URANIUM MIGRATION:
A GEOCHEMICAL EXAMINATION OF SEDIMENTS AND THEIR SOURCE ROCKS IN MCKINLEY COUNTY, NEW MEXICO

by

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The Navajo Nation is hereby acknowledged for allowing access to their property so that this study can exist. Too often do authors of geologic studies discount the importance of the landowner, either public or private.

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ABSTRACT

Uranium exploration by studying the chemical composition of stream sediments is a common and accepted method used by geochemical prospectors worldwide. In the United States, a government-funded program called the National Uranium Resource Evaluation amassed a huge collection of stream sediments in an effort to identify further uranium resources. This study is intended to refine the interpretation of stream-sediment data used for uranium exploration in a sedimentary, semi-arid environment.

The study area is in two small drainages between Gallup and Grants, New Mexico in McKinley County and has streams which flow across uraniferous and non-uraniferous rock outcrops. Samples of rock outcrops and stream sediments were collected and were analyzed at Los Alamos National Laboratory by neutron-activation analysis. A comparison of elemental concentrations is made between stream sediment and its source rock for uranium, thorium, vanadium, hafnium, and organic carbon. An examination is also made of percent -400 mesh. The comparison gives special attention to the changes which occur downstream away from the source rock and the implications for sediment sampling for uranium.

Results indicate that using uranium values alone produces somewhat ambiguous indications of the uranium source. Accounting for the amount of uranium due to zircon (as determined by hafnium concentrations) in sediment with the total uranium content produces a better indication of the uranium source. Thorium concentrations provide only a weak indication of uranium presence and uranium-to-thorium ratios are useless in determining the uranium source. Vanadium concentrations do not distinguish the uranium source very well. Neither organic carbon nor -400 mesh concentrations assist with locating the uranium source.

Uranium exploration by use of stream sediment in this environment is quite different from exploration in terrain composed chiefly of igneous rocks. The total amount of uranium less the amount of uranium bound in zircon approximates the amount of mobile uranium. This parameter, termed excess uranium, when used with conventional exploration techniques holds promise for delineating additional areas in other arid environments for further study.

I. INTRODUCTION

Purpose of the Study

Geochemical surveys are a widely used method for prospecting for mineral deposits. Geochemical prospecting for minerals, as defined by common usage, includes any method of mineral exploration based on systematic measurement of one or more chemical properties of a naturally occurring material (Hawkes and Webb, 1962). Generally, many samples of stream sediment are collected, then analyzed for the element of interest or for pathfinder elements. The proper usage and understanding of data collected for a survey is essential. The relationship between elemental concentrations in bedrock and the associated stream sediment is typically qualitative. The greater the concentration of an element in an outcrop, the greater its concentration in nearby streams. Thus, the further a stream sediment is sampled from an outcrop, the lower the concentration of elements from that outcrop because of dilution and other factors.

Weathering of rock and subsequent erosion into stream channels are chemical and physical processes that define the elemental composition of the sediment. Variations in these processes and dilution by side channels downstream affect the sediment composition and thus the conclusions of a study based on sediment analyses. An examination of the relation between elemental concentrations in bedrock and in their stream sediments, and the dispersion of those elements downstream is essential in data interpretation. The results could be applied to the interpretation of geochemical stream-sediment data such as the U.S.

Department of Energy (DOE) National Uranium Resource Evaluation (NURE). Detailed follow-up studies based on NURE or similar data may have been initiated without complete information. Hence, anomalous areas may have been overlooked and costly detailed studies of barren regions may have been undertaken. This study, which focuses on the pertinent variables involved with employment of stream-sediment data, might aid in the selection of areas for closer examination. Perhaps the applications of this study would be limited to areas of similar climate or geologic provenance, but it is important to know which constraints are applicable. The area that would yield the most data should contain few rock types and have sediment that originates only from those rock types. Because of the potential application to NURE and other geochemical studies and the inevitable need for further uranium resources in the United States, a study area associated with the Morrison Formation, a known host of uranium mineralization, is appropriate.

Location and Geographic Setting

The study area is located within the Colorado Plateau geographic province of Fenneman (1931) approximately 160 km west of Albuquerque, New Mexico (Figure 1). The study area is located in McKinley County, New Mexico on land owned by the Navajo Nation. Access is by route 55 north from Thoreau, New Mexico about 12 km and then west on route 56 approximately 16 km to the Navajo settlement of Mariano Lake. About 7 km south of Mariano Lake is the study area at the southwestern corner

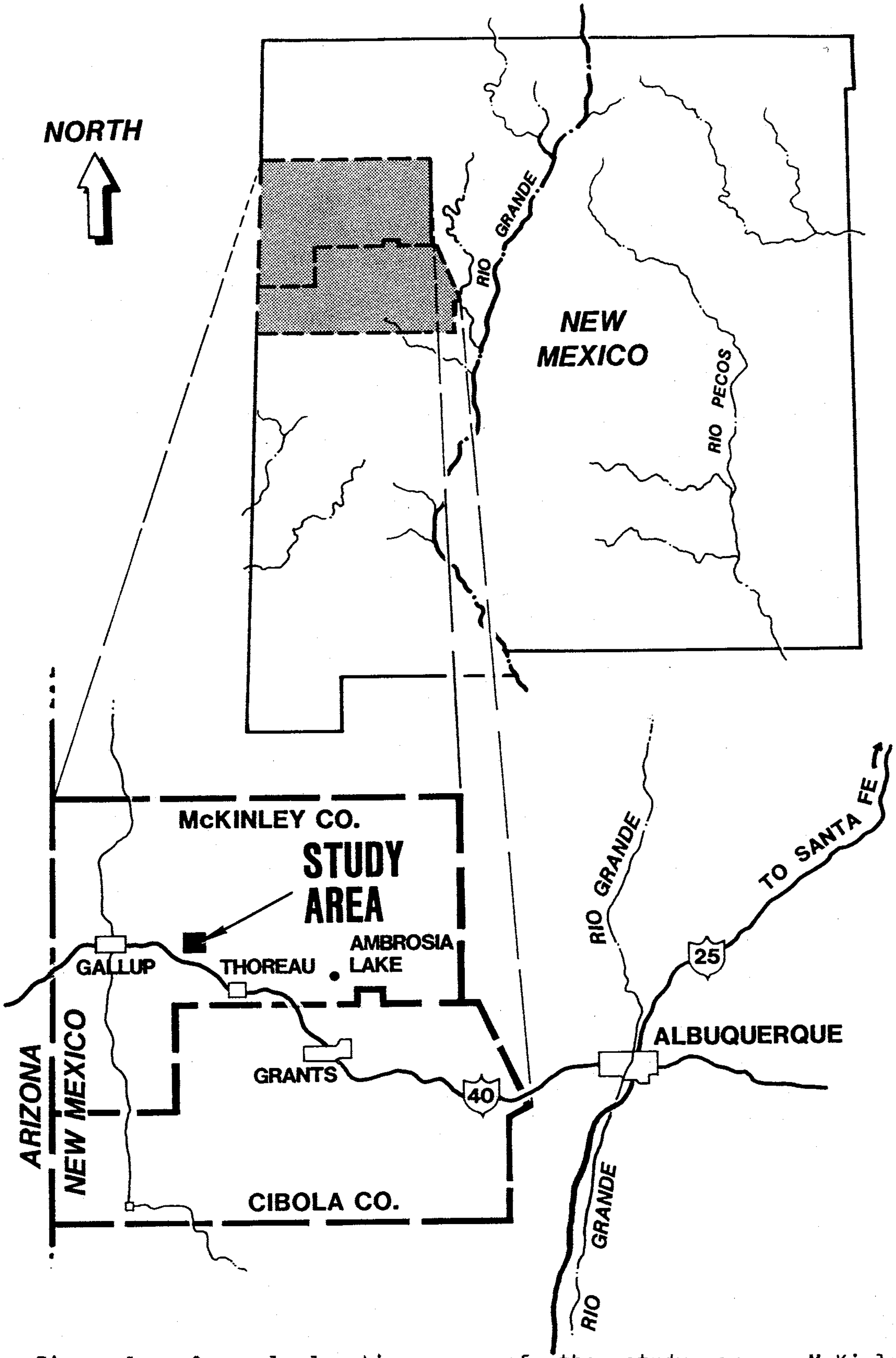


Figure 1: General location map of the study area, McKinley County, New Mexico.

of the Mariano Lake United States Geological Survey (USGS) topographic map. The exact location can be described as T. 15 N., R. 14 W., Sec. 18 or, more simply, the southeast corner of the study area is at 35° 30' north latitude and 108° 15' west longitude. The area chosen for study consists of two small drainage basins on the crown of a large monocline. The southeastern drainage (later referred to as the control area) has better exposures of the rock units than does the northwestern drainage (later referred to as the control test area); therefore, attention is initially focused there.

Within the study area, elevation ranges from 2225 m to 2428 m and vegetation consists of mixed conifers and deciduous trees. Annual precipitation is between 30 and 40 cm, mostly as short but intense thunderstorms in late summer and a few winter snowstorms. Temperatures in the area are typical for a continental climate at this elevation. Sample collection took place in winter of 1983 while there was still some snow present in shaded areas. During this period, there was insufficient moisture to cause sustained flow in any streams in the study area.

Previous Work

There has been a great deal of work on the mineralogy and geochemistry of uranium ore deposits in the Grants Mineral Belt. Although much research has focused on ore genesis models and classification, the data and results from some of those studies are a useful prelude. It is important for a study such as this to understand the transport mechanisms of uranium from source rock to the sediment.

Several works have addressed this issue in studies of uranium mines and mill tailing sites.

Place et al. (1980) studied the Mariano Lake deposit, which is about 10 km north and east of the study area. Ore is located in the Brushy Basin Shale member of the Morrison Formation which is the equivalent of the Poison Canyon sandstone. This deposit is characterized by low concentrations of calcium, molybdenum, and selenium and high concentrations of sulfur and vanadium. The uranium within the deposit is associated with organic carbon. No primary uranium minerals were identified. Distributions of uranium versus calcium, iron, sulfur, vanadium, molybdenum, arsenic, and zinc were found to be positive. It was concluded that the observed distribution of elements resulted from migration of oxidized ore-bearing solutions downdip through a reduced pyritic sandstone. The average uranium content in mineralized rock was about 4000 ppm. No barren rock was sampled.

Brookins (1980) indicates that uranium which forms deposits in the Grants area was probably carried in solution as an oxyion such as $(UO_2(CO_3)_2\ 2H_2O)^{2-}$ and was precipitated where a chemically reducing environment was reached. In ore bodies, uranium is most commonly found as coffinite $(U(SiO_4)_{1-x}(OH)_{4x})$. It was also found that uranium, vanadium, selenium, and molybdenum are transported and deposited in a similar fashion. Vanadium is thought to be most commonly fixed in clay minerals of a deposit. The reducing environment encountered by the enriched solution is caused primarily by the presence of organic carbon. This conclusion is supported by the work of Beck, et al. (1980) except that the positive correlation between uranium and organic carbon holds true only for samples containing greater than 0.04 percent U_3O_8.

Riese and Popp (1980) show that carbonate-bearing solutions are effective carriers for uranium due to dicarbonate and tricarbonate complexing of uranyl ion. This mechanism would be equally effective in ground water as in surficial waters as is concerned in the present study. Although the report by Riese and Popp concerns itself with solution mining of uranium ores, an understanding of the chemistry of uranium and its interactions with host rocks contribute toward the interpretation of uranium distribution for this study. In a similar instance of peripheral relevance, Popp, et al. (1984) studied elemental distributions in a major watershed, the Rio Puerco, of the Grants mineral belt in order to establish baseline geochemistry of sediments impacted by uranium mining and milling. Uranium values were found to be elevated in general, but could not be correlated with the onset of uranium mining in the 1950's. However, it was noted that contributions of mine and mill related metals have apparently been masked by reworking of and dilution by older sediments in the arroyo walls. It is possible that this masking effect can be equally important in the small drainage of the present study. The average uranium content of sediment samples found by Popp, et al. (1984) was 320 parts per million (ppm); far in excess of the average crustal abundance of 2.7 ppm. The hydrogeochemical and stream sediment reconnaissance report by Los Alamos for the Albuquerque quadrangle and the Rio Puerco watershed did not locate any sediment samples in excess of 30 ppm uranium even though some of the 1538 samples were collected from the Rio Puerco and its tributaries (Maassen and Bolivar, 1979). In fact, none of the 100 or more samples from the Rio Puerco watershed contained more than 10 ppm uranium. However, none of these samples were collected from oxbows or from under the surface as they were in the study by Popp, et al. (1984). There apparently is a depletion of uranium in the surface sediment of active channels in large streams perhaps by infiltration of uranium to lower depths of the active channel.

Dreesen, et al. (1982), conducted a study of uranium mill tailings to determine the mobility of contaminants away from the three study sites. The alkaline leachate from the Ambrosia Lake, NM site show appreciable mobility of uranium, which contrasts with surface soil samples taken near the tailings. This implies that soils within the present study area probably contribute only small amounts of uranium to runoff for deposition downstream. In a finding similar to one by Brookins, et al. (1980), Dreesen, et al. (1982) state that uranium in the seepage from tailings ponds is as the carbonate anion complex of the uranyl ion. They conclude that mobilization of uranium and other contaminants is dependent on mineralogy and depositional environment of the source rock, and the extent of migration depends on the potential sorption or precipitation processes downstream that may fix the contaminants. The average uranium content of surface soils in that study is reported to be 2-5 ppm.

Two mining claim markers were found in the present study area, however no mining or even surface disruption took place. The claim markers date back to 1967 and it seems clear that no mineralization was located. Apparently, the fact that the Morrison Formation, which hosts uranium deposits elsewhere, crops out here was sufficient reason for someone to file the claims.

II. GEOLOGY OF THE AREA

Structure

The Grants Uranium Belt extends northwesterly along the southern portion of the San Juan Basin. It is approximately 48 km (30 miles) wide and about 161 km (100 miles) long extending from the Gallup sag to the west to the Rio Grande trough to the east. Most mineralization is located on the Chaco slope. This structure is a northeast-dipping homocline which forms the southern flank of the San Juan Basin (Kelley, 1951). The Chaco slope lies between the Central Basin to the north and the Zuni Uplift to the south. The Zuni Uplift is a broad northwest-trending upward asymmetrical to the southwest. The border of the uranium region cuts across the northern edge of the uplift and is approximately parallel to its trend.

Erosion along a prominent monocline, near the margin of the Zuni Uplift, is responsible for the morphology of the study area drainage, exposing a Morrison Formation homocline which dips 20 degrees to the northeast. Initially, erosion carried sediments toward the northeast across the resistant Dakota Formation. Later, the Todilto Limestone at the southwestern boundary of the basin was eroded enough to cause the drainages to flow the opposite direction and downcut rapidly. A Todilto dipslope and remnant Cow Springs Formation forms much of the southwestern half of the drainages. The northeastern half of the drainages is composed mostly of a sequence of Morrison and Dakota strata. Throughout the drainages there are discontinuous patches of alluvium, some of which resemble soil and probably developed recently through weathering of exposed rock. Others are stratigraphically high enough that they may be remnants of stream sediments deposited before the southwestern boundary was breached.

Rock Units

Figure 2 shows the geology and structure of the area, and Table I gives a brief description of the rock units. Except for alluvium, which is discussed in the next section, the following is a brief description of each rock unit that occurs in the study area.

Todilto Limestone

The Todilto Limestone, which overlies the Entrada Sandstone, was first described from an exposure in Todilto Park, New Mexico (Gregory, 1917). The first formal usage of the name Todilto Formation was by Baker et al. (1927) for 76 m (250 ft) of sand, sandy shale, and limestone beds between the associated cliff-forming sandstones in Utah, even though they doubted the equivalence of this unit to the typical Todilto Limestone of New Mexico and Arizona. Northrop (1950) assigned it to the San Rafael Group because of its uniform lithology and wide extent across southern Colorado and New Mexico. The Todilto is divided into two distinct members: a basal limestone member, and an upper, geographically restricted, gypsum-anhydrite member, which is absent in the study area. The basal member consists of thin-bedded and laminated, gray, fine-grained limestone with some thin siltstones (Hilpert, 1963). In the study area, only the limestone member crops out, but the upper gypsum-anhydrite member has been penetrated by drill

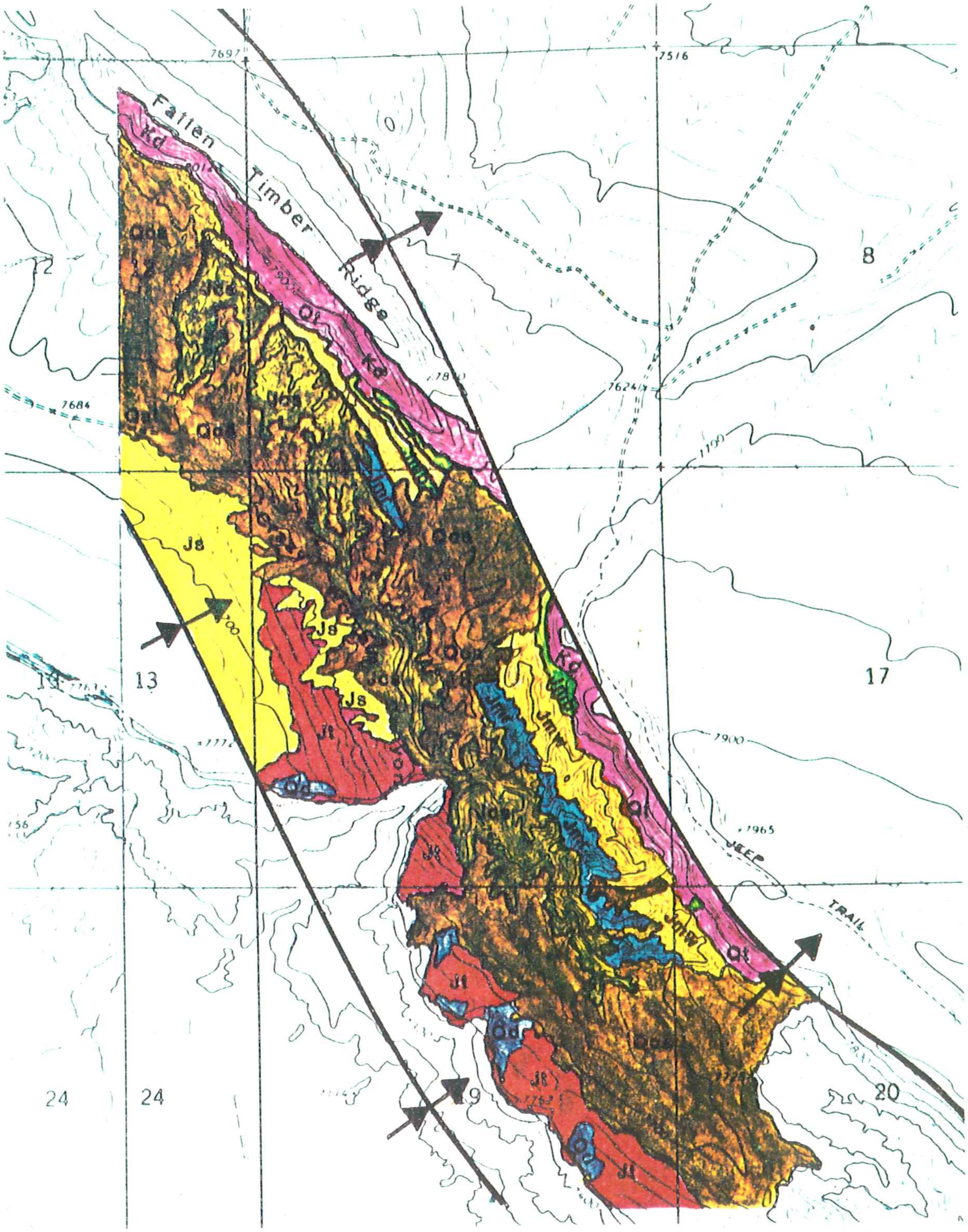


Figure 2: Generalized geologic map of the study area in McKinley County, New Mexico (adapted from Green and Jackson, 1976). See Table I for an explanation of units.

Table I. Principal stratigraphic units occurring in the study area.

🟦	Eolian deposits (Holocene) - Unconsolidated deposits of wind-blown sand and silt. Variable thickness.
🟧	Alluvium and colluvium (Holocene and Pleistocene) - Grayish-brown poorly sorted to partly consolidated silt, sand and gravel; deposited in Recent stream channels as well as terrace and blanket deposits above modern stream flood plains. Variable thickness.
🟪	Dakota sandstone (Upper and lower Cretaceous) - Yellowish-brown to buff, medium- to fine-grained, well-sorted massive siliceous sandstone. Lower contact is sharp and unconformable. Thickness 55-140 ft.
🟨	Brushy Basin member (Upper Jurassic) - Greenish-gray to greenish-blue claystone and sandy siltstone. Largely obscured by talus from overlying Dakota sandstone. Thickness 35-85 ft.
🟧	Westwater Canyon member (Upper Jurassic) - Light to deep reddish-orange, fine to coarse-grained, poorly sorted calcareous feldspathic sandstone. Thickness 150-200 ft.
🟦	Recapture Creek member (Upper Jurassic) - Complexly interbedded light pink to white, very fine to medium-grained, well-sorted sandstone. Interbedded with the underlying Cow Springs sandstone. Thickness 50-100 ft.
🟫	Cow Springs sandstone (Upper Jurassic) - Includes upper and lower subunits. Light greenish-gray to light reddish-brown well-sorted friable sandstone and silty sandstone. Lower subunit interbedded and gradational with underlying Summerville Formation in northwestern part of study area. Thickness 400-600 ft.
🟨	Summerville Formation (Upper Jurassic) - Reddish-brown to light orange, fine-grained, well-rounded, friable calcareous silty sandstone. Absent in southeastern part of study area. Thickness 10-30 ft.
🟥	Todilto Limestone (Upper Jurassic) - massive light- to dark-gray microcrystalline limestone. Thickness 30-50 ft.

Adapted from Green and Jackson (1975).

holes about 13 km to the north. The limestone is as much as 10 m thick, but it averages only about 5 m.

Cow Springs Sandstone

The lower part of the unit is equivalent to the Bluff Sandstone and Recapture Creek Members of the Morrison Formation. The Summerville Formation grades laterally into rocks typical of the lower part of the Cow Springs, and intertonguing occurs between the members of the Morrison Formation and the upper unit of the Cow Springs. It is believed that the Cow Springs Sandstone was laid down as an eolian deposit with intercalated shallow water deposition, probably by reworking of the eolian sands (Harshbarger et al., 1957). In the study area, the Cow Springs is 100-170 m thick.

Morrison Formation

In the Grants Mineral Belt and in the study area, the upper Jurassic Morrison Formation consists of three members which are, in ascending order, Recapture Creek member, Westwater Canyon member, and Brushy Basin member.

Recapture Creek Member. The Recapture Creek Member intertongues with the Cow Springs Sandstone and is up to 34 m (50 ft) thick in the study area. The Recapture Creek consists mostly of grayish to reddish beds of sandstone and siltstone. It is poorly sorted, fine- to medium-grained, thin bedded, and contains much clay. This member of the Morrison Formation contains small quantities of uranium at Marquez, New Mexico, 64 km northwest of Albuquerque, however the Recapture Creek is generally devoid of significant mineralization.

<u>Westwater Canyon Member</u>. Overlying the Recapture member unconformably is the Westwater Canyon member, a dominantly medium-grained, poorly sorted to unsorted, feldspathic, fluvial sandstone (Kozusko and Saucier, 1980). The unit is about 100 m (300 ft) thick in the study area and contains numerous irregular mudstone beds of variable thickness. These mudstones are colored pale green with red mottling and are from a few centimeters thick to about 1 m thick. They appear to be deposited within fractures in localized areas of the Westwater Canyon. Fragments of logs, branches, and bone are fairly common. A depositional feature common to the Westwater Canyon is crossbedding on a small-to medium-scale. The unit was deposited by a braided stream system that flowed east-northeast across the Recapture Creek member.

Within the Westwater Canyon member there are many uranium deposits in the Smith Lake and Ambrosia Lake mining districts. Mineralization in these areas can be either primary or redistributed (Smith and Peterson, 1980).

<u>Brushy Basin Member</u>. The Brushy Basin Member of the Morrison Formation was first named by Gregory (1938) for exposures in Brushy Basin, west of Blanding, Utah. In the study area, the contact between the Dakota Sandstone and the Brushy Basin Member is difficult to place because of talus from the overlying Dakota Sandstone covering the slope at the contact. The contact between the Brushy Basin and the

underlying Westwater Canyon member is conformable. The Brushy Basin here consists of poorly exposed blue-green mudstones and small, discontinuous blue-green sandstone lenses. The mudstones contain an abundance of volcanic derived sediment, sharp, angular, grains of quartz, plagioclase, and potassium feldspars. The thickness of the Brushy Basin Member is about 30 m in the study area, and is often completely obscured by talus debris or older alluvium.

Elsewhere, uranium deposits of significant value have been found and mined in upper and lower sandstone lenses of the Brushy Basin. The mineralized upper sandstone lens is known as the Jackpile Sandstone and has been mined about 24 km (15 miles) east of the study area at Paguate. The mineralized lower sandstone lens is informally called the Poison Canyon sandstone, and has been mined about 11 km (7 miles) east of the study area near the southern edge of the Ambrosia Lake mining district. Neither of these two sandstone sub-units have been found in the study area, however, the Poison Canyon sandstone has been reported in the Mariano Lake mine just 8 km to the northeast and is as much as 14 m thick (Place et al., 1980). It is possible that thin portions of these subunits cropped out in the study area but were later buried beneath rubble from the Dakota Formation. A search along the contact where these subunits should occur revealed no evidence for them nor do Green and Jackson (1975) show them.

Dakota Sandstone

The Dakota Sandstone, a prominent cliff former in the Grants area, unconformably overlies the Morrison Formation. Gregory (1917) describes it as "highly variable in structure, texture, and composition," a statement with which Silver (1951) agrees. The Dakota has had an erratic production history and cannot readily be divided into subunits that remain consistent throughout the San Juan Basin.

The Dakota Sandstone was deposited under dominantly nearshore marine and open marine waters, but it is known to contain some fluvial sandstones near its base (Owen and Siemers, 1977). It is also known that deposition occurred on a vast erosional surface in the San Juan Basin, and therefore there is a major unconformity at its base (Saucier, 1974). The Dakota consists mostly of tan to gray, well-cemented, quartzose sandstone, dark-gray carbonaceous shale, and locally, lenses of conglomerate and impure coal. The sandstone is generally medium-grained, well sorted, and contains numerous small molds of carbonized plant fragments. The sand grains are well rounded and cemented by silica. Only a few uranium deposits occur in the Dakota Sandstone, and most, if not all, are located near the base. These deposits may be related to reworking of detrital mineralization in the underlying Morrison Formation.

III. SAMPLES AND ANALYSIS

Samples Collected

The study area was sampled during two periods in December, 1982, and January, 1983. During the time of sampling, there was some snow on the ground although it was confined mainly to the shaded areas. Three categories of samples were collected for this study: modern sediments, rock outcrops, and Quaternary older alluvium (QOA).

Forty-two modern sediments were collected from the middle portion of stream channels judged to have been recently transported by the normal process of runoff (Figure 3). Care was taken at each sample site to avoid collecting material which might have been deposited by wind. The upper 2 to 5 cm of material were scraped away before the sample was collected. At each significant confluence, sediment was collected at points above the juncture in each stream. Where possible, effort was made to collect the fine-grained fraction, which was probably deposited by moving water. Some tributaries were sampled more than others of similar size because of the Jurassic age rocks through which they flowed. Using a clean polyethylene scoop, about 1 kg of sediment was composited from at least three nearby locations at each site, placed into a polyethylene bag, labeled, and then bagged again to protect against rough handling which might obscure the label or cause puncture, and finally stapled closed.

Fifty-six rock samples were collected directly from their outcrops (Figure 4). About 2 kg of rock was collected at each site, composited from at least five locations within a 5 m radius. Effort was made to avoid heavily weathered material and fragments of rock which were not obviously part of the outcrop. Rock samples were collected at approximately equal spacing throughout the study area although availability of suitable quality material dictated some locations. Commonly, fresh material from an outcrop was exposed using a 1 kg sledge hammer before collecting a sample. Fresh material is defined as rock which previously had no surface exposed to the atmosphere or

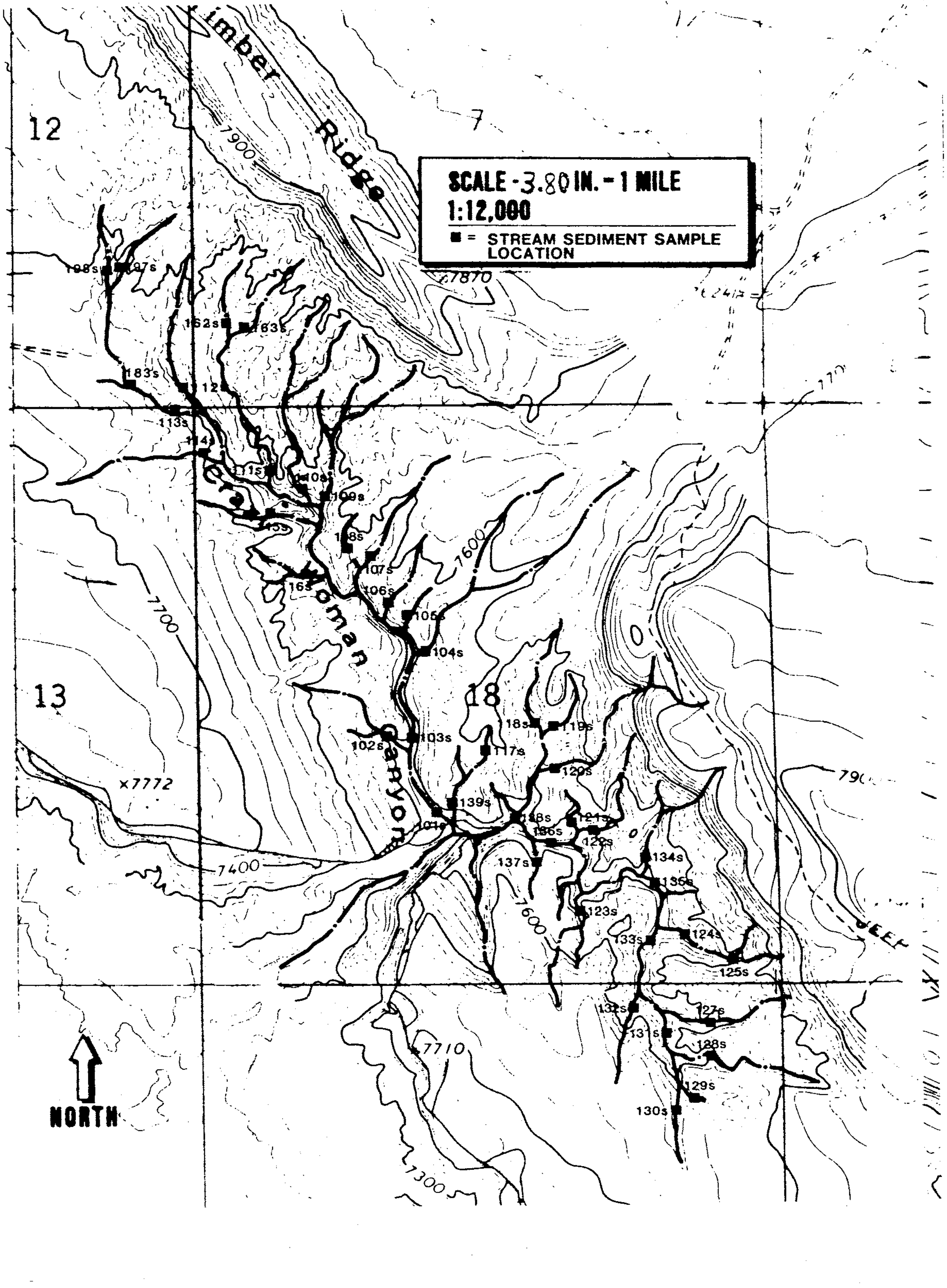


Figure 3: Stream sediment sample location map.

