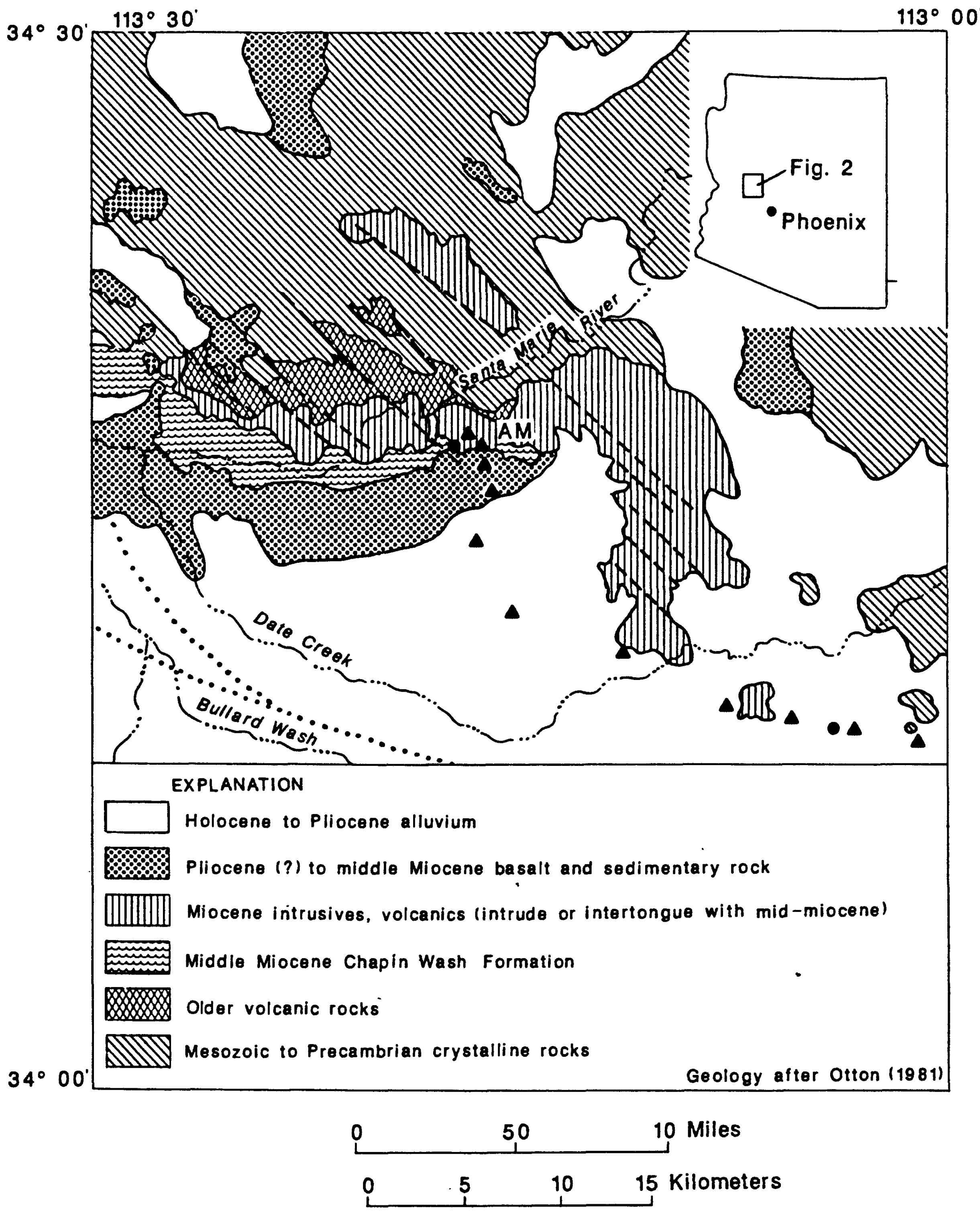

Figure 1--Geologic map of the Date Creek basin area, Arizona.
AM Anderson Mine
▲ Cottontail rabbit scat sample locations
● Mule deer scat sample locations

the lower layers of a stratified lake may have caused coprecipitation of humate, silica, and the associated metal compounds along the interface between water layers.