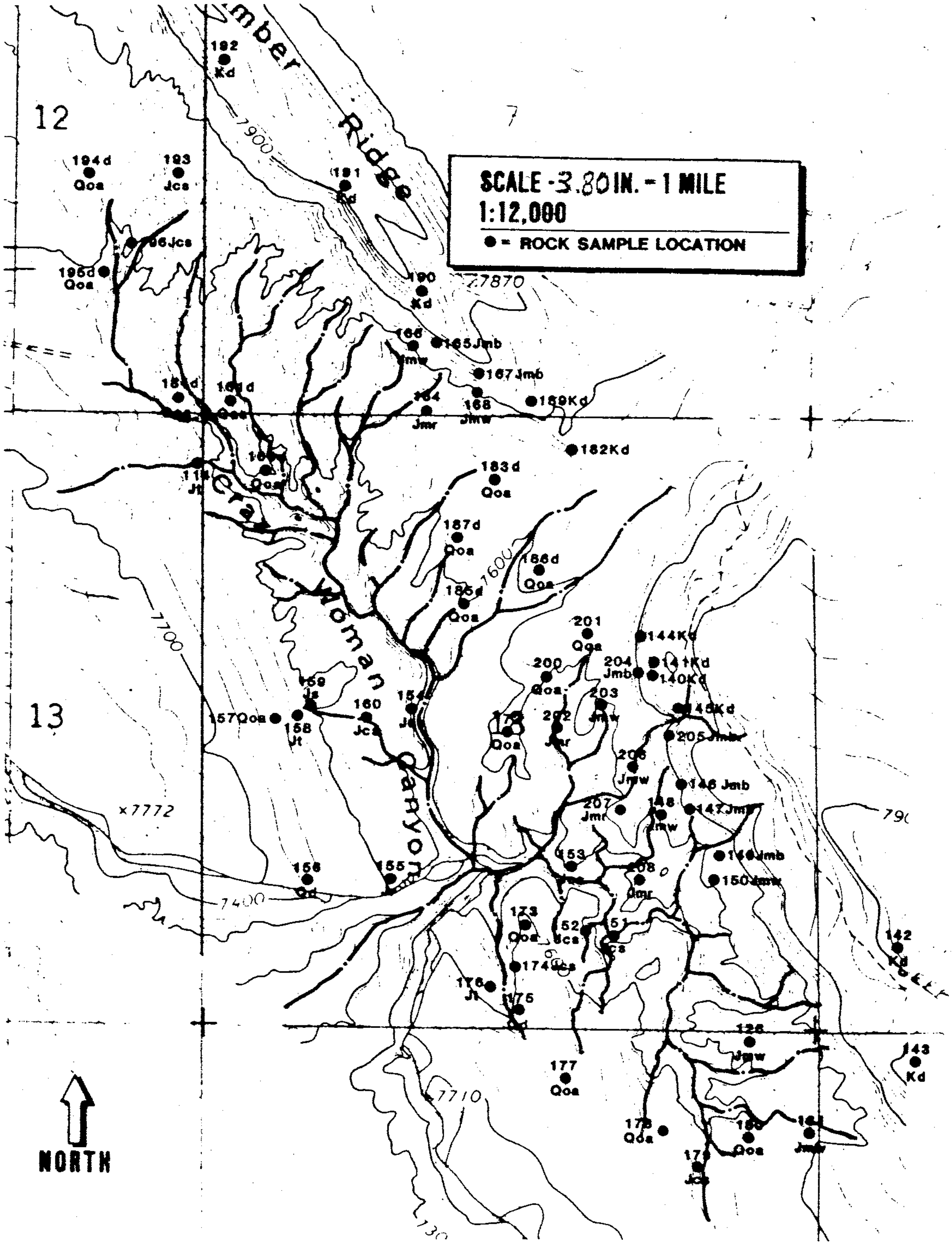


Figure 4: Rock outcrop sample location map.

to a fracture. Samples were placed in one or two double-thickness polyethylene bags, double-labeled on the inner bag, and then stapled shut for transportation.

The third type of sample is QOA. This material is of variable origin ranging from weathered rock which has not been transported, to ancient stream sediment abandoned when the drainage changed direction from a low-gradient northeasterly flow to a steep-gradient southwesterly flow. It is not readily discernable in the field exactly how the older alluvium originated. The QOA is an important sample type because it covers a significant part of the study area, influencing the composition of the modern sediment. It is primarily clastic material derived from nearby outcrops; but QOA also includes material emplaced by mass wasting of hillslopes and local slope wash (colluvium) or aeolian processes, as well as weathered bedrock stripped of its cementing agent. It was undisturbed for many years without transport, subject only to soil-forming processes such as leaching by infiltrating surface moisture. This odd, difficult to characterize combination of origins dictates separation of QOA from the younger two sample types. The seventeen older alluvium samples were collected following procedures similar to those for modern sediments including scraping away the upper 2-5 cm before sampling to avoid collecting recent windblown material.

Sample Preparation

Upon return from the field, all samples were inventoried and inspected for damaged containers. The few leaky containers were placed

into a third plastic bag before being dried. Samples were left inside their original bags, which were placed in a 1000 ml beaker and then dried in a drying oven at 100 C° ± 10°
for 24-36 hours. After cooling and while still in their bags, lumps in sediment and Quaternary alluvium samples were crushed using the rounded edge of a wooden board. Rock sample containers were again stapled shut for processing later.

Sediments and alluvium were then sieved to -100 mesh in the same manner as sediments collected for the NURE program (Olsen, 1977). The sieve apparatus used was a new Tyler U.S. standard 100-mesh screen and catch pan both made of stainless steel. Most common sieves are constructed of brass which is soft enough to be abraded by the sediment as it passes through the screen. To avoid contamination of the sample by copper and zinc from the brass, stainless steel sieves are employed where elemental analysis for minute concentrations is desired. Cleaning between samples was accomplished by running tap water under slight pressure through the sieve and gently brushing both sides of the screen with a paintbrush. The sieves were dried using isopropyl alcohol followed by compressed air. A 4 ml (6 to 10 grams) aliquot of the -100 mesh fraction was taken for Neutron Activation analysis (NAA) utilizing the standard clean "rabbit" that Los Alamos uses in their automated system. The remaining portion, if any, of the -100 mesh fractions was then stored in individually labeled 50 ml plastic bottles. All +100 mesh material was returned to the sample bag and saved for future reference.

In addition to the above, 31 sediments and alluvium samples were selected for size analysis. These samples are from the southeastern half of the study area and were sieved into the following five size (mesh) fractions: -100; +150, -150; +230, -230; +325, -325; +400, and -400. Using brass sieves borrowed from the New Mexico Bureau of Mines and Mineral Resources, 30.0 g of the -100 mesh fraction was placed in the top sieve and agitated for 30 minutes in a Ro-Tap mechanical shaker. The contents of each sieve was carefully cleaned out with a stiff brush onto a waxed paper sheet and then weighed. Weights were recorded and the samples bottled. These particular samples were chosen for this size analysis because they were collected from the southeastern half of the study area where it was anticipated that better exposures of uranium-bearing outcrops would cause significant uranium concentrations in sediments which could then be correlated with the amount of very fine sediment.

Rock samples were taken to Los Alamos for processing. The main reason for this was to use an hydraulic rock breaker with which it is easy to control the location of breakage and therefore the amount of material removed. Although the rock samples were collected to avoid any exterior (exposed) surface, they had been handled and perhaps set down in the dirt before bagging. To avoid these potential contaminants, each of the five specimens from a sample site were broken to expose new, untouched surfaces on all sides. An attempt was also made to break all specimens into equivalent sizes so that each one would be fairly represented after they were combined. To combine the specimens, they were placed into a tungsten-carbide surfaced cylinder-and-piston crusher which was then actuated by an external hydraulic press. The crushed material was then fine ground in a Spex Shatterbox using only tungsten-carbide lined containers. The resulting powder is <25 micron and an aliquot was then loaded into labeled, clean 4 ml rabbits for analysis by NAA. After each step, the containers were thoroughly cleaned and scrubbed.

Elemental Analysis by Neutron Activation

All of the one hundred fifteen samples collected for this study were analysed for total uranium by Delayed Neutron Counting (DNC) (Balestrini et al., 1976 and Minor et al., 1982). A split of each sample (dried and treated as described) was transferred to a 4 ml tared rabbit and its weight recorded, along with the appropriate sample number, in a computer data base. These rabbits were loaded into a transfer clip for irradiation. A 20-second irradiation followed by a 10-second delay and a 30-second count time was used. The uranium concentrations were determined by comparison with in-house standards. The lower limit of detection was 0.01 ppm, which is far below uranium concentrations in natural rocks and sediments. Above 1 ppm uranium the one-sigma error is less than 4%.

Immediately upon completion of the uranium analyses of sediment samples the samples were analyzed by neutron activation analysis. The concentrations of 44 additional elements may be determined by this procedure (Appendix I). Of the 44 elements measured for this study, Cu, I, Mo, Se, Ag, Au, and Hg were below the limit of detection in all samples. Tungsten, cobalt, and tantalum values are reported but should be disregarded because of contamination from the grinding vessel. Following the DNC analysis the samples were allowed to decay for 20 minutes then counted for 500-s for short-lived radionuclides, 96-s re-irradiation, 14-day delay, and finally a 1000-s gamma-ray count for long-lived radionuclides. The samples were counted using lead-shielded Ge(Li) detectors and 4096-channel analyzers. The lower detection limits for the various elements as reflected by the "less than" values (denoted by a minus sign in front of a concentration) in the data listing are the values for the individual elements at which the statistical counting error approaches 50%. Uncertainties in the measured trace element concentrations are usually less than 10% at concentrations one order of magnitude above the lower detection limits (Minor et al., 1982).

The automated multidetector analysis system used at Los Alamos has been evaluated for stability, accuracy, and precision using National Bureau of Standards (NBS) materials (Garcia et al., 1982). Results indicate that the agreement of their elemental concentrations with those of NBS and other values found in the literature were acceptable. A continuing quality assurance program using in-house standards and USGS rock standards was employed. Two USGS standards, GXR-1 and GXR-2 plus one International Atomic Energy Agency (IAEA) standard, SL-1 were analysed for this study. A comparison between measured and cited concentrations for uranium, thorium, vanadium, and hafnium for the standards are given in Table II. The measured values for standards deviated from published values by an average of 5 to 14%. Except for hafnium, the average difference from accepted concentrations was less than 10 percent. Concentrations measured for hafnium averaged 14 percent different from accepted values. A complete data set for the samples and the standards is included in Appendix I and contains concentrations for elements not used in this study . Additionally,

Table II. Comparison of Analyses for Rock Standards GXR-1, GXR-2, and SL-1.

GXR-1

	This Study	Gladney(1984)	Difference
U	30.5 ± 0.8	35.0 ± 1.4	13%
Hf	0.89 ± 0.09	1.1 ± na*	19%
Th	1.75 ± 0.09	2.4 ± na*	17%
V	74.8 ± 4.4	79 ± 9	5%

GXR-2

	This Study	Gladney(1984)	Difference
U	2.93 ± 0.03	2.91 ± 0.07	1%
Hf	7.90 ± 0.03	9.2 ± na	14%
Th	8.7 ± 0.0	8.6 ± 0.2	1%
V	54.00 ± 2.60	61 ± 9	11%

SL-1

	This study	IAEA	Difference
U	3.92 ± 0.11	4.02 ± 0.32	2%
Hf	4.56 ± 0.18	4.16 ± 0.58	9%
Th	13.70 ± 0.40	14 ± 1	2%
V	179 ± 11	170 ± 1	5%

Average Difference

U = 5.3% error
Hf = 14% error
V = 7% error
Th = 6.7% error

*The notation "na" means that too few analyses are available to quote an error limit.

seven samples were selected for replicate analysis to evaluate precision and the results are summarized in Table III. Differences between aliquots of the same sample are generally small, however, large differences sometimes occur when the concentration is very low. The difference in measured concentrations of uranium, vanadium, and thorium in the two aliquots of each sample averaged from 4.8 to 6.5 percent. Measured values for hafnium averaged 12 percent difference due in part to the low concentration of this element. Based on the measured values of the standards and the differences between replicate analyses of the same sample, it is concluded that the elemental values obtained by NAA for this study are accurate within acceptable limits (<20%).

Gravimetric Determination of Organic Carbon in Sediment

Organic matter is associated with the primary uranium deposits of the Grants mineral belt and has led many uranium geologists to believe that this material is critical to the formation of a deposit (Leventhal, 1980). Organic matter can concentrate uranium 10,000 times from water (Szalay, 1964). Thus, water containing 50 parts per billion uranium passing over organic material could result in a concentration of 500 ppm uranium in the organic matter. Not all organic material is capable of concentrating uranium directly (Jennings and Leventhal, 1978). The amount of uranium in petroleum is generally only a few ppm (Erickson et al., 1954). Conversely, even the right kind of organic material will concentrate no uranium if there is little or no uranium to trap. In the Green River Formation

Table III. Mean of duplicate analyses of selected samples for uranium, hafnium, vanadium, and thorium.

	ELEMENT			
Sample #	Uranium	Hafnium	Vanadium	Thorium
Jcs 193	0.44 ± 0.02	2.42 ± 0.35	13.40 ± 1.10	1.88 ± 0.33
Jmr 209	0.89 ± 0.01	3.87 ± 0.05	8.45 ± 0.75	2.52 ± 0.09
Jt 155	0.26 ± 0.01	0.25 ± 0.09	Below detection limit	Below detection limit
138	3.25 ± 0.55	51.90 ± 2.30	49.45 ± 0.05	5.0 ± 0.0
QOA 194	1.67 ± 0.12	7.35 ± 0.55	35.90 ± 1.90	4.45 ± 0.05
QOA 201	1.65 ± 0.05	9.35 ± 1.95	28.05 ± 0.35	3.90 ± 0.70
GXR-2	2.93 ± 0.03	7.90 ± 0.20	54.00 ± 2.60	8.7 ± 0.0
Average Difference	5.4%	12.0%	4.8%	6.5%
Range	3.8 - 17%	1.3 - 21%	0 - 9%	0 - 18%

(Eocene) of Wyoming and Colorado, there is 10-20% organic material present but only 2-4 ppm uranium is found. These same processes which allow concentration of uranium on organic material are occurring in stream channels at the earth's surface. A uraniferous rock outcrop is leached of its uranium by weathering and is transported downstream. The sedimentological factors governing the distribution of plant detritus and clay size particles might prove to be as important as a study of uranium distribution alone.

Studies have sought to characterize the sources and modes of transportation and deposition of uranium in sandstone-type deposits in the Grants district (Rautmann, 1980). Certainly the exact role of the humate material in the formation of uranium deposits has been questioned and there are conflicting views as to whether the uranium was transported through sandstone to the site of the carboniferous humate or vice versa (Fitch, 1980). If the role of carbon in the formation of a uranium deposit is positive but unclear, then it seems reasonable to assume that relating carbon to uranium content in modern stream sediments as a means of geochemical exploration may be valid.

To explore the relationship between carbon and uranium in the study area, analysis for organic carbon was attempted gravimetrically for 20 stream sediments collected in the southeastern drainage (control area). It was reasoned that the difference between sample weight before and after oxidation would represent the amount of carbon converted to CO_2 and removed. Approximately 1 g of homogenized -100 mesh material was weighed to the nearest tenth of a milligram into a clean, dry, and tared Petrie dish. The samples were then dried at

110°C for at least one hour to remove the loosely bound water, cooled, and reweighed. The samples were then oxidized in a low temperature ashing furnace made by LFE Corporation. In this apparatus, the sample is heated only to 100°C and a stream of oxygen gas effects removal of carbon. This equipment is normally used for determination of carbon in coal and peat samples and can provide like information about sediment samples.

The assumption above was that all of the weight loss after oxidation in a low temperature ashing furnace was due to removal of organic carbon. Although clays and other hydrated minerals contain substantial water in their structure, the low temperature (100°C) employed in this method of carbon determination should not change the water content or the weight. Three standards were analyzed with the samples to ensure accurate results. A sediment sample which had previously been heated to 1000°C for 2 hours was used as a blank. The sample weighed 1.1447 grams before analysis and 1.1446 grams afterwards. Two samples of clean, dried quartz sand to which known amounts of charcoal had been added were also used. For one standard, the sand weight was 1.0200 grams and the charcoal weighed 25 milligrams (mg). After ashing the sample weighed 1.0203 grams. For the second standard, the sand weighed 1.1122 grams and the added charcoal weighed 53 mg. After ashing the sample weighed 1.1127 grams. Based on these results it was concluded that the carbon analyses are accurate within about 10%. The carbon content as measured by weight loss was converted to percent and is presented in Table IV.

Table IV. Concentrations of uranium, thorium, vanadium, organic carbon, hafnium, and -400 mesh fraction in sediments from the southeastern half of the study area

Sample location	ppm U	ppm Th	ppm V	percent C	ppm Hf	percent -400 Mesh
118	1.82	3.58	37	0.09	5.44	4.0
119	3.39	5.60	44	0.19	25.8	3.0
120	3.27	5.94	42	0.37	18.7	6.3
121	1.82	3.45	29	0.40	7.24	1.7
122	3.06	3.93	48	0.30	9.63	5.0
123	2.09	2.94	44	0.25	16.7	2.0
124	3.75	6.23	49	0.36	16.4	7.2
125	3.26	5.60	45	0.32	20.2	5.1
127	2.60	3.40	33	0.20	13.1	2.8
128	2.63	5.07	43	0.12	16.6	3.7
129	1.44	3.99	32	0.03	6.74	3.3
130	0.89	2.13	17	0.32	4.68	0.4
131	3.82	3.93	130	0.13	46.9	1.2
132	3.57	4.79	156	0.06	59.0	1.3
133	3.05	4.87	69	0.25	46.0	1.7
134	4.52	7.09	55	0.16	36.1	6.7
135	1.29	2.18	24	0.55	4.43	1.8
136	1.81	3.14	33	0.55	7.68	3.0
137	4.61	4.67	139	0.18	83.9	1.0
138	3.88	5.06	49	0.40	54.2	2.6

IV. RESULTS AND INTERPRETATION

Site Characteristics

The southeastern drainage, the primary focus of the study, is unique in character. The point where the stream drops 100 m or more and out of the study area is only a short distance below sample location number 138 (Figure 3). Upstream from that point, the side streams have steep gradients and are choked with larger size rocks than the main channel. This main channel is contained entirely within the Cow Springs Formation (Figure 2) and rises 80 m to location number 130. Quaternary older alluvium (QOA) covers all other rocks from that point all the way to the crest of the drainage. This distance is approximately equal to the distance from number 130 to the bottom of the drainage. The area covered by QOA is fairly large and was not sampled intensely. The extensive period of time during which leaching of elements and soil formation must have occurred would surely cause the QOA to adopt a character quite unlike the rock outcrops or sediments which are the focus of this study. The statistics for 19 QOA samples indicate a greater homogeneity in elemental content than for other sample types. Also, QOA does not contain appreciable uranium and appears to affect stream sediment more subtly than other rock types. In light of these data, QOA is not discussed in detail.

From location numbers 138 to 130, the area to the northeast of the main channel consists predominantly of the following rock types: Cow Springs Formation, Recapture Creek Member, Westwater Canyon Member, Brushy Basin Member, and Dakota sandstone at the ridge crest

(Figure 2). The area to the southwest of the main channel contains the greater portion of the Cow Springs Formation and QOA above that to the ridge crest. Drainage over the Todilto limestone is isolated from the main stream channel and therefore does not influence its chemical composition.

On the northeastern side of the main channel, the Cow Springs Formation contains an indistinct upper unit in which fractures filled by clay sometimes occur. A similar clay filling was also observed at a few locations within the Westwater Canyon Member. The fractures range in size from a few millimeters to several centimeters and extend only several meters crosscutting the bedding plane. These fracture fillings were certainly not common but samples were taken at two of the largest occurrences.

The Recapture Creek Member is a cliff-forming unit here and is not extensively exposed to stream waters except at the western end of the outcrop. Stream channels formed in this area become quite steep and could not be sampled for water transported sediment any higher than the Westwater Canyon member. The channels are "v" grooves containing large boulders and rocks decomposed *in situ*.

The main channel and side streams were sampled for sediment at intervals depending on stream intersections and distance from last sample. Rocks were sampled at locations where the outcrop seems to be representative of the bulk of that formation. In the discussion which follows, the general philosophy is that the sediment compositions are the key to rock outcrop composition. Elemental concentrations in rock outcrops and stream sediments will be compared and contrasted and attention focused on changes observed downstream. In a manner similar to that used in typical stream sediment surveys, the chemical composition of the sediment will be the main focus. Unlike typical surveys, any interesting results of sediment analyses are followed by closer examination of source rock data which is at hand. A similar geographic distribution of uncommonly high values are considered more significant than isolated higher values. The goal here is a treatment of data which identifies the geographic source of uranium.

Uranium

Exploration for uranium was the primary mission of the NURE program; an extensive government supported endeavor in which most stream systems in the U.S. were sampled at reconnaissance scale (1 sample per 10 km^2). Because so many scientists examined the results from this program in their search for uranium, and there is still considerable interest in the applications of NURE data for exploration of all elements, a closer look at the behavior of uranium in the study area was undertaken in this study.

Data for uranium in rocks and sediments is summarized in Table V. The average uranium content for all rock samples analyzed was 2.02 ppm, and the standard deviation was 2.77 ppm. The mean uranium content in each of the six rock units varied considerably. The rock unit containing the least uranium is the Todilto limestone having only 0.25 ± 0.04 ppm, indicating that in this area, there was little or no uranium deposited with or trapped in the unit as there was at Haystack Butte to the east. The Recapture Creek Member, Cow Springs Formation (excluding fracture fillings), and Dakota sandstone contain 1.03 ppm,

Table V: Basic statistical data for uranium (ppm) in sediments and six rock units in the study area, McKinley County, New Mexico.

Rock unit	Number of samples	Mean	Standard deviation	Range
All sediments	42	2.30	0.99	1.08 - 4.60
Kd	16	0.87	0.21	0.60 - 1.37
Jmb	9	4.60	2.40	2.06 - 9.60
Jmw	11	2.36	1.02	1.11 - 4.80
Jmr	4	1.03	0.55	0.64 - 1.84
Jcs	10	0.98	0.45	0.46 - 1.57
Jt	4	0.25	0.02	0.23 - 0.27
All Rocks	54	2.02	2.77	0.23 - 9.60

Kd = Cretaceous Dakota Sandstone
Jmb = Jurassic Morrison Formation, Brushy Basin member
Jmw = Jurassic Morrison Formation, Westwater Canyon member
Jmr = Jurassic Morrison Formation, Recapture Creek member
Jcs = Jurassic Cow Springs Sandstone
Jt = Jurassic Todilto Limestone

0.98 ppm, and 0.87 ppm uranium, respectively. These values have standard deviations of 0.55 ppm or less which implies that little of the uranium found in the sediment had these rocks as their source. The Westwater Canyon and Brushy Basin Members contain the most uranium. The Westwater Canyon Member contains an average of 2.36 ± 1.0 ppm uranium; twice the amount of other rocks mentioned. The Brushy Basin Member has an average uranium content nearly twice that of the Westwater Canyon Member: 4.60 ± 2.4 ppm. This is not surprising because many uranium mines in the Grants district are in or near these two units. The uranium values for these two members are consistently high throughout the study area and are reflected by their small standard deviations.

As was postulated before the chemical analyses were known, uranium content is highest in the Morrison Formation. Do sediments which are collected downstream give any clues which might lead explorationists to look more closely?

The average uranium content of all sediments is 2.30 ppm. This by itself does not seem anomalous. This is however a rather high value when compared to the uranium content in the source rocks other than the Westwater Canyon Member and Brushy Basin Member. Examination of the uranium content in all sediments from the southeastern half, or control portion of the study area indicates that many higher than average uranium values originate from the northeastern half of the drainage where the Morrison Formation crops out. The uranium content in sediments seems to be a reasonable indicator of uranium in rock outcrops, but there also are above average uranium values downstream from non-uraniferous southwestern outcrops. Compounding the problem of data interpretation, sediments from the main channel are inconsistent in uranium content. This sediment apparently is an inhomogeneous mixture of material from the northeast and southeast sides of the canyon. This results from a combination of several factors including gradient, variation in rock types, difference in bed attitude, amount of vegetation, and degree of water saturation. Because of these factors, the uranium from rocks on the northeastern side is not distributed evenly in sediments of the main channel. A typical reconnaissance geochemical survey will contain only one sample in a drainage such as this, so the location chosen for that sample is crucial. This is illustrated by the difference in uranium content in sample numbers 138 and 136. Sample number 138 contains 3.88 ppm uranium and location 136 has only 1.81 ppm uranium. These samples were both taken near the mouth of the drainage in the main channel only about 100 m from each other. Either site would normally be considered acceptable, and most geologists would not expect to see dramatic differences in the uranium content. The same location as number 138 was sampled in 1979 for the NURE project and was assumed to be representative of the entire drainage area (Purson et al., 1981). Analysis of that sample (number 481621-15) indicated a uranium content of 1.69 ppm which hardly suggests that further exploration is worthwhile. The same location sampled 3.5 years apart indicates a factor of two difference in uranium content. Depending on the methods and criteria used for determining anomalous uranium content, the new data for this location may indicate that it is worthwhile to sample upstream.

Several significant observations can be made from this information. Low order, steep gradient drainage basins such as this one, which contain uraniferous rock outcrops, have stream sediment which varies widely in uranium content from adjacent locations and changes significantly over time. Even though the drainage area is small, there apparently are large differences in water flow from one tributary to another. In this study, sample 138 could be heavily influenced by the small tributary from which sample 137 was taken (sample 136 was collected above this tributary). The same location sampled 3.5 years earlier was apparently composed primarily of main channel sediments which were low in uranium content. If stream sediment is collected very near its source and is undiluted by other nonuraniferous sediment, the uranium content of that sediment will be representative of the uranium content of the source rocks. The distance downstream that uranium can be detected at levels high enough to warrant further investigation is dependent on several important variables. The total area of a uraniferous outcrop is one factor which determines how much sediment it will contribute to the system. In this study, the Westwater Canyon and Brushy Basin members constitute between 25 and 50% of the area of rock outcrops (excluding QOA) and the uraniferous sediments from them are sometimes difficult to see only a short distance downstream. The amount and the form of the uranium in an outcrop also determines if significant levels will be observed in sediments downstream. Uranium as pitchblende is not readily soluble in water and would be transported along with sediment, but uranium in a carbonate cementing agent as is the case here would move both in solution as UO_2^{2+} and as a particle. It can be seen that uranium in the Westwater Canyon and Brushy Basin members is 2 to

4 times that of other rock outcrops yet that difference is obscured in sediments collected a short distance downstream. This is probably due to differences in amount of runoff and the availability of scavenging material in the stream-bed. It is probably rare that enough rainfall occurs to cause sustained flow from outrops to drainage mouth. It is assumed that in arid climates uranium will move away from its origin incrementally, meaning that the uranium in solution is carried short distances until the runoff evaporates or is absorbed in sediment. Some uranium remains in rock fragments and is transported as a solid. If a single sample collected at the mouth of this drainage were to contain enough uranium to suggest further work, the outcrops would need to yield enough uranium to overcome the various obscuring effects; or the explorationist would have to be lucky enough collect a sample at the right place and time.

Carbon and Fine Size Material

There are other factors affecting the distribution of uranium in a drainage basin such as this, that might allow discrimination between sediments containing unusually high amounts of uranium and sediments which indicate a source of uranium is nearby. Organic carbonaceous material can effect removal of uranium from solution. Uranium adsorbed onto a particle will continue to be transported downstream but at a considerably slower pace than uranium in solution. It is postulated that uranium occurs in the Westwater Canyon primarily as fine-grained disseminations in the calcareous cement which holds together the grains of quartz and feldspar (Livingston, 1980). In outcrop, this cement is easily dissolved in rainwater and begins movement downstream. Plant debris is common throughout the study area and after some decay, it is capable of removing some of the uranium from solution. If the amount of runoff is sufficient, uranium bearing organic debris can accumulate downstream in backwater areas along with other fine or low density sediment. A sample collected in such an area could be anomalously high in uranium content. This sample could contain much uranium even if there is no significant mineralization upstream. It may be simply a localized concentration of uranium from rocks having background uranium levels. Analysis of sediment for uranium in a region where organic matter in sediment varies widely could be misleading unless the amount of organic material is determined. It is possible that the same theory holds true for clay content in sediment. Uranium is adsorbed onto clay particles and unusually high content of clays in a sample may also show high concentrations of uranium. Do clays and organic carbon distort the interpretations of analyses of a typical -100 mesh sediment sample used for the NURE? A closer examination of the southeast drainage and the relation between uranium content, and carbon and fine sized mineral content is appropriate.

As stated previously, the NURE program focused on the uranium content of stream sediment as the "pathfinder" element for locating uranium mineralization. It had been speculated that other of the elements reported might prove useful in exploration; however, the responsibility of which elements and how they were to be used was left to the user of the data. Los Alamos conducted a pilot study in which Olsen (1977) determined that analysis of the -100 mesh fraction was optimum for detection of uranium anomalies. Nearly all NURE sediment samples collected by Los Alamos thereafter were sieved accordingly and results of analyses on those samples constitute a remarkably complete data set for stream sediments of the Rocky Mountain states and Alaska. Unfortunately, these data contain very little information about the amount of fine and clay sized particles or the amount of organic carbon in the samples.

For the control area, a plot of -400 mesh sediment versus uranium content does not show any distinction between streams which are known to drain uraniferous rock outcrops and those which do not. A quick comparison of -400 mesh and percent organic carbon in these samples shows no particular relation (Figure 5). The correlation (R^2) between uranium and -400 mesh is only 0.104. Perhaps it is the carbon content alone which is responsible for the higher than average uranium content.

Figure 6 is a plot of carbon versus uranium content in 20 sediment samples collected from the control area. The circled sample numbers denote locations where the sample was collected directly downstream from outcrops of the Morrison Formation and therefore might display a distinctive pattern. The correlation (R^2) between uranium and percent carbon is insignificant at 0.066. There is no apparent difference between samples collected from uraniferous and non-uraniferous areas when uranium is plotted against carbon content. The reason for this is probably a combination of factors. First, the amount of carbon in the sediment is very small and varies from 0.03 to 0.55 percent. Because of wind deposition of light weight organic matter, the carbon in the sediment may or may not have been exposed to uranium-bearing runoff. Second, at least some of the uranium measured

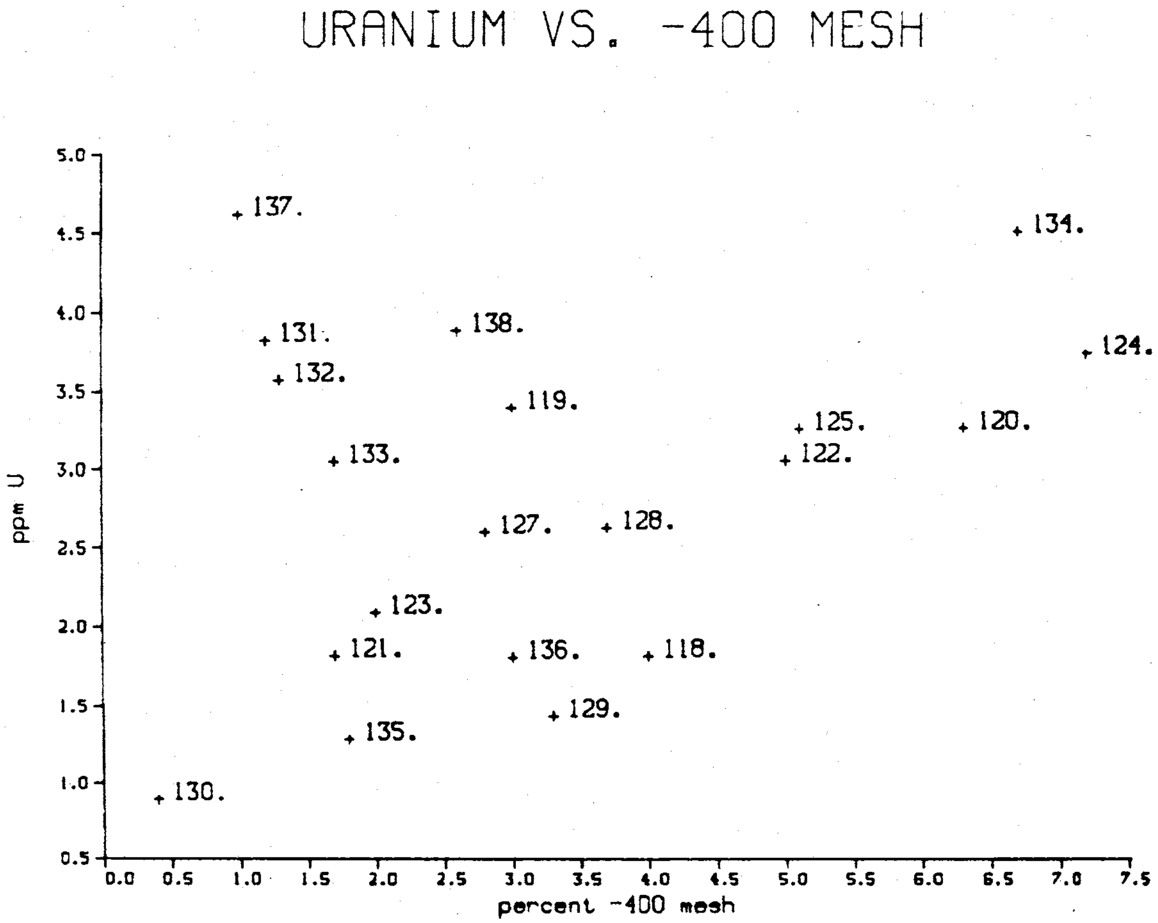


Figure 5: Graph of uranium versus percent -400 mesh in sediment samples from the southeast portion of the study area.

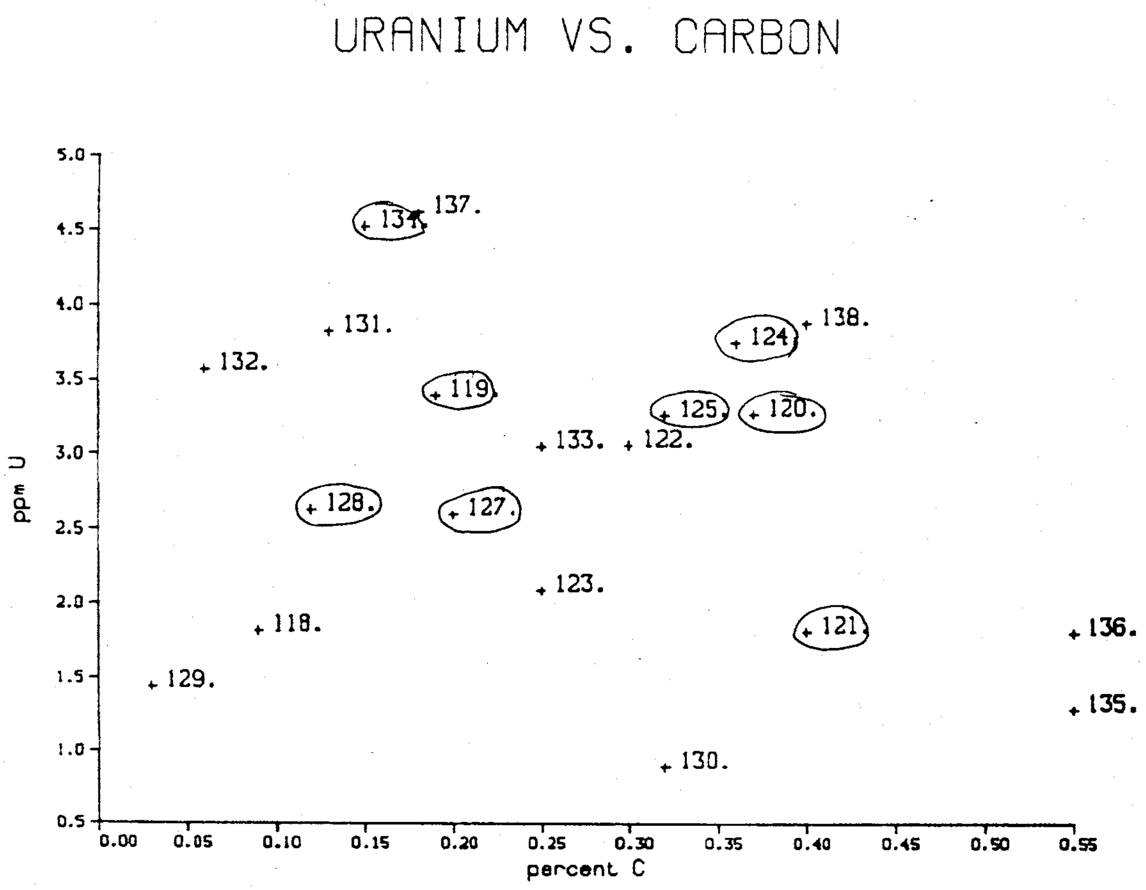


Figure 6: Graph of uranium versus organic carbon in sediment samples from the southeast portion of the study area. Circled sample numbers indicate locations directly downstream from uraniferous outcrops.

in the sediment was probably in a form independent of carbon content. Uranium in zircon or even uranium in carbonate cement which had not yet dissolved contribute to the total uranium content in addition to uranium reduced by organic carbon.

It is concluded that the effect of organic carbon on uranium content in sediment is not dramatic enough for use as an exploration tool under these conditions. Perhaps other elements can be more useful because of similarity in behavior or origin.

Multielement Analyses

The goal of geochemical exploration is to relate chemical variations in natural samples to the existence of ore deposits. The usage of many elements allows the explorationist to understand the source rocks and to extract information from the data that relates to the likelihood of an ore occurrence. A study of elements such as thorium, vanadium, and hafnium can provide additional information about uranium and is included here.

Thorium

This element generally accompanies uranium during igneous processes due to their similar ionic radius (~1A) and valence (+4). A relatively constant U/Th ratio of 0.5 - 0.25 is characteristic of most igneous rocks and many metamorphic and sedimentary rocks (Rogers and Adams, 1970). These two elements are generally very low in concentration in ultramafic, mafic, and intermediate rocks and are most abundant in granites, rhyolites, and some alkaline syenites.

Thorium contrasts with uranium in the surficial environment in that it is nearly immobile due to thorium's lack of a mobile +6 valence oxidation state. The thorium +4 ion, if released by decomposition of its host, tends to precipitate or be strongly adsorbed, and thus migrates only short distances (Kimberley, 1978). Where igneous rock-forming processes are responsible for the formation of a uranium anomaly, thorium enrichment may be a useful indicator of uranium however, in sedimentary environs, the association of thorium with uranium tends to be weak.

Data for thorium and uranium is summarized in Table VI. In the study area, U/Th ratios range from 0.73 in the Westwater Canyon member to 0.43 in the Dakota Formation, the average of all rock units being 0.48. The sediments have an average U/Th ratio of 0.58 which is similar to the surrounding rocks. Sediments which contain higher concentrations of uranium also contain a higher content of thorium, e.g. the range of values for U/Th ratios in sediments (0.43-0.58) is small. This homogeneity in U/Th ratios does not allow adequate discrimination between samples which could be considered anomalous and therefore these ratios can be only a weak pathfinder for uranium mineralization in this environment.

Thorium concentrations alone in rocks and sediments provide more information than do U/Th ratios. Concentrations of thorium in sediment are provided in Table IV and Table VI. The thorium and uranium R^2 is 0.626 which is not very strong. Thorium concentrations increase slightly in sediment taken near the Morrison Formation, but downstream sediment quickly becomes more uniform. A graph of uranium versus thorium in sediment from the control area is

Table VI: Thorium and uranium data (in ppm) for sediments and rocks from the study area, McKinley County, New Mexico.

Source	Number of samples	Avg. Th	Avg. U	Avg. U/Th
All sediments	42	3.97 ± 1.34	2.30 ± 0.99	0.56 ± 0.23
Kd	16	2.03 ± 0.50	0.87 ± 0.21	0.43 ± 0.11
Jmb	9	9.54 ± 3.38	4.60 ± 2.40	0.48 ± 0.15
Jmw	11	3.25 ± 0.76	2.36 ± 1.02	0.37 ± 0.21
Jmr	4	2.28 ± 0.93	1.03 ± 0.55	0.45 ± 0.11
Jcs	10	2.16 ± 0.84	0.98 ± 0.45	0.45 ± 0.18
Jt	4	0.11 ± na*	0.25 ± 0.02	0.44 ± 0.02

*The notation "na" means that too few analyses are available to quote an error limit.

Kd = Cretaceous Dakota Sandstone
Jmb = Jurassic Morrison Formation, Brushy Basin member
Jmw = Jurassic Morrison Formation, Westwater Canyon member
Jmr = Jurassic Morrison Formation, Recapture Creek member
Jcs = Jurassic Cow Springs Sandstone
Jt = Jurassic Todilto Limestone

provided in Figure 7. Circled sample numbers indicate sediment collected directly downstream from the Morrison Formation. Evidently, thorium is mobilized and transported by mechanical rather than chemical means as is the case with uranium. Also, it seems that the distribution of thorium-bearing minerals is more uniform among different rock units as evidenced by higher than average thorium concentrations at scattered locations away from the Morrison Formation. Correlation (R^2) between uranium, and thorium in rocks is 0.336. This indicates that uranium exists in forms independent of thorium. The higher correlation in sediment indicates that uranium is being mobilized leaving relatively more uranium in thorium-bearing resistates minerals. This suggests that, in sedimentary terranes, thorium concentrations in sediments are at best only a weak pathfinder element for uranium-bearing formations.

Vanadium

Vanadium occurs as either a minor or trace element with uranium in sandstone type deposits and, like uranium, is soluble as oxy-anions under oxidizing conditions and is precipitated by reducing conditions. Because of the similar behavior of vanadium and uranium, vanadium may have potential as a uranium pathfinder in stream sediments.

Squires (1980) conducted a study of uranium deposits and mineral associations of the Morrison Formation in the San Juan Basin. He noted that although vanadium is usually present, its concentration is not strongly correlated with uranium or organic matter. Both Squires (1980) and Place, et al. (1980) believe that vanadium is present in mixed layer illite-montmorillonite, and not closely associated with

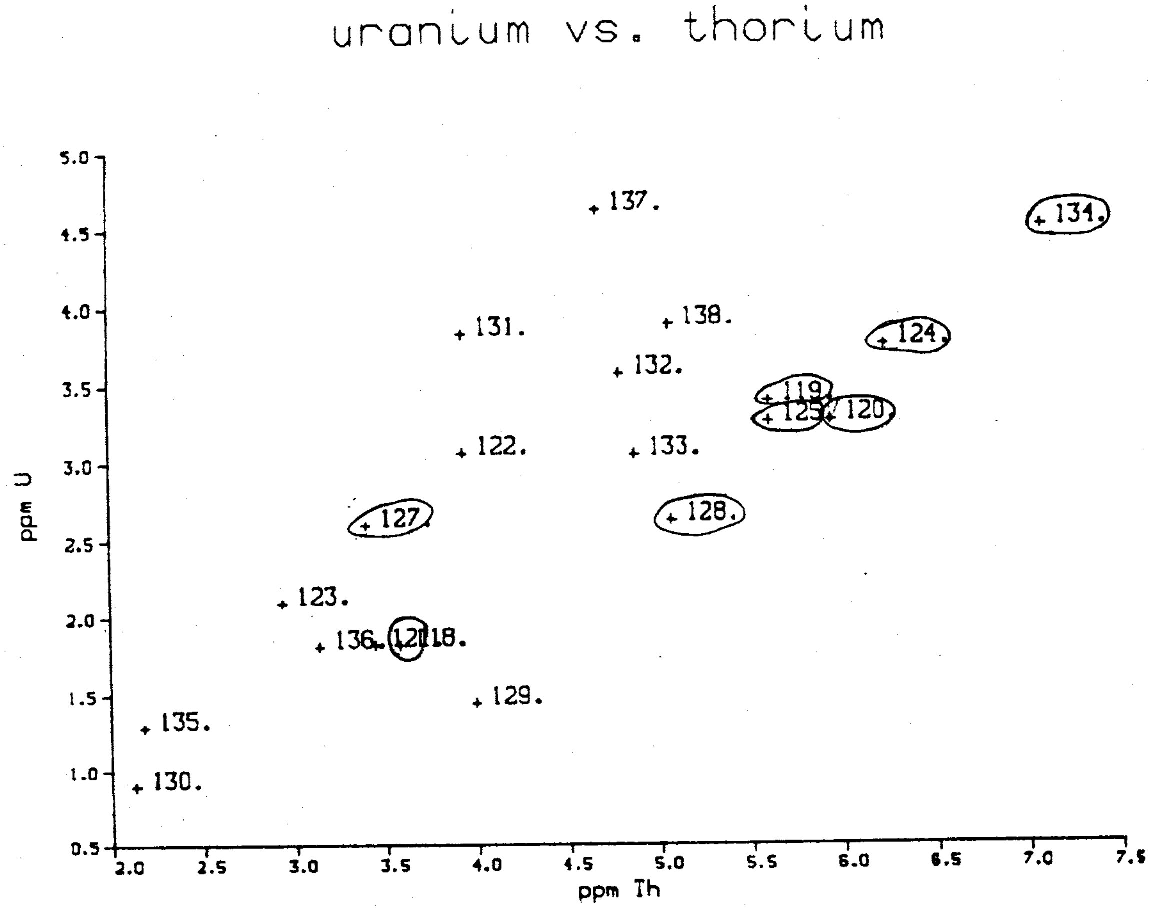


Figure 7: Graph of uranium versus thorium in sediment samples from the southeast portion of the study area. Circled sample numbers indicate locations directly downstream from uraniferous outcrops.

uranium mineralization. Kozusko and Saucier (1980) observed that vanadium is less abundant in primary ore than in redistributed ore. Previous studies lead one to doubt that vanadium can be effective in locating uranium underground, but perhaps the surficial environment is different enough for vanadium to be useful.

Data for vanadium and uranium in rocks and sediments is summarized in Table VII. In the study area, vanadium concentrations in rocks ranged from 4.38 ppm to 125.5 ppm, and in sediments ranged from 17.43 ppm to 156.2 ppm. The average vanadium content in rocks is 25.46 ppm and in sediments is 42.48 ppm.

In rocks, the correlation (R^2) between vanadium and uranium is 0.500. As expected, the Brushy Basin member has the most vanadium, averaging 41.6 ± 28 ppm, followed by the Westwater Canyon member averaging 37.3 ± 27 ppm. Other rock units, the Cow Springs, Recapture member, and Dakota sandstone contain much less than this, having 22.6 ± 51, 15.0 ± 13, and 4.8 ± 10 ppm respectively.

Overall, the correlation (R^2) between vanadium and uranium in sediment is 0.406. Sediments from the southeast drainage average 56 ppm vanadium. The three highest values (130 to 156 ppm) are in sediments collected from the opposite side of the canyon from outcrops of the Morrison Formation (Table IV). Perhaps the very high content of vanadium in these few samples can be attributed to the occurence of a nearby exposed fracture-filling in the Cow Springs. Vanadium from the clay filling could be leaching out causing anomalously high concentrations in sediments a short distance downstream. Figure 8 is a plot of uranium versus vanadium for sediment samples from the southeast portion (control area) of the study area. If the four samples

Table VII: Vanadium and uranium data (in ppm) for sediments and rocks from the study area, McKinley County, New Mexico.

Source	Number of samples	Avg. V	Range	Avg. U
All sediments	42	42.1 ± 30.2	20 - 156	2.30
Kd	16	10.2 ± 4.8	4.5 - 24	0.87
Jmb	9	41.6 ± 21.1	14 - 70	4.60
Jmw	11	37.3 ± 14.4	20 - 74	2.36
Jmr	4	15.0 ± 3.9	8 - 34	1.03
Jcs	10	22.6 ± 7.6	11 - 125	0.98
Jt	4	1.0 ± na*	0 - 5	0.25

*The notation "na" means that too few analyses are available to quote an error limit.

Kd = Cretaceous Dakota Sandstone
Jmb = Jurassic Morrison Formation, Brushy Basin member
Jmw = Jurassic Morrison Formation, Westwater Canyon member
Jmr = Jurassic Morrison Formation, Recapture Creek member
Jcs = Jurassic Cow Springs Sandstone
Jt = Jurassic Todilto Limestone

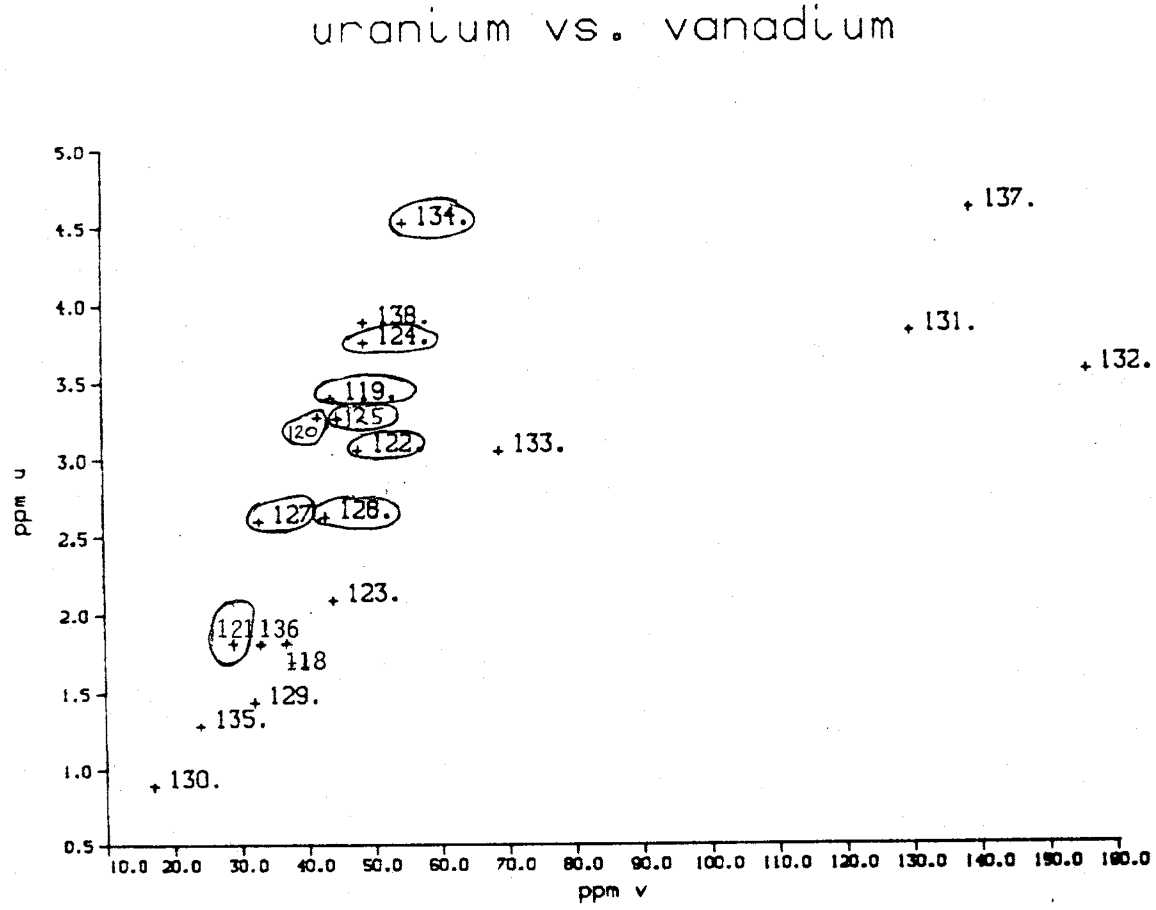
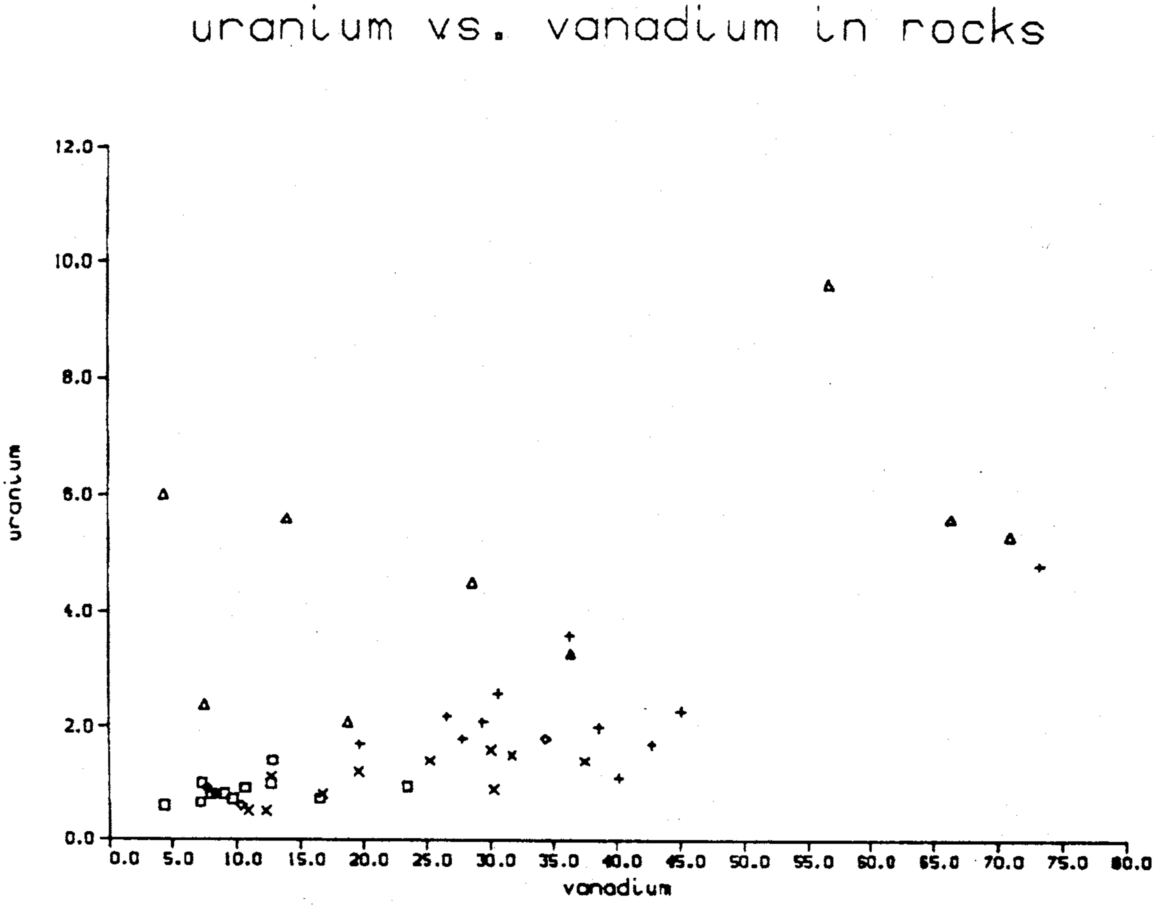


Figure 8: Graph of uranium versus vanadium in sediment samples from the southeast portion of the study area. Circled sample numbers indicate locations which are downstream from uraniferous outcrops.

containing the highest vanadium are disregarded, the remaining samples correlate very well. This indicates that uranium and vanadium generally behave alike in sediment but this fact does not provide a better means for locating the source rock than using uranium data alone. The samples collected downstream from the Morrison Formation appear somewhat clustered together on Figure 7, but if knowledge of the uranium source is lacking, these samples would not be distinctive. In the southeast drainage high vanadium values are scattered throughout both halves of the drainage. Figure 9 is a plot of uranium versus vanadium in rock samples. Uranium acts similar to vanadium in rocks except that in the Brushy Basin member, there is an abundance of uranium-bearing zircon which causes an excess of uranium relative to vanadium. This fact which is relected in Figure 8 might be enough for an explorationist to look further and collect additional samples. The enrichment of uranium relative to vanadium is subtle and only careful examination of the vanadium data alone would incite further study. A better, more useful picture of the sediment geochemistry might be had by studying uranium and zircon content directly rather than their effect on vanadium concentrations.

Although vanadium seems to have its origin in the same rock units as uranium, and vanadium generally behaves similar to uranium, the observed geographic distribution of vanadium by itself in sediments makes it a weak pathfinder element for uranium.



Kd = Cretaceous Dakota Sandstone = □
Jmb = Jurassic Morrison Formation, Brushy Basin member = △
Jmw = Jurassic Morrison Formation, Westwater Canyon member = +
Jmr = Jurassic Morrison Formation, Recapture Creek member = ◇
Jcs = Jurassic Cow Springs Sandstone = x

Figure 9: Graph of uranium versus vanadium for all rock samples from the study area.

Hafnium

Zircon ((Zr,Hf)SiO_4) occurs in the Morrison Formation in greater quantities than in other rock units in the study area. This is due to the granitic source rock which eroded and contributed sediment to the Morrison Formation. Zircon always contains uranium in amounts ranging from 100 to 6000 ppm depending on its source (Price and Ferguson, 1977). This uranium is trapped in the crystal structure of zircon and is usually not removed by weathering because zircon is quite resistant. An increase in uranium in a sediment sample could be simply due to an unusually high concentration of zircon and provide no information regarding the uranium source. Interpretation of uranium data could be more useful if the effect of zircon is known. For example, a hypothetical drainage basin located in a granitic provinance might have sediment containing five percent zircon. If the zircon contains 0.02% uranium, the zircon alone accounts for 10 ppm uranium in a sediment sample. In addition to uranium in zircon, the sediment will contain uranium from other sources including uranium mineralization. This could be on the order of 2 or 3 ppm. Samples collected in this particular drainage might average 12 ppm uranium. In a reconnaissance geochemical survey such as NURE, samples from a very large area are treated as a single data set and anomalous samples are chosen to be 2 or 3 standard deviations above the mean uranium content for all samples in that data set. If the hypothetical drainage basin mentioned above is relatively small and a large area surrounding this basin contains little or no zircon, a problem with interpretation can exist. The few samples collected from the drainage basin will appear quite anomalous when compared to the surrounding area. Exploration would likely be focused in this drainage basin and little attention paid to the surrounding area. This of course would be improper and if the uranium content of a sediment could be corrected for the amount of zircon in the sample, then the explorationist can examine areas which have real potential for significant uranium mineralization.

ASSUMPTIONS AND GOAL

To gauge the effect of uranium in zircon, hafnium concentrations will be used. This is because zirconium analyses by neutron activation are less precise and less accurate than hafnium analyses and because it can be shown that the ratio of hafnium to zirconium is nearly constant due to their similar ionic radii (Price and Ferguson, 1977). Analyses of 50 samples from the Grants Special Study area (Purson et al., 1981) collected outside the present study area were used to verify that the Zr/Hf ratio (~38); and remains constant in this region (Figure 10). In comparison, zircons in other sedimentary rocks have Zr/Hf ratios ranging from 37 to 42 and is discussed in Wedepohl (1978). It is known that the amount of hafnium is directly proportional to the amount of zircon, but are the U/Hf ratios for samples inside the current study area unusual or anomalous when compared to samples from outside the study area? The average U/Hf ratio for 50 samples collected outside the study area is 0.18 and is nearly identical with the U/Hf ratio of 0.17 for samples within the study area. A summary of uranium and hafnium concentrations for samples from within this study area is provided in Table VIII. Uranium-hafnium ratios are summarized in Table IX.

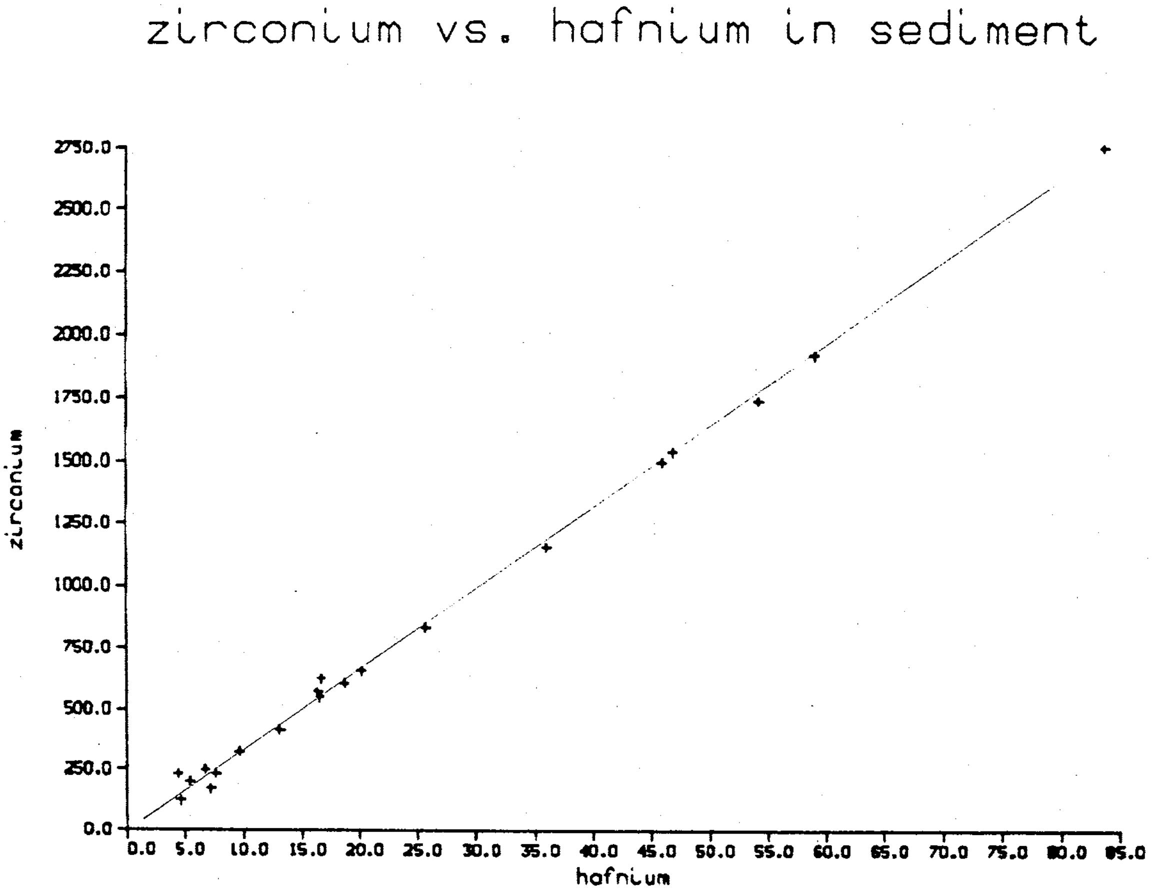


Figure 10: Graph of zirconium versus hafnium for 50 sediment samples collected for the Grants Special Study from outside the study area.