Uranium deposition occurred in various parts of the lacustrine environment but tended to favor sediments deposited on the anoxic lake bottom, especially the distal laminated carbonaceous turbidites. Uranium minerals coprecipitated with both humate and silica. Grades range from a few hundred to almost 10,000 ppm U_3O_8. Because of the nature of the deposition, orebodies have a thin tabular shape but are stacked so that aggregate thicknesses commonly exceed 10 m."

With this information, it was decided to use the Anderson mine as a pilot area for a biogeochemical survey. The objective of this study was to look for any significant differences in uranium content in scat samples collected along a traverse starting well beyond any known mineralization and continuing towards the mine, in order to see if the mine area could be pinpointed as a locality of highly anomalous uranium content.

SAMPLE DESIGN AND COLLECTION

Eleven samples of cottontail rabbit scat and two samples of mule deer scat were collected. The samples were collected at two to five mile intervals along an approximate 25 mile road traverse from U.S. Highway 93, in a west, northwest, and north direction to the Anderson mine. The point of departure from U.S. Highway 93 was approximately 20 miles northwest of Wickenburg, Arizona. Sample localities are shown on Figure 2. Sampling was designed to traverse an area of low background uranium and end in an area of known uranium mineralization.

Only hard spherical-shaped samples of cottontail rabbit scat were collected. These are easily distinguished from deer feces, the latter being larger, elongate, pellet-shaped, sometimes misshapened, and often pointed. Cottontail rabbit scat can be identified from hare, or jack rabbit, pellets by size. Both are round and identical in color and texture, but Webb (1940) states that plant particles in hare scat are larger than that in cottontails, and the average width of hare pellets is 12-14 mm, while the average width of cottontail pellets is 8-9 mm (Cayot, 1978, p. 9). Accordingly only pellets with an average diameter of 8 mm or less were collected.

Cottontail rabbits scatter fecal pellets during feeding and leave them at every feeding place. Lockley (1966) observed that in mild, wet weather a pellet might disappear or disintegrate in two days, although more usually in three to four days as a result of their being devoured by ground fauna such as worms, slugs, beetles, flies, and ants. In very dry, frosty weather he noted that pellets could survive for up to three weeks or longer. No data exist for arid desert areas, but from the author's own extensive and unpublished observations, he estimates the pellets may last up to three months before decaying or disintegrating. Many pellets are undoubtedly destroyed or consumed in a much shorter time by ground insects such as ants, termites, and beetles. Lord (1963) noted that fecal pellet decomposition rates varied with location, temperature, and pellet composition.