Table VIII: Hafnium and uranium data (in ppm) for rocks and sediments from the study area, McKinley County, New Mexico.

Source	Number of Samples	Avg. Hf	Range	Avg. U
All sediments	42	17.52 ± 18.05	3.34 - 83.90	2.30 ± 0.99
Control area sediments	20	24.97 ± 22.18	4.68 - 83.90	2.83 ± 1.08
Control test area sediments	22	9.28 ± 5.78	3.34 - 29.06	1.75 ± 0.53
Kd	16	5.51 ± 2.96	0.81 - 14.26	0.87 ± 0.21
Jmb	9	10.58 ± 3.82	5.79 - 16.80	4.60 ± 2.40
Jmw	11	4.80 ± 1.85	1.87 - 8.97	2.36 ± 1.02
Jmr	4	2.45 ± 1.31	0.95 - 3.82	1.03 ± 0.55
Jcs	10	7.36 ± 5.63	2.07 - 20.81	0.98 ± 0.45
Jt	4	0.21 ± 0.11	0.08 - 0.33	0.25 ± 0.02
All rocks	54	5.87 ± 4.29	0.15 - 20.81	2.02 ± 2.77

Table IX: Uranium - hafnium ratios for sediments examined in this study.

	Control area	Control test area	Fifty samples from Grants special study
U/Hf	0.17	0.22	0.18

Basic assumptions include: 1) Zircon always contains some amount of uranium and in this study, the uranium content is considered constant; 2) Zircon is directly related to hafnium concentrations. No other minerals containing zirconium or hafnium are known or expected in the sediment or rocks; 3) Zircon is not uniformly distributed in rocks or sediments; 4) Uranium in zircon is not extractable and therefore is of no economic interest; 5) Sediment samples and their analyses collected for this study are considered to be representative of the stream sediment for that locality in the stream; and 6) Sediment containing uranium which is not associated with zircon can be used to locate uranium mineralization in source rocks better than total uranium content in sediment alone. Working from these assumptions, the goal is to define the relationship between uranium and zircon and use that information to negate the effect of zircon on uranium concentrations in sediment samples. The uranium in the samples after this subtraction (excess uranium) should be a better indication of the source of uranium mineralization.

Approach

The method will be applied to the following three sets of data: 1) the southeast portion of the study area (refered to as the control area); 2) the northeast portion of the study area (refered to as the control test area); and 3) fifty samples collected from an area outside the study area for the NURE program (Grants Special Study).

In the control area, elemental concentrations are known for rock as well as sediment samples. Exposure of the rocks is good, uranium concentrations are elevated in two of the rock units, and they are confined to one side of the drainage. Elemental concentrations for rock samples will be used to confirm or refute sediment data interpretation. Effort will concentrate on finding a graph which will segregate sediment samples collected from the uraniferous side of the drainage.

Once this is accomplished, the same procedure will be applied to the northwestern drainage. In this control test area, rock exposures are very poor. Other than that, the drainage is quite similar to the control area. Effort will be toward improving the sediment data interpretation obtained by examining uranium values alone.

Providing that a better interpretation can be made using procedures established in the control area, the next step is to apply the method to a new area where rock values are unknown. This will be done using the 50 sediment samples from the Grants Special Study. Any anomalous samples will be traced to a location and a geologic map consulted to help determine the cause of the elevated concentration.

APPLICATION OF APPROACH

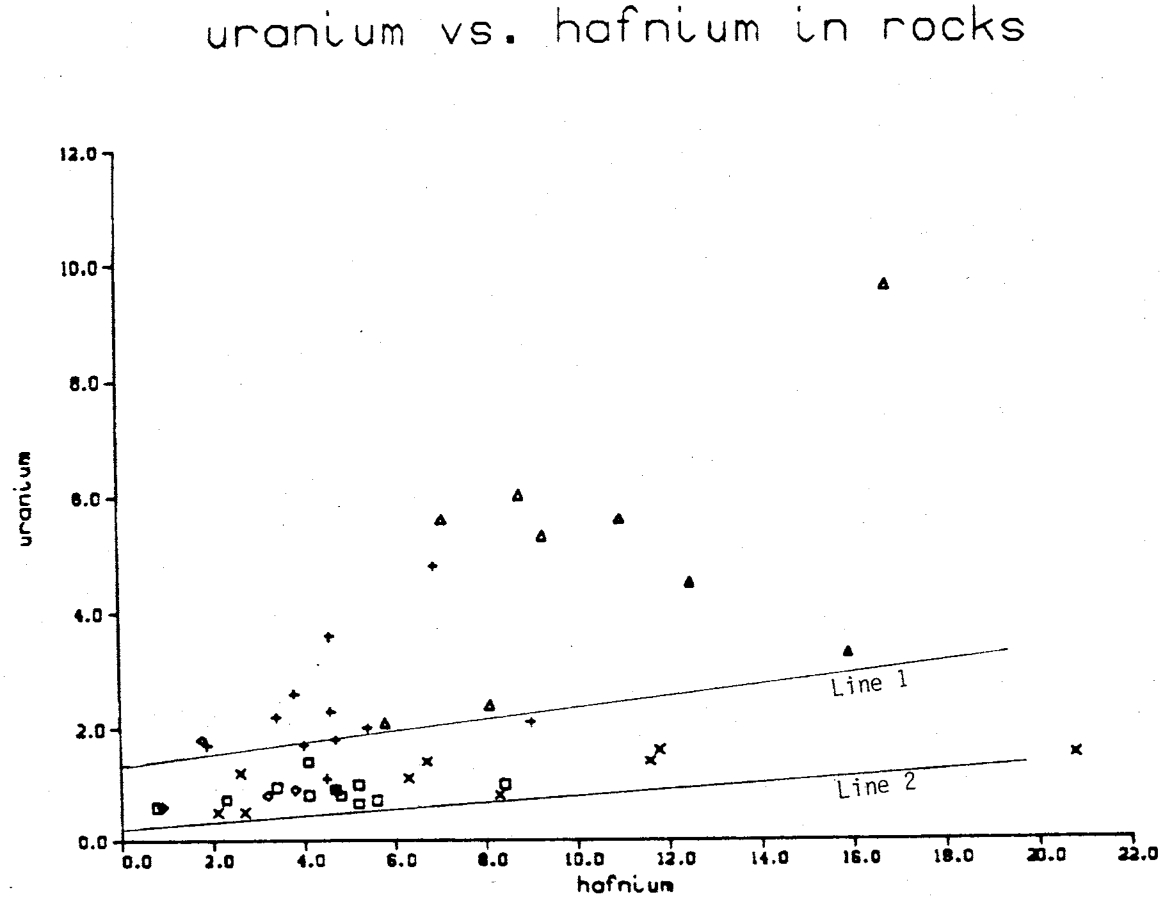
Hafnium and uranium in rocks

Correlation between uranium and hafnium in rocks is insignificant (R^2 = 0.073) probably because uranium is present mostly in the carbonate cement overshadowing the small amount of uranium in zircons. After weathering, the uranium in the cement is largely dissolved, mobilized and removed by runoff. At the same time, zircon is slowly transported due to its higher density. This causes modern sediment samples to have more zircon relative to quartz and feldspar than is found in rock samples. In sediments, the effect of zircons on the total amount of uranium becomes high and for this reason it is good practice to correct for the uranium due to zircon before interpretations are applied.

Figure 11 is a plot of uranium versus hafnium for all rock samples. Each of the five rock units are identified by a different symbol. Rocks containing uranium due mostly to the presence of zircon plot lower and to the right. It can be seen that the two rock units containing the most uranium plot above the others. These two rock units are the Brushy Basin and Westwater Canyon members. Line 1 on the graph is a visual fit; it is not a best fit line but was chosen to separate samples which may contain mineralization. This line is highly subjective and was chosen to separate known uranium mineralized rocks from known non-mineralized rocks. Line 2 on the graph represents an estimate of the minimum amount of uranium due to zircon. It is thought that the area between lines 1 and 2 is populated mostly by samples in which the uranium content is due to the presence of zircon.

Hafnium and uranium in control area sediments

Figure 12 is a plot of uranium versus hafnium for all sediment samples from the southeast portion of the study area. The sample numbers which are circled denote locations downstream from outcrops of the Morrison Formation and should therefore be anomalous. Uranium in the sediments due predominantly to the presence of zircon in the sample plot to the lower right and are from areas where there is no Morrison Formation upstream. Samples which plot further to the upper left indicate that the uranium contained in the sample may be due to uranium



Kd = Cretaceous Dakota Sandstone = □
Jmb = Jurassic Morrison Formation, Brushy Basin member = △
Jmw = Jurassic Morrison Formation, Westwater Canyon member = +
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Jcs = Jurassic Cow Springs Sandstone = x

Figure 11: Graph of uranium versus hafnium for all rock samples from the study area. Lines 1 and 2 are explained in the text.

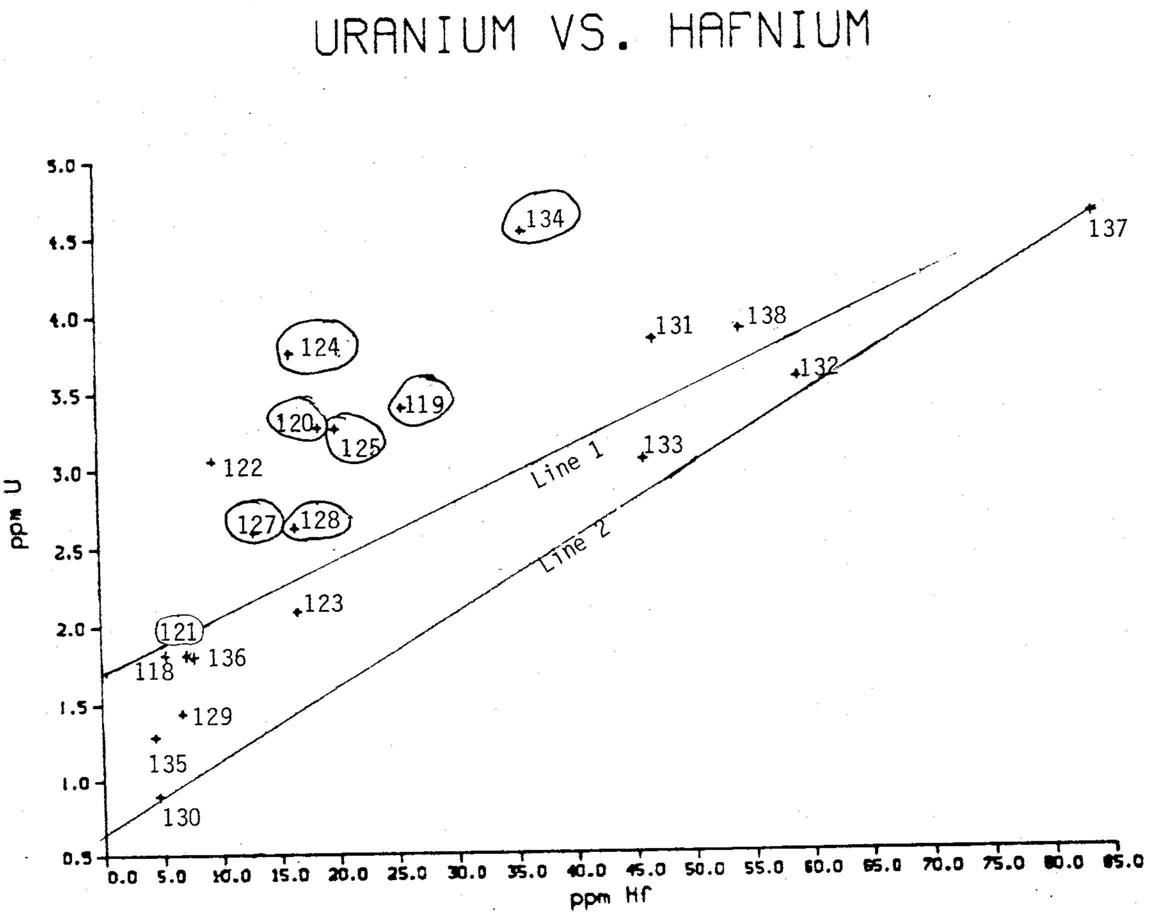

Figure 12: Graph of uranium versus hafnium in sediment samples from the southeast portion (control area) of the study area. Circled sample numbers indicate locations directly downstream from uraniferous outcrops. Lines 1 and 2 are explained in the text.

mineralization which is superimposed on uranium in zircon. The plot indicates that there is a close relation between uranium and hafnium where the uranium is associated with zircon alone and that this relation diminishes where uranium exists due to zircon plus other uranium mineralization. Samples which should be anomalous are clustered in the upper left of the plot, suggesting that other sediment data plotted in this manner could provide a similar segregation. Like Figure 11, line 1 on the graph is an approximate division between samples (above line) which are from streams known to drain uraniferous Morrison Formation, and samples (below line) which were collected from streams draining non-uraniferous rock outcrops. Line 2 is an estimate of the minimum amount of uranium which can be attributed to the presence of zircon in the sample. The lines for rocks (Figure 11) and lines for sediments are quite different from each other. Both sets of lines will be used with the data plots for samples from the control test area to see if they would assist in distinguishing known uraniferous samples. The sediment data from the control test area will next be plotted in the same fashion as the sediment data from the control area.

Hafnium and uranium in control test area sediments

Because plotting uranium versus hafnium appears to identify the primary uranium source in the southeast drainage where outcrops are well exposed, the method was tested in the northwest drainage to see if the poorly exposed uraniferous rocks in that area could be located. In this test, sediment samples from the northwest half of the study area are plotted in Figure 13. The point to the exercise was to determine

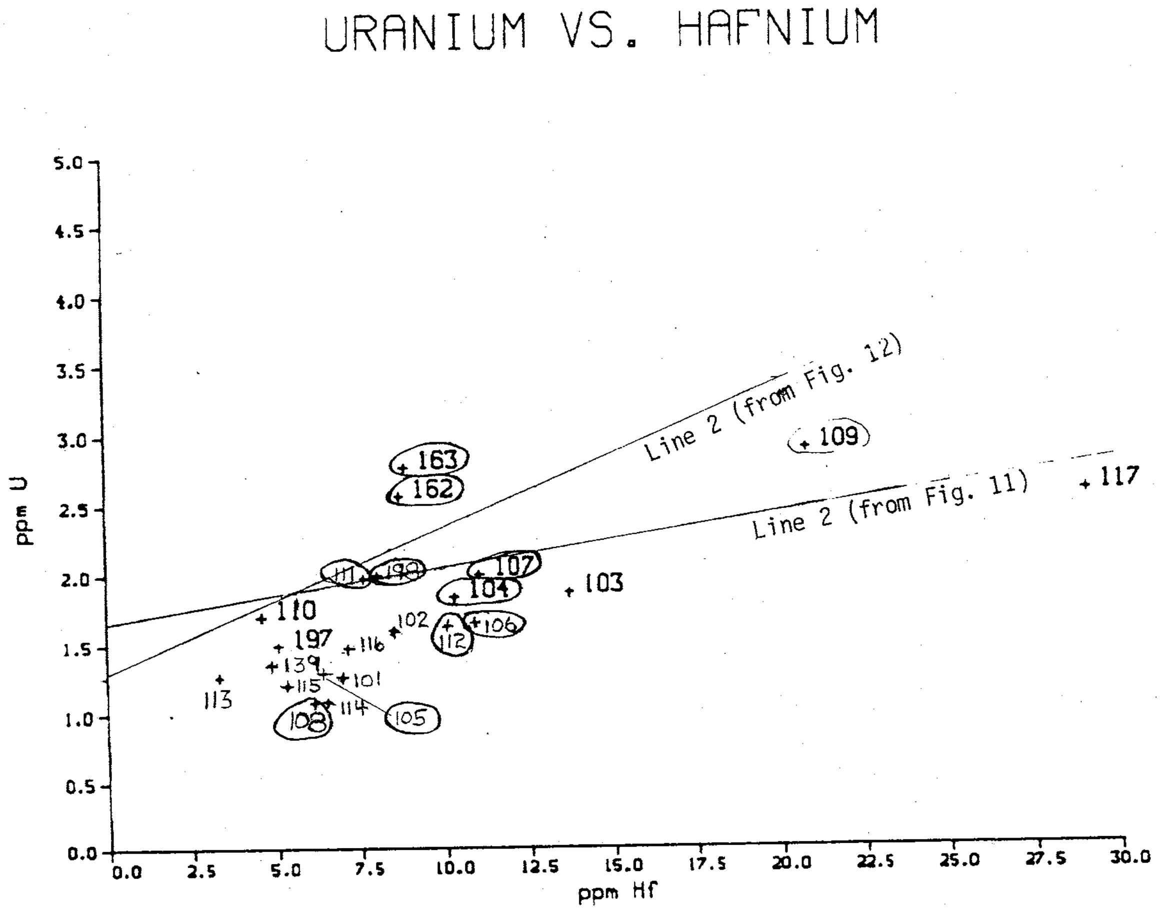

Figure 13: Graph of uranium versus hafnium in sediment samples collected in the northwest portion (control test area) of the study area. Circled sample numbers indicate locations directly downstream from uraniferous outcrops. Lines through the plot are discussed in the text.

if the method would discriminate between known uraniferous areas and non-uraniferous areas. Twelve of the twenty-two sediment samples in the northwest drainage were collected directly downstream from the Morrison Formation and should appear anomalous. Five of the twelve samples could be considered anomalous because they plot on or above the line determined from Figure 12 depicting the upper limit to uranium in sediment due mostly to zircon. This is not a significant improvement over an examination of uranium concentrations alone in which 4 of 12 samples are above average. It should be noted however, that the two sediments collected nearest to outcrops of the Morrison Formation plot furthest to the upper left in Figure 13. These two samples are the only anomalous ones remaining if the interpretation excludes samples below the line from Figure 11 depicting the visual estimate of the upper limit to uranium concentrations in rocks due mostly to zircon. Additionally, only two of the twelve samples which should be anomalous plot near the bottom left, a region normally associated with non-mineralized sediment. The results from this test indicate that there may be only slightly improved interpretation overall for this drainage but also that the two samples which probably contain the most uranium mineralization are well segregated. The criteria used for choosing anomalous samples will determine the percentage of non-mineralized samples omitted from further consideration. In this test area, the criteria used in the control area were applied and the following statements may be made in defense of the results. First, only two sediment samples (162 & 163) were collected very near uraniferous outcrops and they both appear anomalous. It seems that the very small amount of uranium from the outcrop is mobilized and carried away. Second, based on hafnium concentrations, there does not appear to be very much zircon in the samples compared to samples from the control area. Because the gradient is much lower in this area than in the control area, perhaps dilution of outcrop sediment by QOA and aeolian sand becomes a factor. It seems that estimates to minimum and maximum amounts of zircon-related uranium cannot be transfered from area to area. It is probably best to make these estimates for each data set being examined.

Hafnium and uranium outside the study area

An application of this method was made using fifty sediment samples collected for the Grants Special Study (Purson, et al., 1981) and originating from the area around the two drainages previously discussed. A graph of uranium versus hafnium for these samples is provided in Figure 14. The line (#1) through the plot is a visual estimate of the minimum amount of uranium in sediments due mostly to zircon. The four numbered points to the upper left of the plot appear isolated from the other points and contain the most excess uranium. Excess uranium (U_{ex}) for a sample is defined here as total uranium determined by DNC minus the estimated minimum amount of uranium in the sample due to zircon. U_{ex} is found by measuring the perpendicular distance from line 2 to the sample point. The remaining 46 points are assumed to be samples in which most of the uranium is due to zircon and not mineralization. The four isolated samples were located on the field maps used in the Grants Special Study. This was done to see if these samples were collected near a possible source of uranium mineralization such as mine tailings or outcrops of the Morrison

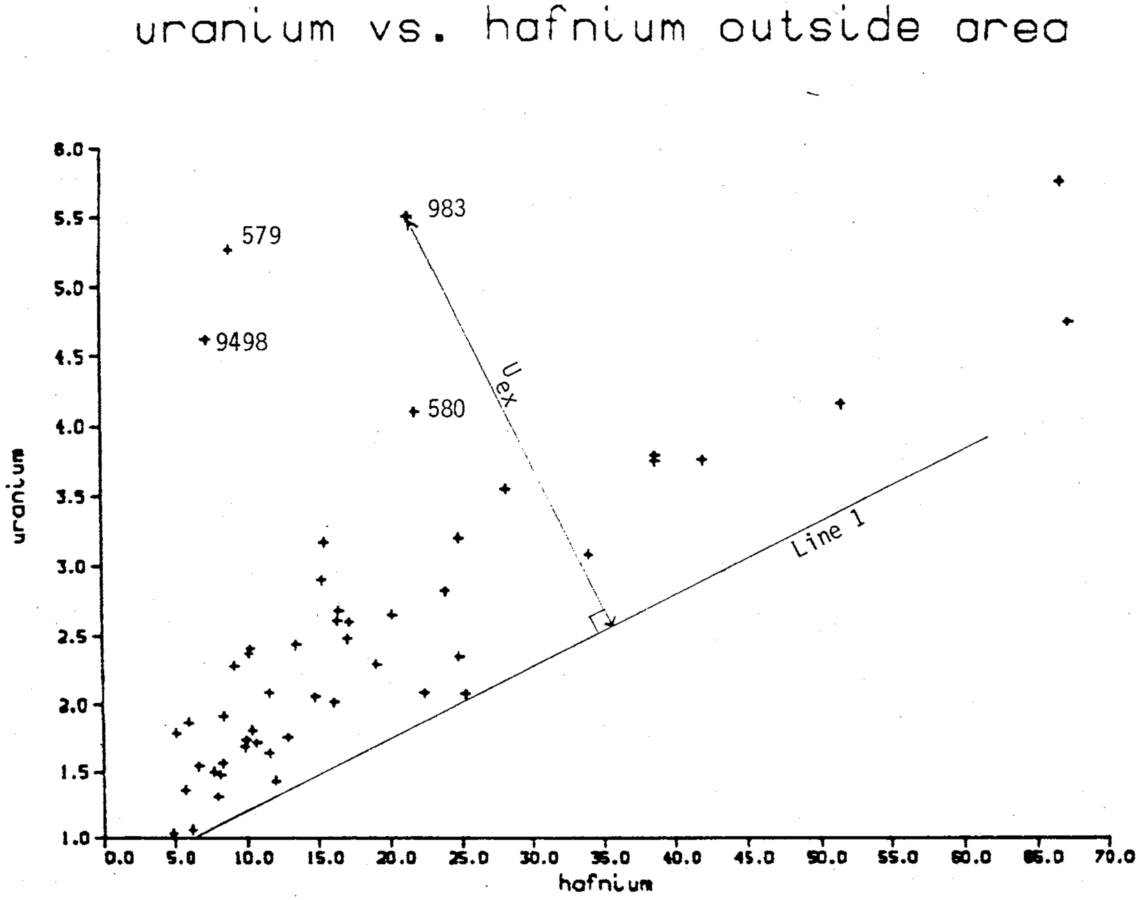

Figure 14: Graph of uranium versus hafnium in 50 sediment samples collected for the Grants Special Study from outside the study area. Numbered data points refer to sample locations identified in the Grants Special Study report and are discussed in the text. Line through the plot is also discussed in the text.

Formation. Samples 579 and 580 were collected about one mile downstream from outcrops of the Morrison Formation about 2 km east of Iyanbito, New Mexico. Sample 983 was collected about 1 km northeast of the present study area from a stream which may be incised deeply enough to expose Morrison Formation under the Dakota Formation dipslope. Sample 9498 was collected near Pinedale, New Mexico from a Puerco River tributary which drains outcrops of the Morrison Formation 3 km upstream.

It seems clear that these four anomalous samples each contain traces of mineralization associated with the Morrison Formation. The proposed exploration method using U/Hf plots appears to be successful when applied to data gathered for a NURE data base. For use with NURE data, it is suggested to calculate U_{ex} from the total uranium and hafnium values which are reported. U_{ex} is a better representation of uranium from mineralized source rock and therefore would provide better indications of areas for more detailed study.

DISCUSSION

If data for a sample collected for a geochemical survey is examined, several interpretation options are available to the explorationist. A common and widely used method is to establish a background concentration for uranium, usually one or two standard deviations above the mean, then choose anomalous samples. Plotting the location of the anomalous samples on a geologic map of the area might show clusters of anomalous samples which would signal that further sampling or investigation of that area is warrented. For NURE studies, an isolated anomalous sample was not considered very important even if surrounding samples were somewhat elevated in uranium content. This situation occurred frequently and it is for the understanding of these samples that the methods examined in this study are beneficial. None of the samples in this study contain large amounts of uranium and they seem quite ordinary when compared to hundreds of samples collected for NURE from around the study area. However, the uranium contents are elevated enough that a more rigorous treatment of the data provides information about the source. The U/Hf plots identify groups of sediment collected downstream from mineralized outcrops. These plots are shown here to be useful in the study area drainage which has outcrops of non-economic mineralized rock. It has also been shown to be useful for 50 samples collected outside the study area. It is certain that this would be an effective treatment for NURE data to define in greater detail areas of potential ore-grade mineralization. At the very least, these methods could delineate areas where uranium has been precipitated and further work might lead to the source. Because uranium is so easily mobilized away from the source rock, it seems odd that NURE studies have relied on uranium concentrations alone for exploration. The multielement approach described here would surely have provided better information on which private industry could follow-up.

RECOMMENDATIONS

Based on the information gathered for this study, several recommendations regarding treatment of existing NURE data are presented.

1) Plot total uranium versus hafnium and visually estimate the minimum amount of uranium in sediments due to zircon. This probably will work best when all the samples come from a similar geologic provinance. Samples containing the most U_{ex} are a good bet to represent samples containing uranium mineralization. Then treat U_{ex} data as would be normal for total uranium.

2) Do not discount the value of a single anomalous sample location. The presence of substantial excess uranium must have some basis and it is doubtful that poor samples or poor analyses is the cause. The author strongly believes that the vast majority of samples reported for NURE are legitimate and that the analyses are good.

3) The sample density of 1 sample per 10 km^2 may be too low to provide indications of anomalies which could lead to substantial quantities of ore-grade mineralization. This is another reason for closely examining an isolated anomalous sample.

4) Detailed follow-up studies based on NURE data and the methods discussed here should include enough rock sample analyses to characterize the outcrops.

V. SUMMARY AND CONCLUSIONS

A total of 115 rock and sediment samples were collected over the 2 square miles of the study area in an effort to understand the mechanisms that influence stream sediment composition collected for uranium exploration at the mouth of a drainage in a sedimentary environment. Uranium, thorium, vanadium, organic carbon, hafnium, and percent -400 mesh in 20 modern sediments were examined to see how best to delineate the upstream source of the uranium. Quaternary older alluvium samples were collected and analyzed, however, the results are not extensively treated in this study. All samples collected were analyzed for 43 additional elements by neutron activation analysis at Los Alamos National Laboratory. Other components of sediment besides uranium that were examined include thorium, vanadium, hafnium, organic carbon, and -400 mesh. Elements in addition to those used in this study are obtained as a part of pre-programmed analysis software and are included in Appendix I for the benefit of completeness.

The study area consists of two drainages. The control area (southwest drainage) was examined most carefully for some technique which would isolate sediment samples collected downstream from known uraniferous outcrops. A successful technique was then tested by applying it to the control test area (northeast drainage) and then to an area outside the study area.

Although sediment samples have a mean uranium content of 2.30 ppm and a range of 0.89 ppm to 4.61 ppm, essentially all of the mobile uranium is in two subunits of the Morrison Formation outcropping on the northeast side of the drainage. Rock samples contain an average of 2.02 ppm uranium and range from 0.23 ppm to 18.32 ppm. Uranium concentrations by themselves do not exclusively define areas from which most of the uranium originates. Some of the higher concentrations are in sediment from the southwest (non-uraniferous) side of the drainage. It would be difficult based on a geographic distribution of uranium in sediment to confidently identify the uranium source. An interesting finding of this study was that a sample collected 3.5 years earlier at the mouth of the drainage contained 230% less uranium than the sample collected at the same location. Perhaps uranium concentrations in sediment are more time dependent than previously thought. More data would be needed to properly address this result, but it seems clear that varying amounts of zircon in the sample due to sampling technique or deposition variations influence the total uranium concentrations significantly.

Because organic carbon is an effective scavenger of mobile uranium, it would be important to correct for this effect if there were significant amounts of uranium trapped with carbon in sediment. The correlation between uranium and carbon content is poor in sediments and the geographic distribution of carbon does not appear to influence interpretation of the uranium data. Fine and clay sized particles are capable of adsorbing uranium and the effect of this mechanism was examined by comparing uranium with the -400 mesh fraction. As with organic carbon, the correlation between uranium and -400 mesh is low and the data do not appear to be useful for locating the uranium source.

Examination of thorium-to-uranium ratios did not provide a means by which to discriminate uranium-bearing source rocks from barren areas. Thorium values increase near uranium-bearing rock units, but the range of concentrations becomes so small downstream that it would be difficult to locate a uranium source using that data alone. The use of thorium for locating uranium mineralization is best in other geologic terranes which have substantial quantities of uranium-bearing monazite.

Except for a few samples, vanadium and uranium correlate well. The few samples which contain the largest amounts of vanadium are from locations away from the Morrison Formation. This leads to considerable confusion when examining a geographic distribution and for this reason, vanadium by itself was not a useful pathfinder element. Hafnium was studied because uranium is known to occur in zircon which has a significant hafnium content. It was reasoned that uranium exists in two forms in the study area: mobile, as in a carbonate cement; and immobile, as bound in a resistate mineral, mostly zircon. Analyses yielded data regarding total uranium and the distinction between mobile or bound uranium is important because only the mobile uranium can indicate ore deposits in the region. When uranium is plotted against hafnium, sediments originating directly downstream from the Morrison Formation group together. Because this method worked well in the control area, it was tried in the control test area. Although not as successful as it was in the control area, two samples collected very near the Morrison Formation were segregated. The method was then applied to 50 samples collected outside the study area for the Grants Special Study. Four samples were considered anomalous and all of them were subsequently found to originate from streams draining outcrops of the Morrison Formation.

This method works well here and probably can be applied successfully elsewhere. By using U/Hf plots, new areas for detailed study can be delineated utilizing existing data in NURE reports. Combining uranium data with U/Hf plots the number of false anomalies should be reduced significantly. Uranium concentrations in sediment best reflect a high uranium content in their source rocks only when a correction is applied for the amount of zircon in the sample. Such a correction would allow the application with greater confidence of a larger portion of a sediment data base such as had been used in the NURE program.

The employment of uranium concentrations alone in sediment as was done for NURE is somewhat useful but represents only one facet of a complex system which can be useful for discovery of new uranium resources.

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Appendix I

Listings of elemental concentrations for samples from the study area in McKinley County, New Mexico. These tables are computer generated data from the INAA facilities at Los Alamos National Laboratory. The analyses for W, Co, and Ta (in Appendix I-A only) are meaningless as the samples were contaminated by grinding in a tungsten carbide swing mill. The quality of the data for other elements is variable and can be determined by examining Appendix I-D which contains analyses of standards.

Appendix I-A: Elemental concentrations in rock samples

KEY:

In left hand column, elemental symbol is followed by the isotope used to determine concentration for that element.

Sample identification - Where used, letters designate rock unit and numbers denote sample location (Appendix II).

kd-xxx = Cretaceous Dakota Sandstone
jmb-xxx = Jurassic Morrison Formation, Brushy Basin member
jmw-xxx = Jurassic Morrison Formation, Westwater Canyon member
jmr-xxx = Jurassic Morrison Formation, Recapture Creek member
jcs-xxx = Jurassic Cow Springs Sandstone
jt-xxx = Jurassic Todilto Limestone

	kd-140	kd-189	kd-145
Na- 24	1418 ± 44	1009 ± 33	2181 ± 61
Mg- 27	< 510	570 ± 170	< 680
Al- 28	24010 ± 890	19510 ± 760	23770 ± 880
Cl- 38	< 16	< 14	< 21
K - 42	13260 ± 890	8040 ± 700	16900 ± 1000
Ca- 49	2020 ± 430	640 ± 230	< 240
Ti- 51	648 ± 60	578 ± 54	657 ± 62
V - 52	10.7 ± 1.2	23.5 ± 1.6	8.0 ± 1.2
Mn- 56	14.73 ± 0.50	16.56 ± 0.53	9.01 ± 0.34
Sr- 87	< 49	< 41	< 54
Ba-139	334 ± 20	187 ± 14	427 ± 23
Dy-165	1.231 ± 0.094	0.807 ± 0.073	1.053 ± 0.077
U -235	0.911 ± 0.026	0.938 ± 0.026	0.787 ± 0.022
Ga- 72	< 4.9	< 4.0	< 6.1
As- 76	2.85 ± 0.21	6.12 ± 0.28	1.46 ± 0.19
Br- 82	< 0.60	< 0.48	< 0.72
Sb-122	< 0.12	0.128 ± 0.050	< 0.15
La-140	7.97 ± 0.31	6.34 ± 0.25	7.43 ± 0.28
Sm-153	0.865 ± 0.045	0.695 ± 0.030	0.861 ± 0.040
Yb-175	0.651 ± 0.074	0.609 ± 0.074	0.807 ± 0.077
W -187	~~0.78 ± 0.25~~	~~0.90 ± 0.19~~	~~< 0.80~~
Sc- 46	1.384 ± 0.026	1.188 ± 0.023	1.057 ± 0.020
Cr- 51	4.65 ± 0.47	3.71 ± 0.39	8.52 ± 0.54
Fe- 59	2631 ± 84	2337 ± 75	1493 ± 57
Co- 60	~~1.026 ± 0.074~~	~~2.69 ± 0.11~~	~~0.802 ± 0.059~~
Zn- 65	< 4.0	9.9 ± 2.0	4.3 ± 2.1
Rb- 86	65.4 ± 4.4	28.5 ± 2.7	81.6 ± 4.5
Zr- 95	138 ± 22	115 ± 20	125 ± 22
Sb-124	< 0.21	< 0.20	< 0.20
Cs-134	2.59 ± 0.16	2.61 ± 0.16	2.14 ± 0.13
Ce-141	20.04 ± 0.74	11.06 ± 0.43	21.52 ± 0.71
Nd-147	< 4.6	< 3.3	10.4 ± 2.7
Eu-152	0.349 ± 0.038	0.196 ± 0.027	0.330 ± 0.034
Tb-160	0.215 ± 0.051	0.098 ± 0.032	0.178 ± 0.032
Lu-177	0.165 ± 0.011	0.0784 ± 0.0075	0.192 ± 0.011
Hf-181	4.75 ± 0.15	3.43 ± 0.12	4.84 ± 0.14
Ta-182	~~0.423 ± 0.080~~	~~0.174 ± 0.053~~	~~0.325 ± 0.061~~
Th-233	2.531 ± 0.096	1.674 ± 0.070	2.86 ± 0.10

	kd-190	kd-192	kd-182
Na- 24	790 ± 28	1954 ± 55	1821 ± 53
Mg- 27	940 ± 220	800 ± 180	< 520
Al- 28	16790 ± 670	18930 ± 740	20490 ± 780
Cl- 38	61.0 ± 8.0	30.3 ± 9.3	18.8 ± 6.3
K - 42	7480 ± 690	9820 ± 760	13470 ± 930
Ca- 49	1040 ± 250	1900 ± 430	< 210
Ti- 51	917 ± 66	713 ± 63	382 ± 49
V - 52	7.28 ± 0.95	7.19 ± 1.00	16.5 ± 1.5
Mn- 56	11.59 ± 0.42	23.44 ± 0.70	14.22 ± 0.47
Sr- 87	< 45	< 51	< 45
Ba-139	157 ± 14	424 ± 23	332 ± 19
Dy-165	0.921 ± 0.087	0.965 ± 0.086	1.077 ± 0.084
U -235	1.013 ± 0.028	0.647 ± 0.018	0.720 ± 0.020
Ga- 72	< 5.2	< 5.2	< 4.9
As- 76	1.27 ± 0.16	1.07 ± 0.14	6.17 ± 0.29
Br- 82	< 0.62	< 0.62	< 0.57
Sb-122	< 0.13	< 0.13	< 0.12
La-140	7.25 ± 0.30	7.50 ± 0.29	6.94 ± 0.27
Sm-153	0.884 ± 0.041	0.772 ± 0.036	0.846 ± 0.036
Yb-175	0.786 ± 0.084	0.461 ± 0.060	0.655 ± 0.075
W -187	~~1.96 ± 0.41~~	~~1.27 ± 0.29~~	~~1.24 ± 0.36~~
Sc- 46	1.980 ± 0.036	1.344 ± 0.024	0.875 ± 0.017
Cr- 51	12.74 ± 0.76	6.16 ± 0.50	2.19 ± 0.34
Fe- 59	4170 ± 120	2999 ± 87	2679 ± 78
Co- 60	~~0.935 ± 0.078~~	~~0.713 ± 0.060~~	~~0.746 ± 0.059~~
Zn- 65	< 2.1	< 2.8	< 2.3
Rb- 86	40.7 ± 3.7	53.0 ± 3.6	53.4 ± 3.5
Zr- 95	320 ± 45	177 ± 29	147 ± 23
Sb-124	< 0.36	< 0.20	< 0.19
Cs-134	2.36 ± 0.18	1.49 ± 0.13	2.18 ± 0.14
Ce-141	19.76 ± 0.75	19.23 ± 0.71	12.42 ± 0.46
Nd-147	15.0 ± 4.6	9.5 ± 2.3	< 3.1
Eu-152	0.321 ± 0.042	0.295 ± 0.034	0.305 ± 0.031
Tb-160	0.221 ± 0.049	< 0.22	0.172 ± 0.036
Lu-177	0.185 ± 0.013	0.1361 ± 0.0098	0.1001 ± 0.0075
Hf-181	8.35 ± 0.23	5.20 ± 0.15	2.266 ± 0.086
Ta-182	~~0.282 ± 0.072~~	~~0.317 ± 0.064~~	~~0.197 ± 0.050~~
Th-233	3.48 ± 0.13	2.697 ± 0.100	1.628 ± 0.067

	kd-141-a	kd-141-b	kd-142-a
Na- 24	454 ± 20	493 ± 22	589 ± 24
Mg- 27	1710 ± 230	1070 ± 210	< 350
Al- 28	15280 ± 630	16310 ± 690	7740 ± 420
Cl- 38	31.1 ± 6.0	< 15	< 11.1
K - 42	6950 ± 630	7960 ± 680	5080 ± 510
Ca- 49	2660 ± 480	1160 ± 320	550 ± 170
Ti- 51	834 ± 68	978 ± 78	796 ± 64
V - 52	12.8 ± 1.3	9.7 ± 1.1	9.0 ± 1.1
Mn- 56	52.2 ± 1.4	18.39 ± 0.61	27.99 ± 0.81
Sr- 87	< 56	< 53	< 43
Ba-139	180 ± 14	148 ± 15	98 ± 11
Dy-165	1.130 ± 0.079	0.785 ± 0.086	0.957 ± 0.078
U -235	1.369 ± 0.038	1.228 ± 0.034	0.665 ± 0.019
Ga- 72	< 3.8	< 5.0	< 3.5
As- 76	3.49 ± 0.20	0.92 ± 0.24	0.78 ± 0.13
Br- 82	1.92 ± 0.16	< 0.99	< 0.44
Sb-122	0.219 ± 0.044	< 0.22	< 0.099
La-140	7.67 ± 0.28	7.57 ± 0.31	6.91 ± 0.28
Sm-153	1.032 ± 0.043	0.649 ± 0.031	0.817 ± 0.038
Yb-175	0.724 ± 0.063	0.64 ± 0.12	0.526 ± 0.055
W -187	~~13.7 ± 2.1~~	~~305 ± 46~~	~~< 0.50~~
Sc- 46	2.147 ± 0.036	2.328 ± 0.042	1.150 ± 0.022
Cr- 51	11.19 ± 0.60	15.8 ± 1.1	8.33 ± 0.59
Fe- 59	6760 ± 140	6880 ± 170	3209 ± 93
Co- 60	~~3.47 ± 0.12~~	~~40.39 ± 0.73~~	~~0.605 ± 0.056~~
Zn- 65	9.1 ± 2.1	< 3.0	< 1.8
Rb- 86	31.2 ± 2.9	28.8 ± 4.6	20.7 ± 2.4
Zr- 95	135 ± 25	150 ± 39	157 ± 27
Sb-124	< 0.28	< 0.45	< 0.25
Cs-134	2.46 ± 0.15	2.70 ± 0.22	0.697 ± 0.086
Ce-141	18.74 ± 0.64	19.92 ± 0.80	19.05 ± 0.70
Nd-147	< 4.1	< 9.8	< 4.0
Eu-152	0.380 ± 0.037	0.262 ± 0.039	0.262 ± 0.036
Tb-160	0.188 ± 0.033	< 0.24	0.235 ± 0.038
Lu-177	0.161 ± 0.010	0.134 ± 0.014	0.144 ± 0.010
Hf-181	4.12 ± 0.12	5.37 ± 0.18	5.70 ± 0.17
Ta-182	~~0.333 ± 0.066~~	~~2.36 ± 0.22~~	~~0.290 ± 0.065~~
Th-233	2.652 ± 0.095	3.07 ± 0.13	2.487 ± 0.095

NOTE:

kd-141-a and kd-141-b were collected within 5 meters of each other from the same stratigraphic horizon.

kd-142-a thru kd-142-e all were collected within a 10 meter radius and are from three slightly different stratigraphic horizons.

	kd-142-b	kd-142-c	kd-142-d
Na- 24	492 ± 20	511 ± 20	530 ± 21
Mg- 27	700 ± 130	590 ± 140	< 380
Al- 28	6810 ± 390	7590 ± 410	7590 ± 390
Cl- 38	24.2 ± 7.0	26.5 ± 6.0	22.1 ± 5.4
K - 42	4740 ± 480	4810 ± 480	4200 ± 470
Ca- 49	3930 ± 600	2150 ± 430	2240 ± 390
Ti- 51	966 ± 67	969 ± 66	959 ± 68
V - 52	6.03 ± 0.89	8.6 ± 1.0	6.70 ± 0.86
Mn- 56	21.14 ± 0.63	25.61 ± 0.74	26.08 ± 0.76
Sr- 87	< 36	< 43	< 44
Ba-139	113 ± 12	108 ± 11	116 ± 12
Dy-165	1.282 ± 0.087	1.184 ± 0.079	0.997 ± 0.079
U -235	0.688 ± 0.019	0.788 ± 0.022	0.729 ± 0.020
Ga- 72	< 3.3	< 3.6	< 4.2
As- 76	0.790 ± 0.099	1.13 ± 0.14	1.42 ± 0.18
Br- 82	0.45 ± 0.11	< 0.56	< 0.30
Sb-122	< 0.083	0.172 ± 0.032	< 0.11
La-140	7.17 ± 0.28	7.14 ± 0.27	7.67 ± 0.29
Sm-153	0.909 ± 0.036	0.987 ± 0.041	0.833 ± 0.037
Yb-175	0.538 ± 0.056	0.726 ± 0.058	0.692 ± 0.083
W -187	~~< 0.42~~	~~12.1 ± 1.9~~	~~8.3 ± 1.3~~
Sc- 46	0.980 ± 0.019	1.092 ± 0.020	1.229 ± 0.023
Cr- 51	6.04 ± 0.49	8.96 ± 0.50	8.44 ± 0.61
Fe- 59	1892 ± 64	2621 ± 73	3264 ± 95
Co- 60	~~0.655 ± 0.056~~	~~2.206 ± 0.090~~	~~1.538 ± 0.086~~
Zn- 65	< 2.8	< 2.7	< 1.2
Rb- 86	15.9 ± 2.1	19.4 ± 2.0	19.4 ± 2.3
Zr- 95	177 ± 27	233 ± 30	276 ± 36
Sb-124	< 0.17	< 0.21	< 0.24
Cs-134	0.590 ± 0.081	0.794 ± 0.075	1.17 ± 0.11
Ce-141	13.18 ± 0.49	18.18 ± 0.60	21.67 ± 0.80
Nd-147	11.0 ± 3.6	< 3.6	11.9 ± 3.4
Eu-152	0.204 ± 0.027	0.297 ± 0.031	0.226 ± 0.033
Tb-160	0.218 ± 0.044	0.251 ± 0.044	0.246 ± 0.042
Lu-177	0.0989 ± 0.0080	0.1663 ± 0.0096	0.168 ± 0.011
Hf-181	5.56 ± 0.16	6.67 ± 0.17	7.44 ± 0.21
Ta-182	~~0.321 ± 0.066~~	~~0.423 ± 0.072~~	~~0.462 ± 0.074~~
Th-233	2.081 ± 0.081	2.401 ± 0.086	2.60 ± 0.10

	kd-142-e	kd-143	kd-144
Na- 24	534 ± 22	638 ± 27	2482 ± 69
Mg- 27	610 ± 150	< 350	< 750
Al- 28	7680 ± 450	9120 ± 530	27030 ± 970
Cl- 38	26.9 ± 7.6	< 11.9	< 23
K - 42	4610 ± 480	6300 ± 620	18700 ± 1100
Ca- 49	2070 ± 400	1640 ± 410	710 ± 220
Ti- 51	1132 ± 72	215 ± 38	519 ± 57
V - 52	8.1 ± 1.1	4.38 ± 0.74	9.1 ± 1.1
Mn- 56	29.30 ± 0.85	8.47 ± 0.34	13.30 ± 0.47
Sr- 87	< 45	< 33	< 61
Ba-139	101 ± 12	132 ± 12	452 ± 23
Dy-165	1.301 ± 0.094	0.667 ± 0.055	1.071 ± 0.084
U -235	0.946 ± 0.026	0.603 ± 0.017	0.843 ± 0.024
Ga- 72	< 3.7	< 3.3	< 7.0
As- 76	1.65 ± 0.22	1.91 ± 0.17	1.15 ± 0.17
Br- 82	< 0.44	0.43 ± 0.12	< 0.78
Sb-122	< 0.093	0.165 ± 0.038	< 0.16
La-140	8.10 ± 0.32	6.12 ± 0.25	7.73 ± 0.30
Sm-153	1.011 ± 0.049	0.722 ± 0.031	0.923 ± 0.041
Yb-175	0.805 ± 0.066	0.406 ± 0.060	0.763 ± 0.091
W -187	~~< 0.50~~	~~< 0.46~~	~~1.35 ± 0.42~~
Sc- 46	1.517 ± 0.027	0.607 ± 0.013	1.157 ± 0.022
Cr- 51	14.38 ± 0.76	4.20 ± 0.46	5.59 ± 0.51
Fe- 59	2930 ± 88	2857 ± 83	2017 ± 69
Co- 60	~~0.822 ± 0.062~~	~~0.545 ± 0.052~~	~~0.919 ± 0.064~~
Zn- 65	< 2.3	7.0 ± 1.6	< 3.1
Rb- 86	20.3 ± 2.5	20.5 ± 2.2	88.7 ± 4.8
Zr- 95	433 ± 45	53 ± 15	160 ± 29
Sb-124	< 0.27	< 0.148	< 0.27
Cs-134	0.94 ± 0.11	1.17 ± 0.11	2.83 ± 0.16
Ce-141	23.88 ± 0.86	12.11 ± 0.45	20.26 ± 0.69
Nd-147	< 5.3	< 2.8	8.0 ± 1.9
Eu-152	0.280 ± 0.037	0.256 ± 0.028	0.376 ± 0.040
Tb-160	0.206 ± 0.047	0.116 ± 0.027	0.177 ± 0.034
Lu-177	0.216 ± 0.013	0.0538 ± 0.0066	0.152 ± 0.010
Hf-181	14.26 ± 0.34	0.805 ± 0.050	4.19 ± 0.13
Ta-182	~~0.512 ± 0.080~~	~~< 0.101~~	~~0.246 ± 0.056~~
Th-233	4.11 ± 0.14	1.200 ± 0.056	2.755 ± 0.099

	kd-174	jmb-205-a	jmb-205-b
Na- 24	485 ± 20	7350 ± 180	2765 ± 80
Mg- 27	850 ± 190	7340 ± 950	11830 ± 710
Al- 28	18140 ± 690	50300 ± 1800	87300 ± 2500
Cl- 38	28.6 ± 5.2	< 65	< 30
K - 42	5900 ± 580	17500 ± 1700	17200 ± 1300
Ca- 49	2790 ± 480	23400 ± 1900	13000 ± 1300
Ti- 51	724 ± 58	990 ± 230	3210 ± 180
V - 52	12.7 ± 1.3	18.8 ± 3.2	44.3 ± 3.1
Mn- 56	27.90 ± 0.81	1402 ± 32	179.9 ± 4.5
Sr- 87	< 49	< 290	< 120
Ba-139	144 ± 14	744 ± 74	369 ± 28
Dy-165	1.26 ± 0.11	1.92 ± 0.24	6.62 ± 0.32
U -235	1.045 ± 0.029	2.059 ± 0.058	5.97 ± 0.17
Ga- 72	< 4.2	< 10.8	< 9.0
As- 76	3.94 ± 0.25	< 0.90	< 0.86
Br- 82	0.76 ± 0.15	< 1.19	3.85 ± 0.47
Sb-122	< 0.12	0.292 ± 0.080	< 0.28
La-140	7.79 ± 0.30	14.59 ± 0.48	43.9 ± 1.2
Sm-153	0.889 ± 0.042	2.075 ± 0.093	6.51 ± 0.24
Yb-175	0.813 ± 0.078	1.23 ± 0.15	3.52 ± 0.19
W -187	~~27.3 ± 4.2~~	~~< 1.29~~	~~6.8 ± 1.1~~
Sc- 46	2.261 ± 0.038	3.976 ± 0.064	8.73 ± 0.13
Cr- 51	9.29 ± 0.73	7.25 ± 0.80	38.5 ± 1.5
Fe- 59	6270 ± 140	37900 ± 570	18850 ± 320
Co- 60	~~5.06 ± 0.16~~	~~5.32 ± 0.16~~	~~5.62 ± 0.10~~
Zn- 65	31.7 ± 3.6	39.6 ± 4.5	39.3 ± 5.0
Rb- 86	35.4 ± 4.0	85.6 ± 5.7	95.6 ± 6.1
Zr- 95	189 ± 40	256 ± 53	329 ± 61
Sb-124	< 0.32	< 0.40	< 0.53
Cs-134	3.35 ± 0.20	4.91 ± 0.27	21.18 ± 0.83
Ce-141	22.83 ± 0.87	39.8 ± 1.4	77.9 ± 2.3
Nd-147	20.3 ± 5.8	18.0 ± 4.2	34.8 ± 6.4
Eu-152	0.358 ± 0.041	0.781 ± 0.059	1.457 ± 0.090
Tb-160	0.218 ± 0.051	0.377 ± 0.069	0.89 ± 0.11
Lu-177	0.188 ± 0.013	0.255 ± 0.017	0.535 ± 0.027
Hf-181	5.16 ± 0.17	5.79 ± 0.19	8.83 ± 0.26
Ta-182	~~0.384 ± 0.071~~	~~0.61 ± 0.13~~	~~1.72 ± 0.20~~
Th-233	2.76 ± 0.11	5.53 ± 0.18	13.26 ± 0.38

NOTE:

jmb-205-a was collected from a thin outcrop of greenish-blue siltstone.

jmb-205-b was collected adjacent to jmb-205-a from a weathered exposure of claystone.

	jmb-165	jmb-167	jmb-147
Na- 24	4550 ± 120	4930 ± 120	2651 ± 82
Mg- 27	14420 ± 810	8780 ± 600	11660 ± 820
Al- 28	57300 ± 1900	73600 ± 2100	87500 ± 2700
Cl- 38	< 48	152 ± 16	< 35
K - 42	12500 ± 1300	21000 ± 1400	22700 ± 1800
Ca- 49	4490 ± 800	9700 ± 1000	11600 ± 1300
Ti- 51	2880 ± 190	2960 ± 160	2960 ± 200
V - 52	36.4 ± 3.2	56.7 ± 3.2	66.3 ± 4.5
Mn- 56	479 ± 12	111.0 ± 2.9	368.0 ± 8.8
Sr- 87	< 190	< 120	< 180
Ba-139	588 ± 38	398 ± 30	626 ± 45
Dy-165	5.05 ± 0.30	5.26 ± 0.28	6.74 ± 0.39
U -235	3.316 ± 0.093	9.59 ± 0.27	5.55 ± 0.16
Ga- 72	8.8 ± 2.7	< 13	< 10.5
As- 76	1.50 ± 0.26	1.59 ± 0.43	< 1.08
Br- 82	< 1.6	8.38 ± 0.52	< 1.8
Sb-122	< 0.28	0.47 ± 0.16	< 0.24
La-140	30.87 ± 0.86	49.2 ± 1.3	37.0 ± 1.1
Sm-153	4.45 ± 0.17	6.25 ± 0.24	5.41 ± 0.25
Yb-175	2.97 ± 0.18	3.38 ± 0.21	3.25 ± 0.21
W -187	~~79 ± 12~~	~~16.1 ± 2.5~~	~~77 ± 12~~
Sc- 46	7.73 ± 0.12	9.43 ± 0.14	14.15 ± 0.21
Cr- 51	26.7 ± 1.4	61.3 ± 2.0	18.7 ± 1.5
Fe- 59	101400 ± 1300	24930 ± 420	30040 ± 510
Co- 60	~~19.47 ± 0.39~~	~~6.94 ± 0.22~~	~~9.37 ± 0.28~~
Zn- 65	88.9 ± 7.4	41.0 ± 6.2	< 10
Rb- 86	76.3 ± 7.0	98.6 ± 6.8	143.7 ± 9.8
Zr- 95	654 ± 80	509 ± 71	400 ± 83
Sb-124	< 0.58	< 0.60	< 0.76
Cs-134	6.28 ± 0.35	18.27 ± 0.73	40.3 ± 1.5
Ce-141	61.8 ± 1.9	144.4 ± 4.3	106.9 ± 3.5
Nd-147	35.9 ± 8.4	51.2 ± 9.6	< 13
Eu-152	1.184 ± 0.076	1.64 ± 0.10	1.55 ± 0.11
Tb-160	1.07 ± 0.16	2.09 ± 0.19	0.81 ± 0.14
Lu-177	0.673 ± 0.030	0.790 ± 0.036	0.836 ± 0.042
Hf-181	15.86 ± 0.38	16.80 ± 0.42	10.97 ± 0.33
Ta-182	~~1.56 ± 0.17~~	~~1.64 ± 0.20~~	~~1.74 ± 0.21~~
Th-233	10.84 ± 0.31	15.83 ± 0.46	17.57 ± 0.51

	jmb-146	jmb-149	jmb-204
Na- 24	3950 ± 110	5050 ± 140	5900 ± 160
Mg- 27	11600 ± 790	7860 ± 720	< 3600
Al- 28	71100 ± 2200	48800 ± 1800	45300 ± 1900
Cl- 38	< 38	< 78	< 116
K - 42	19300 ± 1400	16400 ± 2100	14600 ± 3000
Ca- 49	8300 ± 1100	69100 ± 3900	47900 ± 3300
Ti- 51	2320 ± 170	1610 ± 300	< 1300
V - 52	70.9 ± 4.2	14.0 ± 2.5	< 15
Mn- 56	283.3 ± 6.8	1554 ± 36	2914 ± 67
Sr- 87	< 140	< 350	< 510
Ba-139	549 ± 39	562 ± 64	< 260
Dy-165	4.45 ± 0.27	3.48 ± 0.29	2.86 ± 0.63
U -235	5.29 ± 0.15	2.558 ± 0.072	2.447 ± 0.069
Ga- 72	13.1 ± 3.5	< 11.8	< 13
As- 76	< 0.93	< 1.02	< 1.13
Br- 82	< 1.6	< 1.8	< 0.39
Sb-122	< 0.25	< 0.28	< 0.31
La-140	31.73 ± 0.92	21.99 ± 0.68	25.05 ± 0.75
Sm-153	4.68 ± 0.18	3.57 ± 0.14	3.26 ± 0.13
Yb-175	2.23 ± 0.17	2.40 ± 0.17	2.40 ± 0.18
W -187	~~39.6 ± 6.0~~	~~85 ± 13~~	~~65.0 ± 9.9~~
Sc- 46	7.44 ± 0.11	5.925 ± 0.089	5.301 ± 0.085
Cr- 51	35.3 ± 1.4	15.7 ± 1.2	15.3 ± 1.1
Fe- 59	22120 ± 380	22900 ± 370	18510 ± 330
Co- 60	~~7.33 ± 0.23~~	~~14.08 ± 0.32~~	~~11.06 ± 0.29~~
Zn- 65	73.2 ± 6.1	39.0 ± 4.7	35.2 ± 4.8
Rb- 86	90.7 ± 6.4	93.0 ± 6.2	95.9 ± 6.9
Zr- 95	282 ± 49	231 ± 51	200 ± 44
Sb-124	< 0.51	< 0.52	< 0.55
Cs-134	22.15 ± 0.86	15.45 ± 0.62	11.52 ± 0.51
Ce-141	65.7 ± 2.0	57.7 ± 1.8	72.2 ± 2.3
Nd-147	29.0 ± 8.0	38.7 ± 7.9	33.7 ± 7.7
Eu-152	1.119 ± 0.083	1.128 ± 0.077	0.886 ± 0.070
Tb-160	0.82 ± 0.12	0.672 ± 0.093	0.570 ± 0.081
Lu-177	0.369 ± 0.023	0.481 ± 0.024	0.577 ± 0.030
Hf-181	9.25 ± 0.27	7.14 ± 0.21	8.06 ± 0.24
Ta-182	~~1.60 ± 0.17~~	~~1.15 ± 0.15~~	~~1.08 ± 0.17~~
Th-233	10.70 ± 0.32	9.24 ± 0.28	7.63 ± 0.24

	jmb-165	jmw-148	jmw-166
Na- 24	3192 ± 89	8320 ± 200	10890 ± 260
Mg- 27	10320 ± 690	< 1100	< 1500
Al- 28	85300 ± 2600	50600 ± 1600	54100 ± 1700
Cl- 38	< 32	158 ± 16	< 49
K - 42	23600 ± 1700	24200 ± 1400	23600 ± 1400
Ca- 49	14100 ± 1400	8160 ± 920	1620 ± 440
Ti- 51	2820 ± 190	780 ± 110	920 ± 110
V - 52	28.6 ± 2.4	19.7 ± 1.9	26.6 ± 2.2
Mn- 56	236.4 ± 5.9	91.0 ± 2.4	52.0 ± 1.4
Sr- 87	< 140	< 99	< 110
Ba-139	891 ± 48	653 ± 34	684 ± 35
Dy-165	5.21 ± 0.32	1.50 ± 0.12	2.00 ± 0.14
U -235	4.53 ± 0.13	1.700 ± 0.048	2.175 ± 0.061
Ga- 72	12.3 ± 3.8	< 10.8	< 14
As- 76	1.36 ± 0.24	2.26 ± 0.28	1.87 ± 0.29
Br- 82	< 2.3	< 1.17	< 1.53
Sb-122	< 0.26	< 0.24	0.272 ± 0.075
La-140	39.8 ± 1.1	16.48 ± 0.53	18.40 ± 0.57
Sm-153	5.17 ± 0.24	1.876 ± 0.069	2.222 ± 0.091
Yb-175	3.49 ± 0.21	0.607 ± 0.100	1.12 ± 0.16
W -187	~~20.7 ± 3.2~~	~~< 1.29~~	~~< 1.68~~
Sc- 46	11.50 ± 0.17	1.276 ± 0.023	1.884 ± 0.032
Cr- 51	11.8 ± 1.6	6.18 ± 0.57	6.17 ± 0.67
Fe- 59	27830 ± 450	4780 ± 110	4590 ± 110
Co- 60	~~7.68 ± 0.23~~	~~0.993 ± 0.068~~	~~1.114 ± 0.070~~
Zn- 65	< 8.9	10.0 ± 2.0	12.2 ± 2.2
Rb- 86	116.2 ± 7.8	94.0 ± 5.1	117.9 ± 5.9
Zr- 95	300 ± 55	65 ± 17	87 ± 22
Sb-124	< 0.66	< 0.20	< 0.28
Cs-134	27.0 ± 1.0	3.90 ± 0.20	5.00 ± 0.24
Ce-141	122.0 ± 3.9	27.62 ± 0.88	47.1 ± 1.5
Nd-147	63 ± 10	10.2 ± 2.5	19.8 ± 3.9
Eu-152	1.62 ± 0.10	0.795 ± 0.057	0.922 ± 0.063
Tb-160	1.00 ± 0.12	0.209 ± 0.040	0.270 ± 0.046
Lu-177	0.754 ± 0.035	0.1152 ± 0.0088	0.254 ± 0.014
Hf-181	12.52 ± 0.34	1.869 ± 0.084	3.43 ± 0.11
Ta-182	~~1.61 ± 0.20~~	~~0.267 ± 0.063~~	~~0.598 ± 0.087~~
Th-233	18.18 ± 0.51	3.48 ± 0.12	5.82 ± 0.18