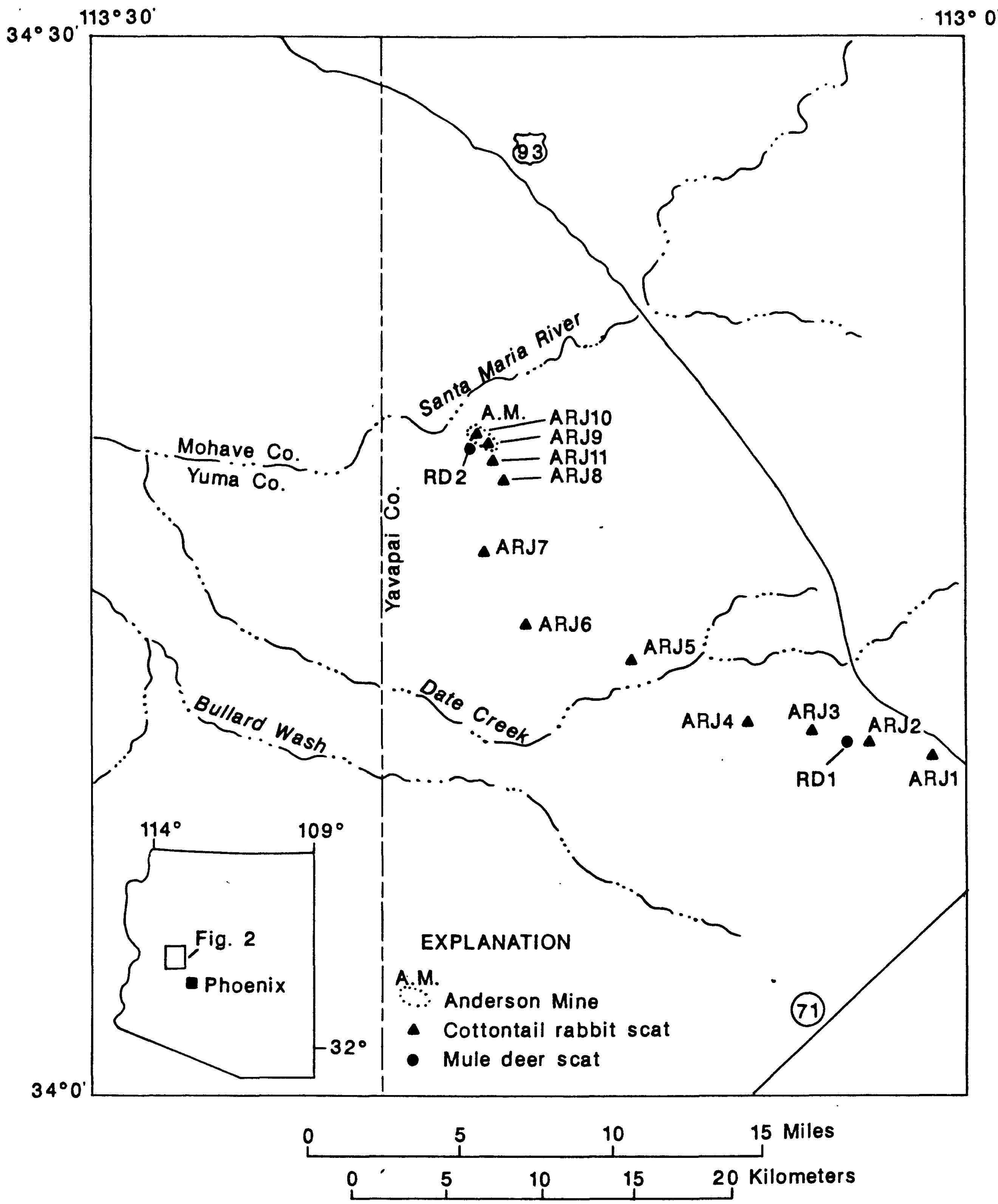

Figure 2--Location map of 11 sample sites of cottontail rabbit scat and 2 mule deer scat samples, along a road traverse to the Anderson mine, Date Creek basin area, Arizona

In general, the hard pellets always sampled appear to be composed of hay or straw-like particles of plant fiber and stalk. It is probable the hard, firm nature of the pellets must partially reflect the variable moisture and fiber content, lignin, and aromatic volatile oil constituents of the browse.

Each scat sample was carefully collected in order to avoid as much contamination as possible from the underlying soil and windblown dust. This was partially facilitated when dead leaves formed a mat-like covering on the ground surface, separating the fecal pellets from contact with the bedrock and soil. Because the pellets harden rapidly after defecation, the possibility of contamination by fluid exchange between the leaf-mat and fecal pellets is considered minimal. In areas where no leaf-mat existed, only the uppermost pellets in a pile were collected, thus avoiding contact with soil contaminants. In some cases, however, samples had to be collected that were in direct contact with the soil. All samples were collected at least 100 yards from roads.

Wherever possible only fresh samples were collected. Collecting samples from the top of a leaf-mat cover ensured that the samples were relatively fresh. Unfortunately this was not always possible and, in some cases, composite samples of weathered and fresh scat had to be collected, or single samples of weathered material.