	jmw-126	jmw-206-a	jmw-206-b
Na- 24	7250 ± 170	4040 ± 100	4340 ± 110
Mg- 27	< 1200	< 820	1290 ± 350
Al- 28	38500 ± 1300	25190 ± 930	27260 ± 980
Cl- 38	41.5 ± 8.9	< 27	< 27
K - 42	21700 ± 1300	13700 ± 1000	12200 ± 950
Ca- 49	2520 ± 430	1660 ± 430	1100 ± 320
Ti- 51	1210 ± 110	1470 ± 100	1179 ± 92
V - 52	36.3 ± 2.4	29.4 ± 2.3	27.8 ± 2.1
Mn- 56	158.2 ± 4.0	87.1 ± 2.3	84.1 ± 2.2
Sr- 87	< 120	< 86	< 78
Ba-139	502 ± 35	398 ± 27	395 ± 26
Dy-165	0.88 ± 0.14	1.52 ± 0.14	1.19 ± 0.10
U -235	3.64 ± 0.10	2.108 ± 0.059	1.837 ± 0.051
Ga- 72	< 13	< 8.3	< 7.9
As- 76	3.40 ± 0.33	2.53 ± 0.26	1.75 ± 0.21
Br- 82	< 1.39	< 0.90	< 0.85
Sb-122	< 0.29	< 0.19	< 0.18
La-140	8.49 ± 0.35	9.92 ± 0.38	8.49 ± 0.32
Sm-153	0.945 ± 0.054	1.449 ± 0.075	1.290 ± 0.048
Yb-175	0.92 ± 0.19	0.76 ± 0.12	0.72 ± 0.10
W -187	~~< 1.59~~	~~< 1.02~~	~~< 0.95~~
Sc- 46	1.911 ± 0.034	1.998 ± 0.034	1.436 ± 0.026
Cr- 51	8.68 ± 0.70	10.00 ± 0.66	7.11 ± 0.52
Fe- 59	12230 ± 230	11600 ± 220	8180 ± 160
Co- 60	~~3.49 ± 0.14~~	~~3.23 ± 0.13~~	~~1.990 ± 0.092~~
Zn- 65	18.5 ± 3.1	11.0 ± 2.8	8.1 ± 2.0
Rb- 86	88.6 ± 5.6	58.1 ± 4.2	49.2 ± 3.8
Zr- 95	190 ± 33	369 ± 48	155 ± 26
Sb-124	< 0.32	< 0.28	< 0.20
Cs-134	2.32 ± 0.17	4.53 ± 0.24	4.22 ± 0.21
Ce-141	26.89 ± 0.97	31.5 ± 1.1	16.47 ± 0.58
Nd-147	< 8.3	< 5.8	< 4.2
Eu-152	0.504 ± 0.052	0.570 ± 0.052	0.459 ± 0.041
Tb-160	< 0.15	0.211 ± 0.056	0.158 ± 0.040
Lu-177	0.147 ± 0.014	0.195 ± 0.013	0.1313 ± 0.0098
Hf-181	4.60 ± 0.16	8.97 ± 0.24	4.72 ± 0.14
Ta-182	~~0.409 ± 0.082~~	~~0.62 ± 0.11~~	~~0.402 ± 0.089~~
Th-233	4.08 ± 0.14	4.28 ± 0.15	2.554 ± 0.094

	jmw-168	150 shale	jmw-150
Na- 24	10560 ± 250	976 ± 38	7070 ± 180
Mg- 27	2280 ± 480	11630 ± 740	< 1700
Al- 28	56900 ± 1800	78400 ± 2400	41200 ± 1500
Cl- 38	< 50	232 ± 21	< 56
K - 42	29200 ± 1600	31200 ± 1800	20300 ± 1900
Ca- 49	2120 ± 470	6700 ± 980	28900 ± 2100
Ti- 51	910 ± 100	3120 ± 180	870 ± 200
V - 52	30.6 ± 2.3	73.2 ± 3.9	42.8 ± 3.9
Mn- 56	97.8 ± 2.5	107.8 ± 2.8	1036 ± 24
Sr- 87	< 120	< 120	< 250
Ba-139	833 ± 40	264 ± 27	787 ± 58
Dy-165	1.85 ± 0.13	5.30 ± 0.29	1.31 ± 0.22
U -235	2.567 ± 0.072	4.83 ± 0.14	1.737 ± 0.049
Ga- 72	< 14	< 10.9	< 10.7
As- 76	5.16 ± 0.37	3.37 ± 0.44	1.38 ± 0.29
Br- 82	< 1.50	< 1.7	< 0.78
Sb-122	0.392 ± 0.093	0.56 ± 0.18	< 0.26
La-140	22.31 ± 0.67	33.4 ± 1.0	14.15 ± 0.50
Sm-153	2.45 ± 0.10	5.63 ± 0.21	1.491 ± 0.069
Yb-175	1.15 ± 0.14	3.33 ± 0.20	0.78 ± 0.16
W -187	~~< 1.65~~	~~17.8 ± 2.8~~	~~147 ± 22~~
Sc- 46	2.145 ± 0.036	16.80 ± 0.25	1.918 ± 0.035
Cr- 51	13.93 ± 0.75	58.4 ± 2.3	11.21 ± 0.68
Fe- 59	11250 ± 200	38500 ± 620	7840 ± 170
Co- 60	~~2.75 ± 0.11~~	~~9.04 ± 0.29~~	~~20.96 ± 0.42~~
Zn- 65	14.3 ± 2.6	< 14	< 5.9
Rb- 86	145.8 ± 6.9	223 ± 12	97.4 ± 6.0
Zr- 95	87 ± 21	< 270	148 ± 29
Sb-124	0.56 ± 0.13	< 0.97	< 0.34
Cs-134	6.12 ± 0.29	43.5 ± 1.6	5.00 ± 0.26
Ce-141	54.0 ± 1.6	111.6 ± 3.5	36.8 ± 1.3
Nd-147	18.6 ± 3.7	< 22	< 6.0
Eu-152	1.136 ± 0.070	1.74 ± 0.12	0.743 ± 0.062
Tb-160	0.382 ± 0.060	1.42 ± 0.18	0.270 ± 0.063
Lu-177	0.245 ± 0.014	0.722 ± 0.043	0.186 ± 0.015
Hf-181	3.84 ± 0.13	6.88 ± 0.28	3.98 ± 0.14
Ta-182	~~0.435 ± 0.080~~	~~2.04 ± 0.29~~	~~1.28 ± 0.14~~
Th-233	5.06 ± 0.16	15.40 ± 0.46	3.94 ± 0.14

NOTE:

150-shale was collected from a fracture filled by clay in the Westwater Canyon member of the Morrison Formation.

	jmw-203	jmw-181	jmw-125
Na- 24	6380 ± 150	4910 ± 130	5340 ± 140
Mg- 27	1070 ± 250	< 2500	< 1700
Al- 28	38600 ± 1300	26200 ± 1300	31100 ± 1200
Cl- 38	< 33	200 ± 42	< 58
K - 42	18100 ± 1200	13300 ± 1800	14100 ± 1400
Ca- 49	1390 ± 330	88700 ± 4300	56900 ± 3000
Ti- 51	2080 ± 130	1270 ± 250	2220 ± 220
V - 52	45.1 ± 2.7	40.2 ± 4.7	38.6 ± 3.5
Mn- 56	95.2 ± 2.5	1897 ± 44	884 ± 20
Sr- 87	< 90	< 360	< 250
Ba-139	560 ± 31	672 ± 62	420 ± 50
Dy-165	1.74 ± 0.13	1.27 ± 0.22	2.43 ± 0.34
U -235	2.287 ± 0.064	1.106 ± 0.031	2.030 ± 0.057
Ga- 72	< 9.1	< 9.1	< 12.0
As- 76	2.06 ± 0.23	1.69 ± 0.22	< 1.14
Br- 82	< 1.01	< 0.59	< 1.1
Sb-122	< 0.21	< 0.20	< 0.30
La-140	12.99 ± 0.44	11.09 ± 0.38	16.32 ± 0.54
Sm-153	1.561 ± 0.062	1.295 ± 0.054	1.695 ± 0.076
Yb-175	0.80 ± 0.12	1.08 ± 0.11	1.28 ± 0.21
W -187	~~< 1.12~~	~~10.0 ± 1.6~~	~~199 ± 30~~
Sc- 46	1.454 ± 0.026	1.731 ± 0.029	2.845 ± 0.048
Cr- 51	8.44 ± 0.67	11.43 ± 0.63	10.52 ± 0.84
Fe- 59	9340 ± 180	7020 ± 140	10910 ± 220
Co- 60	~~2.017 ± 0.091~~	~~6.21 ± 0.17~~	~~25.11 ± 0.42~~
Zn- 65	12.1 ± 2.3	6.2 ± 2.1	< 4.2
Rb- 86	61.5 ± 4.2	64.3 ± 4.2	65.4 ± 5.2
Zr- 95	172 ± 28	107 ± 20	< 139
Sb-124	< 0.23	< 0.25	< 0.44
Cs-134	4.00 ± 0.21	2.95 ± 0.17	3.89 ± 0.25
Ce-141	22.77 ± 0.75	25.91 ± 0.86	52.1 ± 1.7
Nd-147	20.4 ± 2.9	13.8 ± 4.0	< 10.5
Eu-152	0.595 ± 0.049	0.589 ± 0.045	0.780 ± 0.066
Tb-160	< 0.17	0.280 ± 0.041	0.424 ± 0.069
Lu-177	0.137 ± 0.011	0.227 ± 0.012	0.297 ± 0.020
Hf-181	4.64 ± 0.14	4.49 ± 0.13	5.37 ± 0.18
Ta-182	~~0.494 ± 0.084~~	~~0.405 ± 0.067~~	~~1.85 ± 0.18~~
Th-233	4.14 ± 0.14	2.709 ± 0.098	4.51 ± 0.16

	jcs-160	jcs-179	jcs-196-a
Na- 24	4860 ± 130	2602 ± 70	4650 ± 120
Mg- 27	3640 ± 480	2220 ± 320	2570 ± 370
Al- 28	28500 ± 1100	21220 ± 830	25900 ± 1000
Cl- 38	< 35	< 27	< 42
K - 42	15400 ± 1200	12400 ± 1000	15400 ± 1200
Ca- 49	11600 ± 1300	24500 ± 1700	23000 ± 1800
Ti- 51	1370 ± 130	419 ± 81	1270 ± 120
V - 52	25.3 ± 2.4	10.9 ± 1.6	16.7 ± 1.8
Mn- 56	181.3 ± 4.5	215.4 ± 5.2	215.2 ± 5.2
Sr- 87	< 120	< 100	< 130
Ba-139	395 ± 31	266 ± 21	389 ± 28
Dy-165	1.13 ± 0.13	< 0.32	1.27 ± 0.11
U -235	1.351 ± 0.038	0.485 ± 0.014	0.844 ± 0.024
Ga- 72	< 10.3	< 6.1	< 9.9
As- 76	1.19 ± 0.30	< 0.51	< 0.81
Br- 82	< 1.08	< 0.67	< 1.07
Sb-122	< 0.22	< 0.14	< 0.22
La-140	9.15 ± 0.39	6.28 ± 0.26	8.75 ± 0.34
Sm-153	1.114 ± 0.059	0.784 ± 0.031	1.185 ± 0.062
Yb-175	1.02 ± 0.13	0.478 ± 0.075	0.91 ± 0.13
W -187	~~< 1.21~~	~~0.97 ± 0.26~~	~~< 1.19~~
Sc- 46	3.120 ± 0.053	1.366 ± 0.025	2.712 ± 0.043
Cr- 51	20.54 ± 0.94	6.32 ± 0.52	18.63 ± 0.84
Fe- 59	11730 ± 230	3669 ± 95	6680 ± 150
Co- 60	~~3.79 ± 0.16~~	~~1.221 ± 0.071~~	~~1.806 ± 0.096~~
Zn- 65	< 5.0	5.3 ± 1.8	6.5 ± 2.3
Rb- 86	65.7 ± 5.4	40.5 ± 3.2	62.9 ± 4.5
Zr- 95	391 ± 52	130 ± 23	266 ± 38
Sb-124	< 0.34	< 0.21	< 0.32
Cs-134	2.01 ± 0.19	1.59 ± 0.12	1.65 ± 0.14
Ce-141	27.2 ± 1.0	11.71 ± 0.46	23.46 ± 0.77
Nd-147	< 6.8	< 3.5	< 5.3
Eu-152	0.454 ± 0.052	0.369 ± 0.037	0.501 ± 0.047
Tb-160	< 0.18	< 0.15	0.155 ± 0.035
Lu-177	0.234 ± 0.016	0.0848 ± 0.0077	0.215 ± 0.013
Hf-181	11.57 ± 0.30	2.677 ± 0.099	8.28 ± 0.22
Ta-182	~~0.49 ± 0.11~~	~~< 0.203~~	~~0.371 ± 0.092~~
Th-233	3.10 ± 0.12	1.366 ± 0.063	2.61 ± 0.10

NOTE:

Jcs-196-a and jcs-196-b were collected within 5 meters of each other from the same stratigraphic horizon.

	jcs-196-b	jcs-153-a	jcs-153-b
Na- 24	4960 ± 120	2528 ± 71	1888 ± 55
Mg- 27	3560 ± 490	10240 ± 620	2750 ± 320
Al- 28	28600 ± 1100	53600 ± 1700	23120 ± 900
Cl- 38	< 46	< 30	79 ± 12
K - 42	14200 ± 1100	20200 ± 1500	10700 ± 1000
Ca- 49	37500 ± 2100	16800 ± 1500	30800 ± 2000
Ti- 51	1810 ± 160	1450 ± 150	441 ± 82
V - 52	31.7 ± 2.5	125.5 ± 5.5	19.6 ± 2.2
Mn- 56	361.4 ± 8.7	371.9 ± 8.9	299.4 ± 7.2
Sr- 87	< 160	276 ± 77	< 110
Ba-139	477 ± 40	296 ± 29	464 ± 29
Dy-165	1.53 ± 0.20	1.85 ± 0.18	1.01 ± 0.12
U -235	1.511 ± 0.042	18.32 ± 0.51	1.156 ± 0.032
Ga- 72	< 11.5	11.2 ± 3.0	< 5.4
As- 76	< 0.93	1.05 ± 0.22	0.84 ± 0.14
Br- 82	< 1.22	< 0.88	< 0.60
Sb-122	< 0.25	< 0.18	< 0.12
La-140	10.59 ± 0.40	12.99 ± 0.44	8.23 ± 0.30
Sm-153	1.496 ± 0.060	1.75 ± 0.15	0.857 ± 0.039
Yb-175	1.55 ± 0.17	1.03 ± 0.10	0.74 ± 0.11
W -187	~~< 1.42~~	~~< 1.00~~	~~< 0.67~~
Sc- 46	3.532 ± 0.057	8.06 ± 0.12	1.072 ± 0.020
Cr- 51	32.3 ± 1.3	16.9 ± 1.1	6.06 ± 0.55
Fe- 59	12410 ± 240	36550 ± 550	7550 ± 150
Co- 60	~~3.62 ± 0.14~~	~~25.07 ± 0.48~~	~~2.40 ± 0.10~~
Zn- 65	14.6 ± 3.6	83.4 ± 7.3	10.9 ± 2.2
Rb- 86	63.9 ± 5.1	94.6 ± 6.6	26.1 ± 2.8
Zr- 95	696 ± 77	162 ± 27	85 ± 20
Sb-124	0.42 ± 0.13	< 0.51	< 0.20
Cs-134	1.97 ± 0.18	11.30 ± 0.50	2.22 ± 0.14
Ce-141	36.5 ± 1.3	35.6 ± 1.2	14.15 ± 0.51
Nd-147	< 10.8	< 8.3	14.6 ± 4.8
Eu-152	0.548 ± 0.054	0.756 ± 0.060	0.468 ± 0.039
Tb-160	0.517 ± 0.080	0.74 ± 0.12	0.140 ± 0.033
Lu-177	0.350 ± 0.022	0.187 ± 0.018	0.0765 ± 0.0088
Hf-181	20.81 ± 0.48	3.36 ± 0.14	2.599 ± 0.099
Ta-182	~~0.65 ± 0.13~~	~~0.53 ± 0.13~~	~~< 0.234~~
Th-233	3.69 ± 0.14	6.00 ± 0.20	1.427 ± 0.066

Note:

Jcs-153-a was collected from a fracture filled by clay in the Cow Springs Formation.

Jcs-153-b was collected about 2 meters away from the fracture.

	jcs-154	jcs-174	jcs-151
Na- 24	4600 ± 120	4510 ± 110	5140 ± 130
Mg- 27	3190 ± 470	3500 ± 600	4910 ± 610
Al- 28	25600 ± 1000	28600 ± 1100	43000 ± 1500
Cl- 38	< 50	< 41	90 ± 18
K - 42	13000 ± 1200	14900 ± 1300	21300 ± 1700
Ca- 49	40000 ± 2300	19100 ± 1500	45000 ± 2800
Ti- 51	970 ± 150	1440 ± 130	1470 ± 170
V - 52	12.7 ± 2.2	30.1 ± 2.5	37.5 ± 3.2
Mn- 56	620 ± 15	390.9 ± 9.4	452 ± 11
Sr- 87	< 190	< 160	< 180
Ba-139	304 ± 30	378 ± 34	485 ± 44
Dy-165	1.51 ± 0.15	1.39 ± 0.22	2.17 ± 0.20
U -235	1.115 ± 0.031	1.565 ± 0.044	1.379 ± 0.039
Ga- 72	< 9.3	< 10.8	< 10.4
As- 76	< 0.73	< 0.85	< 0.88
Br- 82	< 0.98	< 1.12	< 1.14
Sb-122	< 0.20	< 0.23	< 0.23
La-140	9.14 ± 0.34	9.95 ± 0.38	12.84 ± 0.48
Sm-153	1.171 ± 0.052	1.136 ± 0.053	1.964 ± 0.088
Yb-175	0.81 ± 0.10	0.84 ± 0.13	0.97 ± 0.12
W -187	~~< 1.12~~	~~< 1.32~~	~~3.99 ± 0.72~~
Sc- 46	2.538 ± 0.041	3.168 ± 0.051	4.492 ± 0.072
Cr- 51	14.08 ± 0.68	20.88 ± 0.96	17.98 ± 0.97
Fe- 59	5330 ± 120	11640 ± 220	10270 ± 220
Co- 60	~~1.657 ± 0.085~~	~~3.06 ± 0.13~~	~~4.86 ± 0.17~~
Zn- 65	< 3.1	< 6.0	29.3 ± 4.3
Rb- 86	53.8 ± 3.8	67.0 ± 5.3	90.0 ± 6.1
Zr- 95	246 ± 38	360 ± 49	211 ± 40
Sb-124	< 0.31	< 0.36	< 0.35
Cs-134	1.95 ± 0.15	2.70 ± 0.21	7.38 ± 0.35
Ce-141	23.05 ± 0.78	31.2 ± 1.1	36.6 ± 1.3
Nd-147	< 4.8	< 9.5	< 7.8
Eu-152	0.476 ± 0.046	0.508 ± 0.048	0.784 ± 0.063
Tb-160	0.240 ± 0.044	0.298 ± 0.079	0.523 ± 0.067
Lu-177	0.190 ± 0.012	0.244 ± 0.017	0.293 ± 0.019
Hf-181	6.26 ± 0.17	11.85 ± 0.31	6.72 ± 0.21
Ta-182	~~0.283 ± 0.057~~	~~0.51 ± 0.11~~	~~0.54 ± 0.10~~
Th-233	2.572 ± 0.095	3.18 ± 0.12	5.23 ± 0.18

	jcs-193	jcs-152	jcs-193 r1
Na- 24	3196 ± 93	2996 ± 81	3122 ± 94
Mg- 27	< 2000	2080 ± 440	< 2400
Al- 28	23400 ± 1100	23910 ± 960	22700 ± 1100
Cl- 38	< 66	< 44	< 78
K - 42	12800 ± 2000	10400 ± 1100	12800 ± 1800
Ca- 49	128200 ± 5500	51500 ± 2700	128100 ± 5500
Ti- 51	< 740	1010 ± 190	< 870
V - 52	12.3 ± 2.5	30.3 ± 2.4	14.5 ± 3.4
Mn- 56	1661 ± 38	635 ± 15	1690 ± 39
Sr- 87	< 290	< 190	< 350
Ba-139	363 ± 56	347 ± 35	410 ± 80
Dy-165	2.24 ± 0.29	1.50 ± 0.16	< 1.47
U -235	0.462 ± 0.013	0.890 ± 0.025	0.430 ± 0.012
Ga- 72	< 6.9	< 7.7	< 9.9
As- 76	< 0.60	< 0.69	< 0.82
Br- 82	< 0.99	< 1.1	< 0.49
Sb-122	< 0.16	< 0.18	< 0.22
La-140	10.37 ± 0.37	11.91 ± 0.40	11.73 ± 0.43
Sm-153	1.570 ± 0.060	1.114 ± 0.052	1.551 ± 0.060
Yb-175	1.20 ± 0.11	0.74 ± 0.11	0.96 ± 0.13
W -187	~~20.0 ± 3.1~~	~~72 ± 11~~	~~21.4 ± 3.3~~
Sc- 46	1.582 ± 0.028	2.261 ± 0.038	2.035 ± 0.037
Cr- 51	4.83 ± 0.47	13.12 ± 0.67	4.59 ± 0.63
Fe- 59	4560 ± 110	10710 ± 190	5940 ± 150
Co- 60	~~3.29 ± 0.13~~	~~7.69 ± 0.19~~	~~3.91 ± 0.16~~
Zn- 65	6.9 ± 2.3	18.6 ± 2.6	< 5.3
Rb- 86	44.3 ± 3.5	35.0 ± 3.1	58.9 ± 5.0
Zr- 95	103 ± 27	175 ± 28	< 94
Sb-124	< 0.23	< 0.28	< 0.36
Cs-134	1.60 ± 0.13	2.68 ± 0.17	2.16 ± 0.18
Ce-141	15.83 ± 0.57	30.29 ± 0.94	24.25 ± 0.92
Nd-147	< 4.0	< 4.9	< 8.9
Eu-152	0.704 ± 0.055	0.625 ± 0.046	0.665 ± 0.063
Tb-160	0.263 ± 0.043	< 0.25	0.406 ± 0.063
Lu-177	0.155 ± 0.010	0.179 ± 0.011	0.245 ± 0.018
Hf-181	2.072 ± 0.087	4.73 ± 0.14	2.76 ± 0.12
Ta-182	~~0.422 ± 0.089~~	~~0.580 ± 0.086~~	~~< 0.39~~
Th-233	1.557 ± 0.070	2.633 ± 0.095	2.20 ± 0.10

NOTE:

Jcs-193-rl is a replicate analysis of jcs-193.

	jmr-202	jmr-164	jmr-207
Na- 24	3376 ± 88	9900 ± 240	2494 ± 67
Mg- 27	< 720	< 1400	< 600
Al- 28	30100 ± 1100	53400 ± 1700	25390 ± 910
Cl- 38	< 23	41.8 ± 8.8	< 20
K - 42	18300 ± 1200	25300 ± 1400	15570 ± 980
Ca- 49	< 230	6970 ± 820	1470 ± 300
Ti- 51	377 ± 60	720 ± 130	685 ± 61
V - 52	8.4 ± 1.2	34.4 ± 2.4	7.7 ± 1.1
Mn- 56	21.36 ± 0.68	150.6 ± 3.8	28.51 ± 0.83
Sr- 87	< 65	< 130	< 55
Ba-139	394 ± 24	693 ± 40	476 ± 27
Dy-165	0.873 ± 0.083	1.15 ± 0.15	1.189 ± 0.099
U -235	0.754 ± 0.021	1.844 ± 0.052	0.887 ± 0.025
Ga- 72	< 7.6	< 15	< 6.2
As- 76	1.51 ± 0.23	< 1.2	1.23 ± 0.19
Br- 82	< 0.83	< 1.57	< 0.033
Sb-122	< 0.17	< 0.32	< 0.14
La-140	9.16 ± 0.36	16.80 ± 0.54	9.01 ± 0.34
Sm-153	0.969 ± 0.046	1.617 ± 0.081	0.918 ± 0.043
Yb-175	0.69 ± 0.11	1.21 ± 0.22	0.76 ± 0.10
W -187	~~< 0.92~~	~~< 1.80~~	~~12.7 ± 2.0~~
Sc- 46	1.062 ± 0.021	1.449 ± 0.025	0.976 ± 0.017
Cr- 51	3.58 ± 0.39	11.58 ± 0.56	3.94 ± 0.31
Fe- 59	2127 ± 77	6270 ± 120	1306 ± 42
Co- 60	~~0.928 ± 0.071~~	~~1.387 ± 0.069~~	~~2.665 ± 0.083~~
Zn- 65	< 3.1	4.6 ± 1.8	< 2.0
Rb- 86	97.9 ± 5.6	88.9 ± 4.3	55.7 ± 3.0
Zr- 95	106 ± 24	98 ± 20	120 ± 18
Sb-124	< 0.22	< 0.21	0.236 ± 0.082
Cs-134	2.64 ± 0.17	6.57 ± 0.28	1.590 ± 0.094
Ce-141	23.27 ± 0.84	30.9 ± 1.1	16.40 ± 0.59
Nd-147	< 4.5	12.5 ± 2.7	6.4 ± 1.9
Eu-152	0.416 ± 0.043	0.718 ± 0.044	0.273 ± 0.023
Tb-160	0.142 ± 0.034	0.254 ± 0.042	0.143 ± 0.024
Lu-177	0.1113 ± 0.0090	0.1179 ± 0.0090	0.1251 ± 0.0073
Hf-181	3.24 ± 0.12	1.796 ± 0.074	3.82 ± 0.10
Ta-182	~~0.328 ± 0.097~~	~~0.196 ± 0.041~~	~~0.325 ± 0.050~~
Th-233	2.69 ± 0.10	3.31 ± 0.11	2.429 ± 0.080

	jmr-208	jmr-209 r1	176 jt
Na- 24	1656 ± 55	2574 ± 69	142 ± 18
Mg- 27	< 1500	< 690	< 1500
Al- 28	22200 ± 980	24400 ± 850	< 1000
Cl- 38	< 50	< 23	< 71
K - 42	10100 ± 1500	14250 ± 900	< 3200
Ca- 49	88600 ± 3900	1270 ± 310	415000 ± 12000
Ti- 51	< 580	644 ± 61	< 610
V - 52	10.3 ± 2.3	9.2 ± 1.3	< 6.8
Mn- 56	1239 ± 28	28.53 ± 0.83	826 ± 19
Sr- 87	< 240	< 62	< 250
Ba-139	234 ± 43	390 ± 21	< 130
Dy-165	2.00 ± 0.25	1.245 ± 0.085	< 1.04
U -235	0.641 ± 0.018	0.901 ± 0.025	0.2320 ± 0.0065
Ga- 72	< 5.1	< 6.9	< 4.0
As- 76	< 0.43	1.28 ± 0.17	< 0.33
Br- 82	< 0.55	< 0.43	< 0.53
Sb-122	< 0.12	< 0.15	< 0.083
La-140	7.90 ± 0.30	9.31 ± 0.33	1.53 ± 0.13
Sm-153	1.050 ± 0.039	0.949 ± 0.045	0.157 ± 0.012
Yb-175	0.789 ± 0.092	0.908 ± 0.085	< 0.17
W -187	~~< 0.61~~	~~12.4 ± 1.9~~	~~4.91 ± 0.82~~
Sc- 46	0.617 ± 0.012	0.999 ± 0.017	0.1454 ± 0.0051
Cr- 51	2.14 ± 0.32	5.66 ± 0.35	1.39 ± 0.25
Fe- 59	2802 ± 67	1321 ± 41	138 ± 27
Co- 60	~~0.621 ± 0.042~~	~~2.792 ± 0.084~~	~~1.342 ± 0.071~~
Zn- 65	< 1.4	4.3 ± 1.1	< 0.046
Rb- 86	26.5 ± 2.0	55.9 ± 2.9	< 3.3
Zr- 95	< 36	115 ± 17	< 35
Sb-124	< 0.14	< 0.15	< 0.131
Cs-134	1.032 ± 0.075	1.631 ± 0.090	< 0.102
Ce-141	9.82 ± 0.38	17.60 ± 0.58	3.41 ± 0.24
Nd-147	6.6 ± 1.7	7.1 ± 1.5	< 4.0
Eu-152	0.398 ± 0.030	0.263 ± 0.022	0.078 ± 0.020
Tb-160	0.141 ± 0.023	0.121 ± 0.019	< 0.039
Lu-177	0.0708 ± 0.0054	0.1454 ± 0.0076	0.0260 ± 0.0085
Hf-181	0.947 ± 0.046	3.93 ± 0.10	< 0.078
Ta-182	~~< 0.122~~	~~0.281 ± 0.045~~	~~< 0.199~~
Th-233	1.052 ± 0.043	2.598 ± 0.083	< 0.090

NOTE:

Jmr-209-rl is a replicate analysis of jmr-207.

	158 jt	114 jt	155 jt r1
Na- 24	292 ± 20	176 ± 20	227 ± 25
Mg- 27	1910 ± 390	< 1200	< 1800
Al- 28	1100 ± 260	< 810	< 1300
Cl- 38	< 43	< 58	< 82
K - 42	< 1500	< 2600	< 4000
Ca- 49	405000 ± 12000	395000 ± 12000	415000 ± 13000
Ti- 51	< 300	< 490	< 750
V - 52	5.3 ± 1.5	< 5.4	< 8.2
Mn- 56	253.2 ± 6.1	675 ± 16	1074 ± 25
Sr- 87	258 ± 42	307 ± 80	< 300
Ba-139	< 61	< 93	3300 ± 130
Dy-165	< 0.39	< 0.59	< 0.86
U -235	0.2480 ± 0.0069	0.2580 ± 0.0072	0.2720 ± 0.0076
Ga- 72	< 3.0	< 3.2	< 4.2
As- 76	< 0.26	< 0.31	< 0.33
Br- 82	< 0.25	< 0.33	< 0.36
Sb-122	< 0.063	< 0.074	< 0.083
La-140	0.799 ± 0.080	1.49 ± 0.12	1.32 ± 0.12
Sm-153	0.1252 ± 0.0083	0.214 ± 0.012	0.167 ± 0.010
Yb-175	< 0.123	< 0.17	0.204 ± 0.065
W -187	~~5.88 ± 0.94~~	~~20.4 ± 3.1~~	~~6.2 ± 1.0~~
Sc- 46	0.1015 ± 0.0036	0.0739 ± 0.0035	0.1364 ± 0.0049
Cr- 51	11.25 ± 0.41	3.21 ± 0.28	10.19 ± 0.49
Fe- 59	208 ± 17	110 ± 18	236 ± 22
Co- 60	~~1.465 ± 0.060~~	~~3.33 ± 0.11~~	~~4.72 ± 0.14~~
Zn- 65	< 0.026	< 2.2	< 0.0070
Rb- 86	< 2.2	< 2.7	< 3.8
Zr- 95	< 22	< 28	< 38
Sb-124	< 0.078	< 0.102	< 0.139
Cs-134	< 0.064	< 0.081	< 0.111
Ce-141	1.20 ± 0.11	2.29 ± 0.16	2.76 ± 0.20
Nd-147	< 2.0	< 2.1	< 3.2
Eu-152	0.043 ± 0.012	< 0.0259	0.055 ± 0.014
Tb-160	< 0.046	< 0.039	< 0.25
Lu-177	0.0226 ± 0.0030	< 0.0117	0.0250 ± 0.0052
Hf-181	0.313 ± 0.027	0.145 ± 0.027	0.161 ± 0.025
Ta-182	~~< 0.112~~	~~0.096 ± 0.027~~	~~< 0.199~~
Th-233	0.097 ± 0.014	< 0.073	0.131 ± 0.023

NOTE:

155-jt-r1 is a replicate analysis of 155-jt-r2.