The exact species, and possibly even genera, of rabbit scat collected is not known. Many cottontail rabbits were observed in the area and all appeared similar. From all the documented literature on the distribution of rabbits in the United States it was probably the genera Sylvilagus (cottontail), species auduboni, subspecies arizonae, more commonly known as the western desert cottontail. In a study of cottontail rabbits in the Gila National Forest, west of Silver City, New Mexico, Kundaeli (1969) states that the desert cottontail group (Sylvilagus auduboni) is native to the western part of the United States. The group ranges from Montana, south to Texas, and from Oklahoma west to California. This rabbit is found occupying diverse habitats at elevations ranging from sea level to 10,000 feet, with vegetation varying from desert shrub to mixed conifer. Farming does not restrict the distribution of cottontails and they are observed in areas where hay, grains, garden vegetables, and fruits are the principal crops. In these areas the home range was closely limited by impenetrable clumps of blackberry brambles and relative heights of vegetation. Generally, feeding activity was within 75 yards of these bushes. In summary, desert cottontails inhabit thickets, valley grasslands, foothill woodlands, southern oak woodland, canyon bottoms, and open arid terrain with scattered brush.

The scat pellets collected were positively identified as the droppings of the cottontail rabbit as opposed to that of a hare or other herbivorous mammal. This was accomplished by visits to a zoo and inspection of varied animal scat. The color, shape, texture, and consistency match all descriptions in the literature and by personal observation. They can be distinguished from hare pellets by their size, and the small narrow footprints associated with the scat piles were unquestionably those of a rabbit. The spoor of a rabbit are readily distinguishable from other mammals. The characteristic small narrow footprints, both hind and fore feet, are much smaller than those of a jack rabbit hare.

The positive identification of the genera or species of rabbit is not unduly critical to this report. DeCalesta (1971a) reports that although many species of rabbits exist, they are all essentially the same, exhibiting similar food habits regardless of species or geographic location. Nelson (1909) states that rabbits are most numerous in the arid West, and that the habits of cottontails and jack rabbits are fairly well known and generally considered typical of the rabbit family as a whole. This belief is held true for the majority of species. Robinson (1979) describes the digestive system of the rabbit as characteristic of the leporidae family as a whole.

Cottontail rabbits belong to the mammalian order lagomorpha. As such they have the lagomorph habit of practicing coprophagy, which is the reingestion of food pellets taken directly from the anus and is another way of chewing cud. They discharge two kinds of pellets; a hard kind which are defecated only; and a soft, mucous-covered kind that are reingested. Hamilton and Whitaker (1979, p. 133) that "---As with many lagomorphs, food eaten rapidly in the field is swallowed where eaten, and forms green soft pellets. These pellets are then defecated and eaten in the relative safety of the form, a process called reingestion or coprophagy. The soft pellets are gleaned directly from the anus and the rabbit swallows them whole thereby passing most food twice through the alimentary canal before the production of hard fibrous fecal pellets---."

ANALYTICAL METHOD

The cottontail rabbit scat pellets were routinely dried in an oven at about 40°C. Most of the samples were dry on collection, but additional oven drying ensured hardening of the fresh samples. The samples were repeatedly cleaned by dry vibration in a stainless steel sieve to remove any possible large-grained adherent soil contaminants. The samples were next washed in distilled water and gently vibrated by ultrasonic probe, taking care to avoid disintegration of the individual pellets, to remove fine-grained contaminants. The pellets were then oven dried once more at 40°C and ground to a homogeneous mass in a Wiley mill, with stainless steel blades and sieve. The ground material was weighed to an approximate 6-gm sample and ashed by dry ignition in an electric muffle furnace that was slowly heated from room temperature to about 450°C and maintained at this temperature for 24 hours (Harms and Papp, 1975). The uranium analyses were determined on the ash by fluorometry (Harms, Ward and Erdman, 1981) in the Denver, Colorado, plant laboratory of the U.S. Geological Survey. Fifty-two other major and trace elements were determined for by induction-coupled argon-plasma, optical-emission spectroscopy, (ICP) (Taggart, Lichte and Wahlberg, 1981) in the Denver analytical laboratory of the U.S. Geological Survey.

The analyses for uranium are given in Fig. 3. The bar graph diagram shows the amount of uranium contained in each sample collected along the road traverse towards the Anderson uranium mine. The data are ordered with respect to distance from the mine. The first sample is the most distant removed and the last two samples are from the actual mine locality.

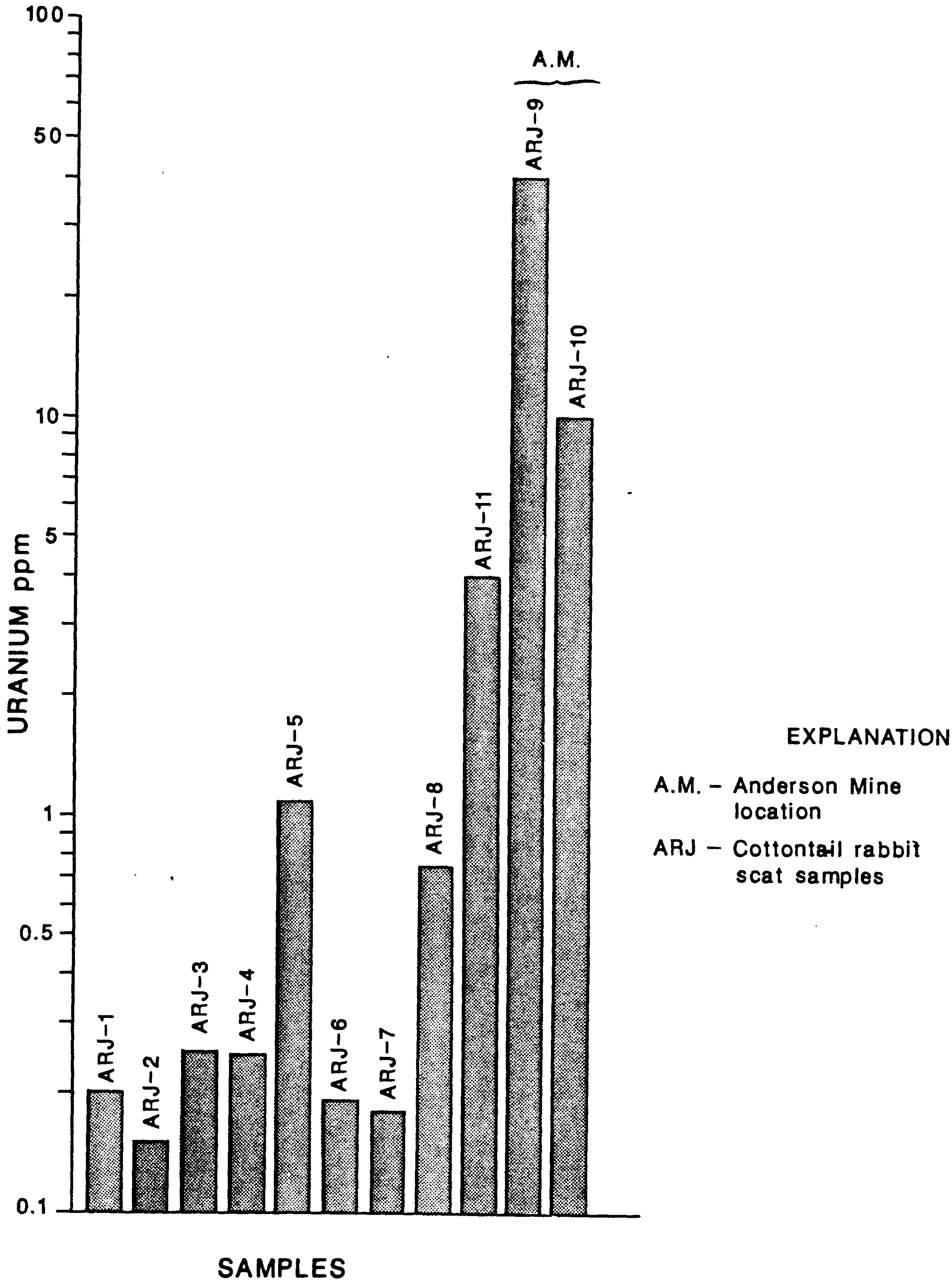

Figure 3--Bar graphs showing sample number and range of individual uranium values (ppm) in ashed cottontail rabbit scat samples from the Anderson mine area, Arizona, ordered in increasing proximity to the mine.