155 jt r2

Na- 24	200	±	24
Mg- 27		<	1800
Al- 28		<	1200
Cl- 38		<	79
K - 42		<	3900
Ca- 49	406000	±	13000
Ti- 51		<	730
V - 52		<	8.0
Mn- 56	1052	±	24
Sr- 87		<	300
Ba-139	3420	±	140
Dy-165		<	1.25
U -235	0.2600	±	0.0073
Ga- 72		<	4.7
As- 76		<	0.38
Br- 82		<	0.58
Sb-122		<	0.096
La-140	1.23	±	0.13
Sm-153	0.136	±	0.012
Yb-175		<	0.20
W -187	~~6.6~~	~~±~~	~~1.1~~
Sc- 46	0.1178	±	0.0051
Cr- 51	9.34	±	0.57
Fe- 59	209	±	25
Co- 60	~~4.34~~	~~±~~	~~0.14~~
Zn- 65		<	0.0030
Rb- 86		<	4.2
Zr- 95		<	42
Sb-124		<	0.16
Cs-134		<	0.128
Ce-141	2.46	±	0.26
Nd-147		<	4.9
Eu-152	0.035	±	0.017
Tb-160		<	0.61
Lu-177		<	0.024
Hf-181	0.329	±	0.056
Ta-182		~~<~~	~~0.247~~
Th-233		<	0.134

Appendix I-B: Elemental concentrations in sediment samples

	163	162	198
Na- 24	4530 ± 120	4180 ± 110	4620 ± 120
Mg- 27	4130 ± 470	3800 ± 510	4180 ± 410
Al- 28	43500 ± 1400	37000 ± 1300	34400 ± 1200
Cl- 38	< 35	< 33	< 42
K - 42	18500 ± 1300	16900 ± 1200	15400 ± 1200
Ca- 49	16600 ± 1400	17900 ± 1400	23300 ± 1700
Ti- 51	2370 ± 170	1550 ± 120	1570 ± 140
V - 52	39.6 ± 2.8	33.8 ± 2.5	35.7 ± 2.7
Mn- 56	271.3 ± 6.5	287.9 ± 6.9	315.0 ± 7.6
Sr- 87	< 130	< 120	< 150
Ba-139	576 ± 35	603 ± 36	768 ± 41
Dy-165	3.48 ± 0.23	2.25 ± 0.16	1.93 ± 0.15
U -235	2.762 ± 0.077	2.562 ± 0.072	1.995 ± 0.056
Ga- 72	< 9.9	< 8.4	< 10.1
As- 76	1.31 ± 0.24	2.01 ± 0.30	1.52 ± 0.25
Br- 82	< 1.03	< 0.87	< 1.05
Sb-122	< 0.21	< 0.18	0.173 ± 0.071
La-140	17.41 ± 0.56	14.58 ± 0.48	11.54 ± 0.42
Sm-153	2.19 ± 0.11	1.991 ± 0.080	1.618 ± 0.068
Yb-175	1.60 ± 0.12	1.54 ± 0.13	1.31 ± 0.11
W -187	< 1.20	< 1.22	< 1.23
Sc- 46	3.469 ± 0.052	2.449 ± 0.039	2.707 ± 0.043
Cr- 51	19.30 ± 0.77	18.19 ± 0.65	18.76 ± 0.68
Fe- 59	12590 ± 210	8960 ± 150	10060 ± 170
Co- 60	4.60 ± 0.13	2.906 ± 0.093	3.057 ± 0.095
Zn- 65	< 3.7	21.9 ± 2.1	21.3 ± 2.2
Rb- 86	62.7 ± 3.6	45.5 ± 2.9	57.2 ± 3.3
Zr- 95	378 ± 47	251 ± 30	292 ± 34
Sb-124	0.323 ± 0.094	< 0.19	0.340 ± 0.090
Cs-134	5.30 ± 0.24	3.19 ± 0.16	3.16 ± 0.16
Ce-141	32.3 ± 1.3	19.28 ± 0.73	22.52 ± 0.70
Nd-147	13.6 ± 3.1	< 3.5	11.5 ± 2.7
Eu-152	0.594 ± 0.041	0.505 ± 0.036	0.483 ± 0.035
Tb-160	0.396 ± 0.054	0.189 ± 0.029	0.215 ± 0.042
Lu-177	0.301 ± 0.015	0.1856 ± 0.0098	0.214 ± 0.011
Hf-181	8.88 ± 0.21	8.73 ± 0.21	8.06 ± 0.19
Ta-182	0.461 ± 0.075	0.416 ± 0.059	0.478 ± 0.068
Th-233	4.98 ± 0.15	3.32 ± 0.11	3.30 ± 0.11

	197	101	102
Na- 24	4850 ± 120	4290 ± 110	5190 ± 130
Mg- 27	5310 ± 550	3380 ± 450	3920 ± 380
Al- 28	35000 ± 1200	28100 ± 1000	34300 ± 1200
Cl- 38	< 38	< 30	< 33
K - 42	20700 ± 1300	14900 ± 1000	15800 ± 1100
Ca- 49	10600 ± 960	8160 ± 980	15200 ± 1200
Ti- 51	1390 ± 120	1109 ± 100	1470 ± 120
V - 52	25.3 ± 2.2	20.5 ± 1.8	29.0 ± 2.4
Mn- 56	185.5 ± 4.6	159.6 ± 4.0	208.0 ± 5.0
Sr- 87	< 120	< 100	< 110
Ba-139	521 ± 35	516 ± 30	527 ± 31
Dy-165	1.24 ± 0.14	1.34 ± 0.13	2.14 ± 0.16
U -235	1.486 ± 0.042	1.268 ± 0.036	1.600 ± 0.045
Ga- 72	< 12.0	< 8.8	< 9.0
As- 76	1.45 ± 0.30	1.08 ± 0.22	1.30 ± 0.18
Br- 82	< 1.22	< 0.90	0.63 ± 0.20
Sb-122	< 0.24	< 0.19	0.283 ± 0.070
La-140	10.83 ± 0.41	8.33 ± 0.33	9.71 ± 0.35
Sm-153	1.450 ± 0.064	1.008 ± 0.052	1.310 ± 0.054
Yb-175	1.06 ± 0.13	0.932 ± 0.098	1.12 ± 0.10
W -187	< 1.64	< 1.21	< 1.05
Sc- 46	3.127 ± 0.050	2.023 ± 0.032	2.328 ± 0.037
Cr- 51	17.41 ± 0.71	15.09 ± 0.59	16.06 ± 0.59
Fe- 59	9200 ± 170	6850 ± 130	7030 ± 130
Co- 60	3.32 ± 0.11	2.011 ± 0.076	2.469 ± 0.081
Zn- 65	< 2.6	< 2.7	9.3 ± 1.7
Rb- 86	56.4 ± 3.6	50.9 ± 3.3	44.1 ± 2.8
Zr- 95	167 ± 30	230 ± 28	291 ± 34
Sb-124	< 0.27	0.170 ± 0.050	< 0.18
Cs-134	2.73 ± 0.16	1.92 ± 0.12	2.15 ± 0.12
Ce-141	23.06 ± 0.78	15.19 ± 0.67	12.85 ± 0.44
Nd-147	< 6.6	< 3.6	< 3.2
Eu-152	0.411 ± 0.036	0.318 ± 0.028	0.320 ± 0.027
Tb-160	0.375 ± 0.070	0.170 ± 0.044	0.209 ± 0.038
Lu-177	0.174 ± 0.012	0.1518 ± 0.0091	0.1664 ± 0.0095
Hf-181	5.08 ± 0.15	6.93 ± 0.17	8.52 ± 0.20
Ta-182	0.256 ± 0.052	0.147 ± 0.039	0.269 ± 0.044
Th-233	2.95 ± 0.10	2.307 ± 0.081	2.241 ± 0.076

	103	104	105
Na- 24	4580 ± 110	5140 ± 130	4920 ± 120
Mg- 27	3230 ± 400	4190 ± 460	4720 ± 550
Al- 28	31000 ± 1100	40700 ± 1300	35600 ± 1200
Cl- 38	< 38	< 42	< 33
K - 42	16500 ± 1200	15800 ± 1100	16800 ± 1200
Ca- 49	11000 ± 1100	9670 ± 990	7540 ± 930
Ti- 51	1620 ± 120	1780 ± 140	1290 ± 120
V - 52	30.7 ± 2.2	36.2 ± 2.6	23.8 ± 2.0
Mn- 56	225.7 ± 5.4	262.6 ± 6.3	196.4 ± 4.9
Sr- 87	< 130	< 140	< 120
Ba-139	605 ± 33	544 ± 40	487 ± 33
Dy-165	1.67 ± 0.12	1.94 ± 0.19	1.53 ± 0.14
U -235	1.861 ± 0.052	1.833 ± 0.051	1.329 ± 0.037
Ga- 72	< 9.9	< 12.5	< 9.7
As- 76	1.21 ± 0.17	1.89 ± 0.36	0.98 ± 0.19
Br- 82	< 1.00	< 1.27	< 1.01
Sb-122	< 0.20	0.228 ± 0.075	< 0.20
La-140	10.30 ± 0.37	13.89 ± 0.49	10.13 ± 0.40
Sm-153	1.422 ± 0.061	1.573 ± 0.074	1.258 ± 0.058
Yb-175	1.53 ± 0.11	1.54 ± 0.16	1.02 ± 0.12
W -187	< 1.16	< 1.44	< 1.17
Sc- 46	2.525 ± 0.040	3.377 ± 0.054	2.514 ± 0.040
Cr- 51	22.02 ± 0.70	23.94 ± 0.91	17.65 ± 0.65
Fe- 59	9810 ± 160	12060 ± 210	9250 ± 170
Co- 60	2.860 ± 0.089	3.40 ± 0.11	2.790 ± 0.098
Zn- 65	16.6 ± 2.0	16.1 ± 2.6	< 3.3
Rb- 86	54.7 ± 3.2	72.0 ± 4.4	53.9 ± 3.3
Zr- 95	447 ± 42	292 ± 37	209 ± 28
Sb-124	< 0.26	< 0.29	< 0.21
Cs-134	2.45 ± 0.13	4.08 ± 0.20	2.71 ± 0.15
Ce-141	20.46 ± 0.65	30.1 ± 1.1	19.54 ± 0.84
Nd-147	22.1 ± 3.0	17.2 ± 5.1	< 4.2
Eu-152	0.418 ± 0.030	0.495 ± 0.040	0.411 ± 0.033
Tb-160	0.218 ± 0.041	0.245 ± 0.047	0.203 ± 0.043
Lu-177	0.254 ± 0.012	0.283 ± 0.017	0.173 ± 0.011
Hf-181	13.73 ± 0.30	10.32 ± 0.25	6.41 ± 0.17
Ta-182	0.483 ± 0.069	0.389 ± 0.066	0.252 ± 0.047
Th-233	3.008 ± 0.096	4.34 ± 0.14	2.881 ± 0.095

	106	107	108
Na- 24	4250 ± 110	4330 ± 110	3607 ± 94
Mg- 27	2800 ± 360	3540 ± 450	3930 ± 460
Al- 28	32500 ± 1100	36300 ± 1300	28330 ± 990
Cl- 38	< 32	< 40	< 30
K - 42	14900 ± 1100	18100 ± 1300	13810 ± 970
Ca- 49	4250 ± 670	11300 ± 1100	5280 ± 710
Ti- 51	1920 ± 120	1680 ± 140	880 ± 88
V - 52	33.8 ± 2.5	34.4 ± 2.6	23.9 ± 1.9
Mn- 56	225.3 ± 5.4	313.0 ± 7.5	155.8 ± 3.9
Sr- 87	< 110	< 140	< 110
Ba-139	380 ± 26	720 ± 40	410 ± 29
Dy-165	2.16 ± 0.16	2.13 ± 0.15	1.17 ± 0.15
U -235	1.645 ± 0.046	1.994 ± 0.056	1.075 ± 0.030
Ga- 72	< 8.7	< 9.9	< 9.8
As- 76	1.37 ± 0.22	1.07 ± 0.19	1.44 ± 0.27
Br- 82	< 0.89	< 1.00	< 0.99
Sb-122	< 0.18	0.220 ± 0.045	< 0.19
La-140	11.60 ± 0.41	13.29 ± 0.45	8.48 ± 0.33
Sm-153	1.462 ± 0.060	1.793 ± 0.075	0.998 ± 0.041
Yb-175	1.43 ± 0.11	1.65 ± 0.12	0.96 ± 0.11
W -187	< 1.22	< 1.15	< 1.38
Sc- 46	2.290 ± 0.037	2.744 ± 0.044	2.188 ± 0.035
Cr- 51	20.51 ± 0.70	22.28 ± 0.69	16.96 ± 0.68
Fe- 59	8550 ± 150	10130 ± 160	7730 ± 140
Co- 60	2.718 ± 0.087	3.059 ± 0.095	2.071 ± 0.079
Zn- 65	12.8 ± 1.8	15.4 ± 2.0	9.0 ± 1.9
Rb- 86	46.4 ± 3.0	64.0 ± 3.6	51.2 ± 3.3
Zr- 95	355 ± 37	363 ± 37	213 ± 29
Sb-124	< 0.19	0.296 ± 0.077	< 0.25
Cs-134	2.35 ± 0.14	4.41 ± 0.19	2.64 ± 0.15
Ce-141	16.34 ± 0.54	25.19 ± 0.78	16.70 ± 0.58
Nd-147	8.7 ± 2.2	< 4.2	< 5.6
Eu-152	0.391 ± 0.030	0.499 ± 0.034	0.359 ± 0.030
Tb-160	0.191 ± 0.035	0.251 ± 0.042	0.167 ± 0.043
Lu-177	0.206 ± 0.011	0.255 ± 0.012	0.157 ± 0.011
Hf-181	10.90 ± 0.25	11.07 ± 0.25	6.13 ± 0.16
Ta-182	0.438 ± 0.063	0.442 ± 0.057	0.348 ± 0.078
Th-233	2.828 ± 0.093	3.87 ± 0.12	2.433 ± 0.088

	109	110	111
Na- 24	4760 ± 120	3809 ± 99	4660 ± 120
Mg- 27	6120 ± 630	2620 ± 360	3760 ± 480
Al- 28	42100 ± 1400	30800 ± 1100	34700 ± 1200
Cl- 38	< 38	< 28	< 39
K - 42	19500 ± 1500	17500 ± 1200	18500 ± 1200
Ca- 49	14800 ± 1400	8990 ± 950	9800 ± 1100
Ti- 51	1890 ± 140	1410 ± 110	1550 ± 110
V - 52	43.2 ± 3.0	24.1 ± 1.9	30.0 ± 2.3
Mn- 56	352.8 ± 8.5	162.0 ± 4.1	191.9 ± 4.6
Sr- 87	< 150	< 93	< 120
Ba-139	712 ± 41	513 ± 29	507 ± 29
Dy-165	2.60 ± 0.20	1.48 ± 0.12	1.90 ± 0.13
U -235	2.885 ± 0.081	1.698 ± 0.048	1.961 ± 0.055
Ga- 72	< 10.3	< 8.3	< 10.2
As- 76	1.20 ± 0.24	1.08 ± 0.20	1.73 ± 0.33
Br- 82	< 1.05	< 0.81	< 1.04
Sb-122	< 0.21	< 0.17	< 0.20
La-140	16.09 ± 0.53	10.07 ± 0.36	12.48 ± 0.42
Sm-153	2.02 ± 0.10	1.261 ± 0.053	1.564 ± 0.078
Yb-175	2.04 ± 0.14	1.30 ± 0.14	0.99 ± 0.11
W -187	< 1.45	< 1.07	< 1.21
Sc- 46	3.676 ± 0.055	1.691 ± 0.027	2.768 ± 0.044
Cr- 51	33.15 ± 0.96	8.62 ± 0.43	15.69 ± 0.58
Fe- 59	15230 ± 240	6250 ± 110	9220 ± 160
Co- 60	4.29 ± 0.12	1.974 ± 0.071	3.052 ± 0.092
Zn- 65	< 3.8	18.9 ± 1.9	7.5 ± 1.9
Rb- 86	66.7 ± 4.1	47.2 ± 2.9	60.7 ± 3.5
Zr- 95	619 ± 58	154 ± 20	274 ± 34
Sb-124	< 0.26	< 0.16	< 0.24
Cs-134	5.69 ± 0.25	2.40 ± 0.13	3.34 ± 0.16
Ce-141	31.5 ± 1.3	13.01 ± 0.53	24.49 ± 0.76
Nd-147	< 5.4	< 2.9	< 3.9
Eu-152	0.623 ± 0.042	0.334 ± 0.026	0.481 ± 0.034
Tb-160	0.272 ± 0.051	0.161 ± 0.032	0.225 ± 0.036
Lu-177	0.352 ± 0.016	0.1295 ± 0.0079	0.206 ± 0.011
Hf-181	20.80 ± 0.46	4.61 ± 0.12	7.67 ± 0.18
Ta-182	0.598 ± 0.083	0.292 ± 0.049	0.389 ± 0.059
Th-233	5.35 ± 0.16	1.977 ± 0.069	3.54 ± 0.11

	112	113	114
Na- 24	4260 ± 110	4330 ± 110	5860 ± 150
Mg- 27	3570 ± 440	2900 ± 340	3440 ± 410
Al- 28	31900 ± 1100	33500 ± 1200	33200 ± 1100
Cl- 38	< 36	< 31	< 33
K - 42	16100 ± 1100	15900 ± 1200	16200 ± 1100
Ca- 49	6750 ± 850	8020 ± 910	3340 ± 530
Ti- 51	1460 ± 110	1190 ± 110	1190 ± 98
V - 52	27.7 ± 2.2	19.7 ± 1.9	21.5 ± 1.8
Mn- 56	211.6 ± 5.1	152.9 ± 3.8	162.1 ± 4.1
Sr- 87	< 120	< 110	< 99
Ba-139	470 ± 33	482 ± 31	388 ± 24
Dy-165	1.61 ± 0.19	1.05 ± 0.10	1.37 ± 0.13
U -235	1.626 ± 0.046	1.272 ± 0.036	1.086 ± 0.030
Ga- 72	< 11.0	< 9.5	< 9.4
As- 76	1.00 ± 0.23	1.26 ± 0.28	0.87 ± 0.22
Br- 82	< 1.09	< 0.95	< 0.95
Sb-122	0.276 ± 0.080	< 0.19	< 0.20
La-140	10.03 ± 0.38	9.40 ± 0.37	8.77 ± 0.33
Sm-153	1.067 ± 0.057	1.063 ± 0.061	1.037 ± 0.046
Yb-175	1.41 ± 0.17	0.88 ± 0.13	0.817 ± 0.076
W -187	< 1.47	< 1.08	< 1.09
Sc- 46	2.657 ± 0.043	2.342 ± 0.037	2.095 ± 0.034
Cr- 51	20.94 ± 0.73	12.82 ± 0.62	12.76 ± 0.52
Fe- 59	9750 ± 170	7050 ± 130	6060 ± 110
Co- 60	2.913 ± 0.099	2.444 ± 0.088	1.960 ± 0.073
Zn- 65	12.0 ± 2.1	< 2.9	5.2 ± 1.5
Rb- 86	52.5 ± 3.4	51.7 ± 3.3	45.5 ± 2.8
Zr- 95	311 ± 34	143 ± 28	195 ± 26
Sb-124	< 0.24	< 0.21	0.259 ± 0.084
Cs-134	2.33 ± 0.14	2.68 ± 0.14	1.70 ± 0.10
Ce-141	18.89 ± 0.64	17.84 ± 0.75	11.92 ± 0.41
Nd-147	< 6.4	< 3.9	6.2 ± 1.9
Eu-152	0.340 ± 0.030	0.363 ± 0.031	0.318 ± 0.025
Tb-160	0.195 ± 0.042	0.201 ± 0.035	0.169 ± 0.042
Lu-177	0.198 ± 0.013	0.1248 ± 0.0092	0.1316 ± 0.0082
Hf-181	10.03 ± 0.24	3.34 ± 0.10	6.53 ± 0.16
Ta-182	0.488 ± 0.078	0.313 ± 0.056	0.379 ± 0.055
Th-233	2.95 ± 0.10	2.565 ± 0.087	2.233 ± 0.076

	115	116	117
Na- 24	4160 ± 110	6760 ± 160	4930 ± 130
Mg- 27	2720 ± 320	6940 ± 650	4920 ± 560
Al- 28	28440 ± 1000	41200 ± 1400	44400 ± 1500
Cl- 38	< 34	< 45	< 36
K - 42	15400 ± 1000	18800 ± 1300	15900 ± 1300
Ca- 49	7170 ± 820	11900 ± 1200	8320 ± 940
Ti- 51	1084 ± 92	1610 ± 140	2530 ± 160
V - 52	20.1 ± 1.9	22.5 ± 2.1	52.7 ± 3.4
Mn- 56	136.3 ± 3.4	166.6 ± 4.2	370.4 ± 8.9
Sr- 87	< 100	< 130	< 150
Ba-139	531 ± 29	569 ± 40	418 ± 34
Dy-165	1.45 ± 0.11	2.02 ± 0.23	3.30 ± 0.23
U -235	1.214 ± 0.034	1.466 ± 0.041	2.580 ± 0.072
Ga- 72	< 9.3	< 15	< 10.5
As- 76	1.31 ± 0.19	2.00 ± 0.31	2.33 ± 0.26
Br- 82	< 0.91	< 1.45	< 1.08
Sb-122	< 0.18	< 0.28	0.372 ± 0.086
La-140	8.28 ± 0.31	12.81 ± 0.47	17.02 ± 0.56
Sm-153	1.013 ± 0.048	1.510 ± 0.074	2.02 ± 0.11
Yb-175	0.89 ± 0.10	1.06 ± 0.17	2.16 ± 0.14
W -187	< 1.04	< 2.0	< 1.51
Sc- 46	2.052 ± 0.033	3.671 ± 0.059	4.633 ± 0.069
Cr- 51	15.37 ± 0.54	22.42 ± 0.83	52.5 ± 1.3
Fe- 59	6770 ± 120	9930 ± 180	16300 ± 260
Co- 60	2.278 ± 0.075	4.01 ± 0.12	4.32 ± 0.12
Zn- 65	4.3 ± 1.6	< 2.8	< 4.3
Rb- 86	50.8 ± 2.8	67.6 ± 4.1	63.0 ± 3.9
Zr- 95	158 ± 22	270 ± 41	930 ± 81
Sb-124	< 0.20	< 0.31	< 0.28
Cs-134	2.35 ± 0.12	2.96 ± 0.17	5.16 ± 0.23
Ce-141	15.74 ± 0.50	24.65 ± 0.81	35.3 ± 1.4
Nd-147	< 3.3	< 7.5	19.1 ± 4.8
Eu-152	0.349 ± 0.028	0.475 ± 0.039	0.620 ± 0.042
Tb-160	0.161 ± 0.030	0.345 ± 0.046	0.464 ± 0.057
Lu-177	0.1505 ± 0.0087	0.198 ± 0.013	0.434 ± 0.019
Hf-181	5.33 ± 0.13	7.17 ± 0.19	29.06 ± 0.61
Ta-182	0.260 ± 0.047	0.377 ± 0.066	0.507 ± 0.070
Th-233	2.485 ± 0.082	3.81 ± 0.13	6.15 ± 0.18

	118	119	120
Na- 24	4930 ± 120	6640 ± 170	5050 ± 130
Mg- 27	4360 ± 460	2820 ± 470	3280 ± 430
Al- 28	40700 ± 1300	43100 ± 1400	39900 ± 1300
Cl- 38	< 35	< 47	< 41
K - 42	19100 ± 1200	17600 ± 1300	18200 ± 1300
Ca- 49	13100 ± 1200	6700 ± 890	8880 ± 920
Ti- 51	1720 ± 130	2190 ± 150	1740 ± 140
V - 52	37.5 ± 2.5	41.2 ± 2.7	41.7 ± 2.8
Mn- 56	257.4 ± 6.2	331.3 ± 8.0	349.1 ± 8.4
Sr- 87	< 120	< 160	< 150
Ba-139	530 ± 31	719 ± 40	618 ± 41
Dy-165	2.62 ± 0.18	2.95 ± 0.18	2.70 ± 0.24
U -235	1.821 ± 0.051	3.388 ± 0.095	3.265 ± 0.091
Ga- 72	< 9.4	< 12.5	< 12.3
As- 76	1.61 ± 0.24	1.68 ± 0.26	2.63 ± 0.30
Br- 82	< 0.94	< 1.24	< 1.24
Sb-122	0.327 ± 0.080	< 0.24	< 0.25
La-140	14.33 ± 0.47	17.72 ± 0.57	17.93 ± 0.57
Sm-153	2.096 ± 0.080	2.70 ± 0.11	2.28 ± 0.11
Yb-175	1.42 ± 0.11	2.39 ± 0.15	2.15 ± 0.16
W -187	< 1.08	< 1.7	< 1.7
Sc- 46	2.913 ± 0.044	3.219 ± 0.048	3.401 ± 0.054
Cr- 51	12.90 ± 0.55	32.10 ± 0.90	28.75 ± 0.95
Fe- 59	8750 ± 150	12720 ± 200	13020 ± 220
Co- 60	3.040 ± 0.091	3.395 ± 0.098	3.64 ± 0.11
Zn- 65	22.0 ± 2.2	13.9 ± 2.3	21.5 ± 2.7
Rb- 86	57.5 ± 3.4	68.6 ± 3.7	63.1 ± 4.0
Zr- 95	199 ± 27	833 ± 71	607 ± 58
Sb-124	0.38 ± 0.10	< 0.25	0.344 ± 0.096
Cs-134	4.60 ± 0.20	6.25 ± 0.26	6.00 ± 0.26
Ce-141	21.38 ± 0.66	35.4 ± 1.1	40.6 ± 1.4
Nd-147	< 3.6	11.5 ± 2.6	20.3 ± 4.1
Eu-152	0.526 ± 0.035	0.635 ± 0.040	0.588 ± 0.042
Tb-160	0.233 ± 0.041	0.399 ± 0.044	0.437 ± 0.054
Lu-177	0.1785 ± 0.0098	0.477 ± 0.019	0.396 ± 0.019
Hf-181	5.44 ± 0.14	25.81 ± 0.54	18.66 ± 0.41
Ta-182	0.403 ± 0.063	0.618 ± 0.077	0.750 ± 0.096
Th-233	3.58 ± 0.11	5.60 ± 0.16	5.94 ± 0.18

	121	122	123
Na- 24	4520 ± 120	6500 ± 160	4280 ± 110
Mg- 27	3220 ± 470	3680 ± 500	3750 ± 460
Al- 28	39600 ± 1300	44900 ± 1500	32900 ± 1200
Cl- 38	< 35	< 40	< 40
K - 42	18700 ± 1300	19400 ± 1300	16000 ± 1200
Ca- 49	25100 ± 1700	12400 ± 1300	15500 ± 1400
Ti- 51	1500 ± 130	2400 ± 180	1860 ± 140
V - 52	28.8 ± 2.4	48.3 ± 3.2	43.9 ± 2.9
Mn- 56	307.1 ± 7.4	333.9 ± 8.0	325.6 ± 7.8
Sr- 87	< 140	< 140	< 140
Ba-139	609 ± 40	644 ± 39	570 ± 33
Dy-165	2.12 ± 0.18	2.46 ± 0.17	1.58 ± 0.13
U -235	1.823 ± 0.051	3.064 ± 0.086	2.092 ± 0.059
Ga- 72	< 9.7	< 11.2	< 10.1
As- 76	< 0.76	1.36 ± 0.22	< 0.76
Br- 82	< 0.96	< 1.11	< 0.99
Sb-122	< 0.20	< 0.23	< 0.20
La-140	11.89 ± 0.43	17.13 ± 0.55	8.47 ± 0.33
Sm-153	1.565 ± 0.072	2.427 ± 0.100	1.180 ± 0.052
Yb-175	1.23 ± 0.12	1.49 ± 0.15	1.291 ± 0.098
W -187	< 1.30	< 1.50	< 1.13
Sc- 46	2.698 ± 0.043	2.653 ± 0.042	2.260 ± 0.036
Cr- 51	13.95 ± 0.64	19.19 ± 0.71	37.17 ± 0.93
Fe- 59	9110 ± 160	10460 ± 180	13350 ± 200
Co- 60	2.976 ± 0.095	2.960 ± 0.095	3.043 ± 0.091
Zn- 65	< 3.1	11.1 ± 2.0	< 2.2
Rb- 86	62.3 ± 3.6	59.7 ± 3.4	54.3 ± 3.2
Zr- 95	170 ± 24	323 ± 35	625 ± 56
Sb-124	< 0.21	< 0.20	< 0.24
Cs-134	4.61 ± 0.21	4.99 ± 0.22	2.85 ± 0.15
Ce-141	21.81 ± 0.89	22.74 ± 0.70	16.31 ± 0.52
Nd-147	11.3 ± 3.0	11.0 ± 2.5	10.0 ± 2.4
Eu-152	0.511 ± 0.037	0.550 ± 0.038	0.420 ± 0.031
Tb-160	0.305 ± 0.052	0.284 ± 0.043	0.156 ± 0.031
Lu-177	0.196 ± 0.011	0.233 ± 0.012	0.252 ± 0.012
Hf-181	7.24 ± 0.18	9.63 ± 0.23	16.73 ± 0.37
Ta-182	0.398 ± 0.062	0.561 ± 0.068	0.384 ± 0.054
Th-233	3.45 ± 0.11	3.93 ± 0.12	2.937 ± 0.094