RESULTS

Uranium content in the 11 ashed-scat samples varies from 0.15 to 40.0 ppm U (geometric mean 0.80 ppm). A break in the cumulative frequency distribution curve suggests that samples which contain in excess of 0.75 ppm uranium are anomalous. This is substantiated by the bar graph diagram (Fig. 3). Accepting 0.75 ppm uranium as the anomalous threshold shows that higher than normal concentrations of uranium occur in ashed cottontail rabbit scat from two localities, one of which is known to contain ore-grade uranium. Three of the samples containing anomalous concentrations of uranium are located at or in the vicinity of the Anderson mine and its surroundings, which is the original target area of the study. The remaining sample containing an anomalous concentration of uranium was collected near the southerly spur of the Black Mountains, southeast of the Anderson mine. Otton (1981) characterizes this area as one of upper Oligocene to mid-upper Miocene volcanics and sedimentary rocks that are enriched in uranium. The volcanic rocks vary in composition from rhyodacite to andesite and are underlain by Eocene arkoses and rhyolitic tuffs.

The two samples of ashed mule deer scat that were collected in conjunction with the cottontail rabbit scat, contain 0.13 ppm and 22.0 ppm uranium respectively. The former sample was collected at the start of the road traverse and farthest from the mine. The latter sample was collected in the vicinity of the Anderson mine.

The analyses for 52 other elements, determined by ICP, are considered to have sufficient precision for meaningful statistical treatment. There appear to be several consistent positive and negative correlation coefficients between uranium and these elements or other factors, that are significant at the 95 percent confidence level. Their exact interpretation and meaning is not known at this time. Little or nothing has been published on analyses of scat samples, and on the biological implications of interaction between mammalian digestive systems, associated internal bacteria and protozoa, and trace elements contained in browse material.

The most significant positive correlations of uranium at the 95 percent confidence level are for those with lithium (0.97), molybdenum (0.92), vanadium (0.81), magnesium (0.80), phosphorus (0.70), manganese.(0.66), copper (0.61), strontium (0.60), and zinc (0.60). Uranium showed significant negative correlation with barium (0.84) and lead (0.66). Although not significant at the 95 percent confidence level, uranium showed a negative correlation with both percent ash (0.47) and the degree of weathering of the samples (0.33).

The degree of weathering of the scat samples was quantified on an arbitrary scale of 1 to 5, the former being fresh, the latter being very weathered. If the sample comprised half fresh and half weathered pellets, it was given a 3 rating.

Otton (verbal commun.) states that lithium, molybdenum, vanadium and magnesium, all in dolomitic mudstones, and strontium and magnesium, are all known to occur in anomalous concentrations at the Anderson mine. Analyses of the rabbit scat samples confirm these observations, plus the addition of copper. Average values for the eight samples of rabbit scat collected outside the mine are: lithium (16 ppm), molybdenum (6.5 ppm), vanadium (34 ppm), magnesium (1.05%), manganese (618 ppm), strontium (1325 ppm), and copper (70 ppm). Average values for the three samples of rabbit scat collected within the vicinity of the mine are: lithium (93 ppm), molybdenum (31 ppm), vanadium (75 ppm), magnesium (2.4%), manganese (1000 ppm), strontium (3300 ppm), and copper (108 ppm).

The association of uranium with other elements, although of interest, is not unduly critical to this study. It suggests that scat may be of use in the exploration for other mineral commodities. The use of cottontail rabbit fecal material as a viable exploration medium for uranium is the purpose of the investigation. Can rabbit scat define a uranium anomally. In this respect, possible contamination of the samples, and its effect, is more important than the association of uranium with other elements.

Ash yields of the rabbit and deer scat samples ranged from 10 to 32 percent dry weight. Based on his experience of ashing vascular plant material as well as bryophytes, Shacklette (1965, p. D18) states that any samples yielding more than 10 percent ash are probably slightly contaminated, and ash percentages in excess of 20 percent almost certainly represent extraneous material to the plant tissue. Although the fecal material is derived from plant material, it may have undergone changes in its passage through the digestive system that affects the amount of the ash yield. However, some similarities must still exist. Based on Shacklette's assumption, all the ashed samples were X-rayed to determine the mineralogy of the samples. The one sample whose ash content was greater than 30 percent, which had been described as a fresh sample in the field, was found to contain excessive amounts of quartz and microcline. It contained only 0.25 ppm uranium. All other samples had variously been described as weathered to fresh in the field. Several of these samples were extremely fresh and young in age. In all samples, the X-ray diffractograms obtained from the ash indicate the presence of crystalline calcite, apatite, and quartz in highly variable amounts. Raw unashed splits of some samples indicate only the presence of quartz in any significant amount, with occasional traces of calcite and no apatite, suggesting the latter are formed by high temperature ashing.

With the exception of the one sample known to be contaminated with microcline feldspar and quartz, no significant relationship could be established between ash content and the amount of calcite, apatite, and quartz that was present, or between the ash content and ratios of the respective minerals. The correlation between ash content and uranium is a negative 0.47. Robinson (in press) found the exact same situation in the ashed scat of northern whitetail deer and states that "Erdman, Gough and White (1977), in an article on calcium oxalate as a source of high ash yields in lichen, reported that the occurrence of important calcium compounds in ashed vegetation is not unusual. This is expected because of the high calcium content in vegetation. They found that as the ash content increased, the ratio of calcite to quartz also increased, suggesting that quartz is not totally responsible for variations in ash content. The presence of biogenic calcite was based on mineralogical analysis of the unashed lichen. The X-ray diffractograms of unashed samples showed no calcite present, but did show the presence of calcium oxalate ($CaC_2O_4 \cdot H_2O$, the mineral whewellite) in the lichen thalli. The absence of calcite indicates that calcium oxalate in the lichen tissue decomposes during high-temperature ashing to form calcite. The authors further stated that:

> "Crystals of usnic acid also are present in the lichen tissue, as well as those of other unidentified compounds; amounts of usnic acid tend to decrease relative to the amount of oxalate as the ash content increases. This relation suggests that high ash percentages of dry weight are due to high contents of calcium oxalate and that low ash percentages may be due to high contents of lichenic acids, which contribute to the dry weight but not to ash yield because these acids are lost during combustion."

On the basis of these results, the authors believed that lichens yield amounts of ash that are related to their calcium oxalate content, but that any plant tissue which produces oxalates might also show some natural variation in ash content."

Although the samples of ashed cottontail rabbit scat do not show the exact relationships reported above, the presence of biogenic calcite and apatite formed by high temperature ashing was established. These minerals, formed from calcium and phosphorus in the plant matter and scat, are not contaminants, but their highly variable presence must have some effect on the weight percent ash. Quartz is the main contaminant, and in one case microcline feldspar. Undoubtedly most of the samples are contaminated to some extent; contamination is inescapable. The rabbits eat unwashed plant material and some quartz must be accidentally ingested during feeding as particulate matter on the leaves.

Robinson (in press) further states that: "The effect of quartz contamination is not a serious problem and does not significantly inhibit the results. Its presence acts as a dilutant rather than a contaminant. In addition, amorphous silica is also a common constituent in many of the plant species eaten by herbivorous animals. Grasses and sedges are high in amorphous SiO_2 owing to the presence of phytoliths in the tissue. Scat that is derived from these plants would therefore be high in amorphous silica. This high SiO_2 content suggests that some of the quartz noted on the X-ray diffraction patterns may be formed by recrystallization of phytoliths during high-temperature ashing and is not a contaminant."

Some of the variation in ash content may also be related to the type of vegetation eaten by the cottontail rabbits and the degree of mineralization of the soil or bedrock upon which the vegetation grew. Ingestion, concentration, and subsequent extrusion of heavy chemical elements contained in fecal pellets may significantly increase the ash weight percent. The scat samples are probably composites of different species and amounts of plant material. If the calcium oxalate composition or the amount of contained elements in the vegetation vary appreciably, this may significantly influence the biogenic compounds formed on high-temperature ashing and the resultant dry ash weight. Also, the presence of other oxalates cannot be discounted. It may be advantageous in future sampling to experiment with "wet" ashing, using sulfuric and nitric acids to remove organic matter. This procedure will avoid the formation of high-temperature inorganic compounds.

DISCUSSION AND CONCLUSIONS

The results of a study of the uranium content of cottontail rabbit scat show increasing concentrations of uranium in samples collected along a road traverse from a point 25 miles distant from a known uranium mine and culminating at the mine. The responsiveness of the widely-separated scat samples to uranium suggests that scat may be effectively used as a prospecting medium in the search for undiscovered uranium deposits and that it may be a useful biogeochemical exploration sample medium for other elemental commodities. Scat may be especially effective in arid areas blanketed by alluvial sedimentary cover or in other areas covered by glacial till or loess deposits, where rabbits are present. The scientist has to use whatever species of scat samples are at his disposal. Documented observations of the movements of cottontail rabbits suggest that these herbivorous mammals spend their lives within a relatively small area. They have a tendency to establish territorial homes of a few acres and, if environmental conditions permit, live on relatively well-balanced diets of plants.

Thompson and Worden (1956) suggest that rabbits may consume up to 18 oz or more of fresh food daily. If, as stated earlier, rabbits defecate approximately 4 oz of hard scat every 24 hours, this implies that between 20 and 25 percent of the total food intake is excreted as feces. This is close to the same value for whitetail deer (Robinson, in press), who are estimated to defecate 25 percent of their total food intake as fecal matter.

The animals concentrate trace elements obtained from plants that are in excess of normal metabolic requirements or are not required in their excrement. Uranium appears to be such a non-nutrient element. As previously state, Koval'skii (1976), in Russia, reported that sheep excreted 96.1 to 98.4 percent of the total uptake of uranium in their food chain in fecal droppings; Kennington (1981) in a study of the Shirley Basin area, Wyoming, states that wild animals seem to eliminate radioactive material naturally from their bodies through the digestive system; and Robinson (in press), by means of a simple controlled experiment, substantiated that northern whitetail deer excrete most, if not all, of the uranium contained in their food in their fecal material. He concluded that the uranium in the fecal material was concentrated and enriched by a factor of 4 or 5. It is postulated a similar enrichment occurs in rabbits and the uranium is of no nutritional value.

The feed plants of rabbits, in many instances, have the root capacity to penetrate through considerable thicknesses of overburden, absorbing the available elements through their root system and concentrating them into the new plant growth. Thus plants may concentrate, in their tissue, elements organically available in solution at or near bedrock contact. When the plant material is eaten, the elements are further concentrated by the digestive system of an animal and rejected from the body in excrement. The fecal pellets thereby represent the concentrated organic remains of vegetation consumed within a relatively small or restricted area of forage.

Robinson (in press) states that: "The use of scat as a geochemical sampling medium is not without problems. The aspect of possible contamination must be carefully studied before conclusive statements may be made. Initial results, however, suggest the digestive systems of herbivorous mammals act as concentrating mechanisms for certain elements and eject these elements from the body after digesting the plant material. The animals thus act as collectors, concentrators, and geochemical integrators over their relatively small territorial areas. Analyses of these discrete scat samples may be of significant value in the exploration for concealed and shallow buried mineral deposits or mineralized areas."

The scat samples are lightweight, easy to find, and only a few grams are needed. Assuming an average ash yield of 15 percent, and requirements of 600 mg of ash for uranium and ICP analysis, then 7 grams, or approximately one-quarter ounce, of raw sample will be sufficient. It is probably advantageous to collect more than this amount for statistical compositing and averaging purposes of a representative sample. The scat samples have an advantage over vegetation samples because they are naturally composited in the same manner as a stream sediment, thus it is not necessary to carefully and consistently collect specific parts and species as with plants. In addition, the scat samples are representative of a finite or limited area, not a spot sample like vegetation. Wherever possible care should be taken to obtain only scat samples uncontaminated by mineral matter and samples with the same relative degree of freshness and weathering.

Further testing of cottontail rabbit scat as a sample medium is planned in an area of known uranium enrichment. The area has not yet been mined or disturbed environmentally, and is thereby free of contamination.

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