	124	125	127
Na- 24	5990 ± 150	6650 ± 170	6630 ± 160
Mg- 27	3600 ± 530	3700 ± 490	2150 ± 410
Al- 28	47500 ± 1500	44000 ± 1500	36600 ± 1200
Cl- 38	< 45	< 41	< 38
K - 42	20200 ± 1300	19400 ± 1400	15600 ± 1100
Ca- 49	10300 ± 1000	5720 ± 930	7430 ± 970
Ti- 51	2570 ± 180	2140 ± 160	1950 ± 150
V - 52	49.1 ± 3.2	45.1 ± 3.0	33.6 ± 2.5
Mn- 56	319.1 ± 7.7	292.7 ± 7.0	259.5 ± 6.2
Sr- 87	< 150	< 140	< 120
Ba-139	584 ± 39	774 ± 43	642 ± 36
Dy-165	2.89 ± 0.23	3.22 ± 0.24	2.60 ± 0.18
U -235	3.75 ± 0.10	3.255 ± 0.091	2.604 ± 0.073
Ga- 72	< 14	< 11.9	< 10.6
As- 76	2.65 ± 0.36	1.53 ± 0.27	1.25 ± 0.21
Br- 82	< 1.40	< 1.18	< 1.05
Sb-122	< 0.28	0.228 ± 0.082	< 0.21
La-140	19.86 ± 0.64	18.46 ± 0.61	13.47 ± 0.46
Sm-153	2.69 ± 0.12	2.41 ± 0.12	1.839 ± 0.074
Yb-175	2.48 ± 0.17	2.31 ± 0.17	1.45 ± 0.12
W -187	< 1.69	< 1.6	< 1.22
Sc- 46	4.006 ± 0.060	3.314 ± 0.053	2.111 ± 0.034
Cr- 51	27.65 ± 1.00	23.61 ± 0.85	16.15 ± 0.66
Fe- 59	16120 ± 260	12920 ± 220	8060 ± 150
Co- 60	3.88 ± 0.12	3.04 ± 0.10	2.254 ± 0.079
Zn- 65	15.7 ± 2.9	< 3.7	18.7 ± 2.0
Rb- 86	77.4 ± 4.6	69.5 ± 4.1	54.8 ± 3.1
Zr- 95	571 ± 58	658 ± 62	415 ± 39
Sb-124	< 0.32	0.432 ± 0.092	0.278 ± 0.086
Cs-134	8.02 ± 0.34	7.07 ± 0.30	3.66 ± 0.17
Ce-141	38.9 ± 1.2	34.6 ± 1.4	19.17 ± 0.73
Nd-147	31.1 ± 7.1	13.3 ± 3.4	11.0 ± 2.2
Eu-152	0.632 ± 0.044	0.665 ± 0.043	0.479 ± 0.033
Tb-160	0.582 ± 0.076	0.400 ± 0.051	0.240 ± 0.039
Lu-177	0.387 ± 0.019	0.382 ± 0.018	0.247 ± 0.012
Hf-181	16.42 ± 0.36	20.19 ± 0.44	13.09 ± 0.29
Ta-182	0.734 ± 0.092	0.742 ± 0.088	0.607 ± 0.071
Th-233	6.23 ± 0.19	5.60 ± 0.17	3.40 ± 0.11

	128	129	130
Na- 24	5780 ± 140	5800 ± 140	3910 ± 100
Mg- 27	3100 ± 410	3270 ± 470	2900 ± 400
Al- 28	40700 ± 1300	39100 ± 1300	27800 ± 1000
Cl- 38	< 44	< 43	< 28
K - 42	18600 ± 1300	15200 ± 1100	14700 ± 1100
Ca- 49	11000 ± 1100	10030 ± 990	7030 ± 860
Ti- 51	2520 ± 170	1550 ± 130	1100 ± 100
V - 52	43.3 ± 3.0	32.2 ± 2.4	17.4 ± 1.6
Mn- 56	300.2 ± 7.2	239.8 ± 5.8	147.4 ± 3.7
Sr- 87	< 150	< 140	< 98
Ba-139	654 ± 37	498 ± 38	458 ± 28
Dy-165	2.85 ± 0.19	1.70 ± 0.20	0.901 ± 0.094
U -235	2.630 ± 0.074	1.442 ± 0.040	0.887 ± 0.025
Ga- 72	< 11.7	< 14	< 8.8
As- 76	1.76 ± 0.25	< 1.02	< 0.70
Br- 82	< 1.15	< 1.32	< 0.87
Sb-122	0.281 ± 0.080	< 0.26	< 0.18
La-140	15.36 ± 0.51	14.46 ± 0.49	8.09 ± 0.32
Sm-153	2.168 ± 0.091	1.741 ± 0.068	0.840 ± 0.052
Yb-175	1.89 ± 0.13	1.26 ± 0.13	0.64 ± 0.13
W -187	< 1.51	< 1.48	< 1.00
Sc- 46	3.056 ± 0.046	2.839 ± 0.045	2.001 ± 0.032
Cr- 51	27.37 ± 0.79	24.07 ± 0.82	11.32 ± 0.53
Fe- 59	12090 ± 190	10690 ± 180	6070 ± 120
Co- 60	3.368 ± 0.098	3.10 ± 0.10	2.513 ± 0.088
Zn- 65	15.4 ± 2.2	16.6 ± 2.5	< 2.7
Rb- 86	66.3 ± 3.6	57.3 ± 3.6	46.4 ± 3.1
Zr- 95	551 ± 51	247 ± 35	121 ± 22
Sb-124	< 0.25	0.37 ± 0.10	< 0.18
Cs-134	4.91 ± 0.21	4.01 ± 0.20	2.09 ± 0.13
Ce-141	31.29 ± 0.94	28.5 ± 1.1	13.74 ± 0.60
Nd-147	< 4.9	< 6.8	< 3.4
Eu-152	0.522 ± 0.034	0.540 ± 0.039	0.342 ± 0.029
Tb-160	0.349 ± 0.046	0.343 ± 0.058	0.241 ± 0.045
Lu-177	0.357 ± 0.016	0.213 ± 0.014	0.1092 ± 0.0076
Hf-181	16.57 ± 0.36	6.74 ± 0.18	4.68 ± 0.13
Ta-182	0.454 ± 0.062	0.438 ± 0.067	0.226 ± 0.052
Th-233	5.07 ± 0.15	3.99 ± 0.13	2.134 ± 0.077

	131	132	133
Na- 24	4590 ± 120	3698 ± 100	4190 ± 110
Mg- 27	2960 ± 520	2740 ± 420	4100 ± 570
Al- 28	30400 ± 1100	28800 ± 1100	30900 ± 1100
Cl- 38	< 40	< 49	< 42
K - 42	15300 ± 1200	12600 ± 1300	17300 ± 1400
Ca- 49	9400 ± 1000	11600 ± 1300	10500 ± 1000
Ti- 51	4370 ± 240	4680 ± 250	2830 ± 180
V - 52	130.1 ± 5.6	156.2 ± 6.6	69.6 ± 3.7
Mn- 56	658 ± 15	835 ± 19	445 ± 11
Sr- 87	< 170	< 220	< 170
Ba-139	591 ± 40	505 ± 39	453 ± 37
Dy-165	2.99 ± 0.23	2.50 ± 0.20	2.44 ± 0.24
U -235	3.82 ± 0.11	3.57 ± 0.10	3.050 ± 0.085
Ga- 72	< 9.4	< 10.3	< 11.6
As- 76	0.84 ± 0.19	< 0.76	< 0.89
Br- 82	< 0.92	< 0.99	< 1.13
Sb-122	< 0.18	0.319 ± 0.064	< 0.23
La-140	11.75 ± 0.41	10.17 ± 0.37	11.01 ± 0.40
Sm-153	1.652 ± 0.069	1.204 ± 0.058	1.359 ± 0.073
Yb-175	3.13 ± 0.16	3.66 ± 0.18	2.62 ± 0.16
W -187	< 1.26	< 1.17	< 1.5
Sc- 46	2.968 ± 0.047	3.707 ± 0.056	3.016 ± 0.048
Cr- 51	63.1 ± 1.5	109.4 ± 2.2	67.1 ± 1.5
Fe- 59	30930 ± 430	48050 ± 670	22130 ± 330
Co- 60	4.60 ± 0.12	6.50 ± 0.14	3.85 ± 0.11
Zn- 65	29.3 ± 3.0	69.8 ± 5.0	19.9 ± 2.8
Rb- 86	39.8 ± 3.1	44.8 ± 3.4	58.1 ± 4.2
Zr- 95	1540 ± 120	1920 ± 150	1500 ± 120
Sb-124	0.50 ± 0.12	0.359 ± 0.093	0.53 ± 0.13
Cs-134	2.39 ± 0.15	1.87 ± 0.13	3.08 ± 0.18
Ce-141	14.93 ± 0.51	21.01 ± 0.67	24.07 ± 0.82
Nd-147	< 5.0	< 6.1	< 8.8
Eu-152	0.401 ± 0.029	0.438 ± 0.032	0.427 ± 0.035
Tb-160	0.208 ± 0.036	0.269 ± 0.054	0.288 ± 0.049
Lu-177	0.510 ± 0.021	0.690 ± 0.026	0.566 ± 0.024
Hf-181	46.95 ± 0.94	59.0 ± 1.2	46.00 ± 0.97
Ta-182	0.554 ± 0.068	0.652 ± 0.080	0.634 ± 0.096
Th-233	3.93 ± 0.13	4.79 ± 0.14	4.87 ± 0.16

	134	135	136
Na- 24	7080 ± 180	3640 ± 95	4390 ± 110
Mg- 27	4930 ± 660	2320 ± 340	3110 ± 430
Al- 28	49300 ± 1600	27340 ± 980	32300 ± 1100
Cl- 38	< 44	< 29	< 37
K - 42	18300 ± 1400	14900 ± 1100	18800 ± 1300
Ca- 49	8800 ± 1100	9010 ± 940	11800 ± 1100
Ti- 51	2490 ± 170	1380 ± 110	1530 ± 130
V - 52	55.3 ± 3.5	24.4 ± 2.1	33.1 ± 2.6
Mn- 56	398.5 ± 9.6	193.6 ± 4.6	226.8 ± 5.4
Sr- 87	< 160	< 99	< 120
Ba-139	629 ± 39	517 ± 29	551 ± 31
Dy-165	3.78 ± 0.26	1.42 ± 0.13	1.63 ± 0.12
U -235	4.52 ± 0.13	1.294 ± 0.036	1.813 ± 0.051
Ga- 72	< 13	< 8.0	< 10.3
As- 76	3.02 ± 0.37	0.87 ± 0.23	0.83 ± 0.18
Br- 82	< 1.26	< 0.79	< 0.97
Sb-122	< 0.25	0.195 ± 0.057	0.241 ± 0.078
La-140	20.70 ± 0.64	8.40 ± 0.33	9.94 ± 0.36
Sm-153	2.58 ± 0.14	1.133 ± 0.043	1.565 ± 0.064
Yb-175	3.18 ± 0.19	0.91 ± 0.12	1.44 ± 0.13
W -187	< 1.7	< 0.93	< 1.12
Sc- 46	3.842 ± 0.058	1.503 ± 0.024	2.283 ± 0.037
Cr- 51	33.4 ± 1.0	10.58 ± 0.51	16.21 ± 0.58
Fe- 59	15390 ± 250	6670 ± 120	9760 ± 160
Co- 60	4.17 ± 0.12	1.850 ± 0.068	2.724 ± 0.084
Zn- 65	< 4.1	7.1 ± 1.5	21.9 ± 2.2
Rb- 86	70.5 ± 4.2	42.4 ± 2.7	58.9 ± 3.2
Zr- 95	1154 ± 97	230 ± 31	231 ± 26
Sb-124	< 0.27	< 0.16	0.40 ± 0.11
Cs-134	5.97 ± 0.26	2.34 ± 0.13	3.69 ± 0.17
Ce-141	38.4 ± 1.5	11.61 ± 0.41	21.42 ± 0.66
Nd-147	< 6.5	10.5 ± 2.5	< 3.8
Eu-152	0.686 ± 0.044	0.328 ± 0.029	0.457 ± 0.032
Tb-160	0.371 ± 0.055	0.135 ± 0.029	0.232 ± 0.032
Lu-177	0.574 ± 0.024	0.0983 ± 0.0071	0.224 ± 0.011
Hf-181	36.13 ± 0.76	4.43 ± 0.12	7.68 ± 0.18
Ta-182	0.86 ± 0.10	0.289 ± 0.051	0.359 ± 0.055
Th-233	7.09 ± 0.21	2.179 ± 0.076	3.14 ± 0.10

	137	138	139
Na- 24	3900 ± 100	4070 ± 110	4180 ± 100
Mg- 27	3010 ± 540	2750 ± 450	3490 ± 400
Al- 28	28500 ± 1100	30200 ± 1100	34400 ± 1200
Cl- 38	< 45	< 37	< 30
K - 42	13400 ± 1400	17700 ± 1500	14300 ± 1100
Ca- 49	8970 ± 980	9500 ± 1100	9500 ± 1000
Ti- 51	4740 ± 270	3120 ± 190	1360 ± 110
V - 52	139.8 ± 6.0	49.4 ± 3.3	29.1 ± 2.2
Mn- 56	692 ± 16	497 ± 12	198.5 ± 4.8
Sr- 87	< 200	< 160	< 100
Ba-139	440 ± 51	792 ± 45	400 ± 27
Dy-165	1.93 ± 0.24	2.71 ± 0.22	1.65 ± 0.13
U -235	4.61 ± 0.13	3.88 ± 0.11	1.357 ± 0.038
Ga- 72	< 11.8	< 9.6	< 8.9
As- 76	< 0.87	1.39 ± 0.18	1.51 ± 0.21
Br- 82	< 1.13	< 0.93	< 0.87
Sb-122	< 0.22	< 0.19	< 0.17
La-140	9.43 ± 0.36	12.23 ± 0.43	11.54 ± 0.40
Sm-153	1.173 ± 0.066	1.437 ± 0.088	< 0.021
Yb-175	3.92 ± 0.20	3.63 ± 0.18	0.925 ± 0.093
W -187	< 1.6	< 1.30	< 1.02
Sc- 46	3.727 ± 0.056	3.053 ± 0.049	2.354 ± 0.038
Cr- 51	136.3 ± 2.7	65.5 ± 1.5	11.93 ± 0.51
Fe- 59	40740 ± 570	16070 ± 260	7560 ± 140
Co- 60	6.06 ± 0.15	3.44 ± 0.11	2.849 ± 0.088
Zn- 65	50.3 ± 4.3	< 3.5	16.9 ± 1.9
Rb- 86	51.7 ± 4.2	44.9 ± 3.3	44.2 ± 2.8
Zr- 95	2750 ± 210	1740 ± 140	105 ± 17
Sb-124	0.46 ± 0.14	< 0.23	< 0.19
Cs-134	2.38 ± 0.18	2.71 ± 0.15	3.07 ± 0.15
Ce-141	20.01 ± 0.72	23.00 ± 0.78	14.75 ± 0.49
Nd-147	< 11.2	< 5.9	< 3.2
Eu-152	0.404 ± 0.037	0.446 ± 0.036	0.358 ± 0.029
Tb-160	0.285 ± 0.058	0.471 ± 0.060	0.177 ± 0.033
Lu-177	0.839 ± 0.034	0.676 ± 0.026	0.1368 ± 0.0088
Hf-181	83.9 ± 1.7	54.2 ± 1.1	4.83 ± 0.13
Ta-182	0.607 ± 0.089	0.556 ± 0.070	0.294 ± 0.047
Th-233	4.67 ± 0.15	5.05 ± 0.16	2.435 ± 0.083

	138 r1
Na- 24	3870 ± 100
Mg- 27	2480 ± 340
Al- 28	28500 ± 1100
Cl- 38	< 40
K - 42	15100 ± 1200
Ca- 49	8190 ± 1000
Ti- 51	2990 ± 180
V - 52	49.5 ± 3.1
Mn- 56	474 ± 11
Sr- 87	< 170
Ba-139	771 ± 41
Dy-165	2.96 ± 0.20
U -235	3.78 ± 0.11
Ga- 72	< 9.8
As- 76	1.33 ± 0.22
Br- 82	< 0.94
Sb-122	0.284 ± 0.087
La-140	12.09 ± 0.41
Sm-153	1.750 ± 0.077
Yb-175	3.35 ± 0.16
W -187	< 1.32
Sc- 46	2.985 ± 0.045
Cr- 51	57.4 ± 1.3
Fe- 59	15820 ± 240
Co- 60	3.093 ± 0.090
Zn- 65	15.2 ± 2.0
Rb- 86	50.1 ± 3.1
Zr- 95	1620 ± 130
Sb-124	0.33 ± 0.10
Cs-134	2.93 ± 0.15
Ce-141	26.49 ± 0.82
Nd-147	12.0 ± 3.0
Eu-152	0.451 ± 0.032
Tb-160	0.269 ± 0.037
Lu-177	0.633 ± 0.023
Hf-181	49.62 ± 0.99
Ta-182	0.607 ± 0.072
Th-233	5.09 ± 0.15

NOTE:

138 rl is a replicate analysis of 138.

Appendix I-C: Elemental concentrations in Quaternary older alluvium (QOA) samples

	goa-173	goa-160	goa-180
Na- 24	4390 ± 110	6330 ± 160	5970 ± 140
Mg- 27	6160 ± 540	4990 ± 550	4060 ± 430
Al- 28	53200 ± 1700	41500 ± 1400	37000 ± 1200
Cl- 38	< 42	< 38	< 33
K - 42	16800 ± 1200	18300 ± 1300	16500 ± 1100
Ca- 49	25100 ± 1700	17100 ± 1400	8670 ± 930
Ti- 51	2330 ± 160	1900 ± 140	2640 ± 150
V - 52	59.8 ± 3.5	31.1 ± 2.5	37.7 ± 2.4
Mn- 56	301.9 ± 7.2	241.2 ± 5.8	218.2 ± 5.2
Sr- 87	< 150	< 130	< 110
Ba-139	815 ± 46	580 ± 37	464 ± 29
Dy-165	1.49 ± 0.19	1.89 ± 0.15	2.29 ± 0.16
U -235	1.892 ± 0.053	1.840 ± 0.052	2.103 ± 0.059
Ga- 72	< 11.3	< 10.6	< 9.3
As- 76	1.47 ± 0.36	< 0.86	1.38 ± 0.21
Br- 82	2.92 ± 0.36	< 1.13	1.12 ± 0.25
Sb-122	< 0.24	< 0.23	< 0.20
La-140	11.43 ± 0.42	14.27 ± 0.49	14.46 ± 0.46
Sm-153	1.226 ± 0.050	1.900 ± 0.085	1.919 ± 0.075
Yb-175	0.81 ± 0.13	1.65 ± 0.17	1.90 ± 0.12
W -187	< 1.35	< 1.30	< 1.34
Sc- 46	1.749 ± 0.030	3.769 ± 0.057	2.756 ± 0.044
Cr- 51	18.06 ± 0.74	22.25 ± 0.73	24.55 ± 0.79
Fe- 59	16810 ± 270	11580 ± 200	9320 ± 160
Co- 60	4.75 ± 0.14	3.87 ± 0.11	2.995 ± 0.090
Zn- 65	17.6 ± 2.7	< 3.8	19.0 ± 2.1
Rb- 86	44.9 ± 3.6	65.5 ± 3.7	45.4 ± 2.9
Zr- 95	175 ± 27	370 ± 41	552 ± 50
Sb-124	< 0.23	< 0.24	0.298 ± 0.097
Cs-134	2.99 ± 0.17	3.37 ± 0.17	2.75 ± 0.14
Ce-141	23.44 ± 0.80	26.8 ± 1.1	19.75 ± 0.63
Nd-147	< 6.5	< 4.6	10.5 ± 2.2
Eu-152	0.589 ± 0.045	0.614 ± 0.041	0.410 ± 0.030
Tb-160	0.186 ± 0.047	0.356 ± 0.057	0.276 ± 0.037
Lu-177	0.152 ± 0.011	0.269 ± 0.013	0.233 ± 0.011
Hf-181	7.78 ± 0.20	11.09 ± 0.26	17.76 ± 0.39
Ta-182	0.332 ± 0.077	0.357 ± 0.054	0.511 ± 0.072
Th-233	2.517 ± 0.093	4.29 ± 0.13	3.69 ± 0.11

	9oa-177	9oa-161	9oa-157
Na- 24	6530 ± 160	5180 ± 130	6590 ± 160
Mg- 27	3790 ± 430	4000 ± 430	4340 ± 550
Al- 28	37600 ± 1300	38900 ± 1300	33600 ± 1200
Cl- 38	< 44	< 39	< 37
K - 42	17100 ± 1200	17100 ± 1200	15500 ± 1200
Ca- 49	3260 ± 590	9200 ± 1000	11300 ± 1100
Ti- 51	1670 ± 120	1840 ± 140	1440 ± 120
V - 52	23.3 ± 2.0	39.4 ± 2.6	21.6 ± 2.3
Mn- 56	240.1 ± 5.8	242.3 ± 5.8	203.5 ± 5.1
Sr- 87	109 ± 33	< 130	< 120
Ba-139	382 ± 26	503 ± 35	345 ± 27
Dy-165	1.81 ± 0.14	1.43 ± 0.17	1.38 ± 0.14
U -235	1.245 ± 0.035	1.954 ± 0.055	1.166 ± 0.033
Ga- 72	< 11.4	< 11.4	< 10.3
As- 76	1.34 ± 0.22	1.73 ± 0.26	1.30 ± 0.29
Br- 82	1.99 ± 0.48	1.27 ± 0.26	< 1.11
Sb-122	< 0.24	< 0.24	< 0.22
La-140	11.23 ± 0.39	14.53 ± 0.48	8.68 ± 0.35
Sm-153	1.387 ± 0.060	1.699 ± 0.083	1.120 ± 0.057
Yb-175	1.21 ± 0.11	1.56 ± 0.15	0.90 ± 0.11
W -187	< 1.35	< 1.6	< 1.24
Sc- 46	3.128 ± 0.047	3.260 ± 0.049	2.561 ± 0.041
Cr- 51	23.33 ± 0.75	24.95 ± 0.82	22.09 ± 0.73
Fe- 59	9090 ± 150	12360 ± 210	7800 ± 140
Co- 60	3.565 ± 0.100	3.96 ± 0.11	3.058 ± 0.098
Zn- 65	10.9 ± 2.1	< 4.2	14.6 ± 2.1
Rb- 86	59.9 ± 3.4	57.7 ± 3.6	52.8 ± 3.3
Zr- 95	285 ± 33	466 ± 49	290 ± 34
Sb-124	0.51 ± 0.15	< 0.28	0.45 ± 0.12
Cs-134	2.59 ± 0.14	3.16 ± 0.17	1.79 ± 0.11
Ce-141	23.39 ± 0.73	29.6 ± 1.1	17.12 ± 0.74
Nd-147	17.5 ± 4.2	14.8 ± 3.9	< 4.0
Eu-152	0.443 ± 0.033	0.572 ± 0.041	0.374 ± 0.031
Tb-160	0.193 ± 0.042	0.225 ± 0.046	0.213 ± 0.036
Lu-177	0.209 ± 0.011	0.312 ± 0.016	0.1710 ± 0.0097
Hf-181	8.78 ± 0.20	13.36 ± 0.31	10.94 ± 0.25
Ta-182	0.422 ± 0.057	0.445 ± 0.062	0.294 ± 0.050
Th-233	3.74 ± 0.12	4.35 ± 0.13	2.849 ± 0.094

	goa-178	goa-201	goa-184
Na- 24	6860 ± 160	7070 ± 170	5370 ± 130
Mg- 27	3520 ± 460	3790 ± 510	4290 ± 480
Al- 28	37600 ± 1300	40200 ± 1300	38300 ± 1300
Cl- 38	< 38	< 46	< 40
K - 42	16900 ± 1200	17300 ± 1200	17100 ± 1200
Ca- 49	3550 ± 670	4000 ± 710	8890 ± 900
Ti- 51	1750 ± 130	2130 ± 150	1820 ± 140
V - 52	24.6 ± 2.2	28.4 ± 2.4	29.0 ± 2.3
Mn- 56	258.8 ± 6.2	229.0 ± 5.5	240.2 ± 5.8
Sr- 87	< 120	< 140	< 130
Ba-139	400 ± 28	461 ± 30	509 ± 35
Dy-165	1.98 ± 0.15	2.36 ± 0.16	1.82 ± 0.19
U -235	1.392 ± 0.039	1.713 ± 0.048	1.559 ± 0.044
Ga- 72	< 10.1	< 11.9	< 11.9
As- 76	1.74 ± 0.26	1.91 ± 0.27	1.56 ± 0.25
Br- 82	1.18 ± 0.28	< 1.25	2.15 ± 0.31
Sb-122	< 0.21	0.327 ± 0.065	< 0.25
La-140	11.60 ± 0.41	14.50 ± 0.48	13.66 ± 0.46
Sm-153	1.429 ± 0.057	1.972 ± 0.081	1.633 ± 0.073
Yb-175	1.33 ± 0.13	1.61 ± 0.13	1.33 ± 0.13
W -187	< 1.42	< 1.40	< 1.65
Sc- 46	2.568 ± 0.041	3.458 ± 0.052	3.450 ± 0.052
Cr- 51	18.42 ± 0.63	24.21 ± 0.75	24.13 ± 0.82
Fe- 59	7760 ± 140	10580 ± 170	11180 ± 190
Co- 60	3.034 ± 0.094	3.64 ± 0.10	4.01 ± 0.12
Zn- 65	12.9 ± 1.9	22.0 ± 2.5	< 2.0
Rb- 86	48.3 ± 2.9	60.2 ± 3.5	67.2 ± 3.9
Zr- 95	319 ± 35	359 ± 37	354 ± 41
Sb-124	0.40 ± 0.11	0.49 ± 0.11	0.50 ± 0.13
Cs-134	1.95 ± 0.12	3.49 ± 0.17	3.11 ± 0.17
Ce-141	17.35 ± 0.56	30.00 ± 0.93	28.23 ± 0.90
Nd-147	< 3.4	14.0 ± 3.5	< 6.7
Eu-152	0.374 ± 0.031	0.510 ± 0.035	0.475 ± 0.036
Tb-160	0.196 ± 0.030	0.237 ± 0.033	0.200 ± 0.042
Lu-177	0.1633 ± 0.0090	0.302 ± 0.014	0.223 ± 0.012
Hf-181	8.93 ± 0.21	11.30 ± 0.26	9.61 ± 0.23
Ta-182	0.395 ± 0.060	0.698 ± 0.079	0.484 ± 0.072
Th-233	3.023 ± 0.097	4.56 ± 0.14	3.92 ± 0.13

	qoa-194	qoa-187	qoa-185
Na- 24	6560 ± 160	6340 ± 160	6420 ± 160
Mg- 27	5800 ± 740	5420 ± 590	5770 ± 550
Al- 28	45900 ± 1600	47000 ± 1600	53300 ± 1700
Cl- 38	< 44	< 42	< 47
K - 42	18100 ± 1500	19000 ± 1400	20800 ± 1400
Ca- 49	33300 ± 2200	25300 ± 1900	8000 ± 1000
Ti- 51	2340 ± 180	2040 ± 140	2990 ± 170
V - 52	37.8 ± 3.0	42.0 ± 2.9	58.4 ± 3.3
Mn- 56	384.0 ± 9.2	268.4 ± 6.4	240.0 ± 5.8
Sr- 87	< 160	153 ± 43	< 140
Ba-139	545 ± 39	626 ± 40	544 ± 33
Dy-165	2.16 ± 0.19	2.59 ± 0.18	3.62 ± 0.21
U -235	1.791 ± 0.050	1.920 ± 0.054	2.263 ± 0.063
Ga- 72	< 11.4	< 10.9	< 13
As- 76	< 0.96	3.50 ± 0.34	4.13 ± 0.33
Br- 82	1.40 ± 0.34	4.38 ± 0.40	2.08 ± 0.27
Sb-122	< 0.25	0.44 ± 0.10	0.558 ± 0.094
La-140	15.43 ± 0.52	16.44 ± 0.53	22.58 ± 0.68
Sm-153	1.978 ± 0.089	2.374 ± 0.085	3.27 ± 0.13
Yb-175	1.28 ± 0.13	1.76 ± 0.17	2.16 ± 0.15
W -187	< 1.6	< 1.18	< 1.42
Sc- 46	3.722 ± 0.056	3.665 ± 0.055	4.915 ± 0.074
Cr- 51	23.88 ± 0.81	20.16 ± 0.73	33.52 ± 0.97
Fe- 59	12760 ± 220	10920 ± 190	17070 ± 260
Co- 60	4.80 ± 0.13	4.11 ± 0.12	5.25 ± 0.13
Zn- 65	< 3.9	24.8 ± 2.6	25.2 ± 2.9
Rb- 86	68.7 ± 4.3	53.2 ± 3.5	79.6 ± 4.4
Zr- 95	314 ± 40	239 ± 31	368 ± 41
Sb-124	< 0.25	0.41 ± 0.11	< 0.33
Cs-134	3.48 ± 0.18	3.35 ± 0.17	5.75 ± 0.25
Ce-141	28.8 ± 1.2	24.18 ± 0.77	43.6 ± 1.3
Nd-147	< 5.0	< 4.1	20.9 ± 4.0
Eu-152	0.602 ± 0.043	0.557 ± 0.041	0.835 ± 0.048
Tb-160	0.341 ± 0.070	0.306 ± 0.050	0.474 ± 0.054
Lu-177	0.254 ± 0.014	0.233 ± 0.013	0.377 ± 0.016
Hf-181	7.86 ± 0.20	8.22 ± 0.21	12.57 ± 0.29
Ta-182	0.510 ± 0.079	0.472 ± 0.066	0.801 ± 0.087
Th-233	4.52 ± 0.14	4.07 ± 0.13	6.78 ± 0.20

	qoa-186	qoa-172	qoa-188
Na- 24	5000 ± 130	5600 ± 140	5140 ± 130
Mg- 27	6260 ± 590	4810 ± 510	5030 ± 540
Al- 28	50800 ± 1600	42800 ± 1500	45700 ± 1500
Cl- 38	< 43	< 36	< 38
K - 42	16600 ± 1200	17600 ± 1400	16000 ± 1300
Ca- 49	19300 ± 1600	8000 ± 1000	16500 ± 1500
Ti- 51	2380 ± 160	1760 ± 140	2020 ± 140
V - 52	42.2 ± 2.9	39.8 ± 2.8	36.1 ± 2.6
Mn- 56	280.2 ± 6.7	212.7 ± 5.3	263.3 ± 6.3
Sr- 87	< 150	< 130	< 130
Ba-139	379 ± 34	460 ± 33	438 ± 31
Dy-165	3.03 ± 0.25	2.27 ± 0.17	3.21 ± 0.20
U -235	2.126 ± 0.060	1.391 ± 0.039	1.708 ± 0.048
Ga- 72	< 13	< 11.0	< 10.3
As- 76	4.52 ± 0.40	5.05 ± 0.42	3.13 ± 0.32
Br- 82	4.21 ± 0.59	3.10 ± 0.34	4.19 ± 0.39
Sb-122	< 0.28	0.321 ± 0.071	0.486 ± 0.096
La-140	21.71 ± 0.67	14.89 ± 0.52	20.48 ± 0.63
Sm-153	2.79 ± 0.11	1.988 ± 0.091	2.83 ± 0.10
Yb-175	2.52 ± 0.23	1.16 ± 0.11	1.97 ± 0.14
W -187	< 1.5	< 1.35	< 1.08
Sc- 46	5.086 ± 0.076	3.680 ± 0.055	3.969 ± 0.060
Cr- 51	30.4 ± 1.0	21.42 ± 0.79	20.88 ± 0.79
Fe- 59	14740 ± 250	11760 ± 200	11350 ± 190
Co- 60	5.47 ± 0.15	6.70 ± 0.16	4.13 ± 0.12
Zn- 65	32.5 ± 3.5	< 3.9	31.0 ± 2.9
Rb- 86	75.8 ± 4.7	56.6 ± 3.6	50.1 ± 3.2
Zr- 95	314 ± 42	246 ± 36	301 ± 36
Sb-124	0.41 ± 0.11	< 0.92	< 0.26
Cs-134	5.88 ± 0.28	3.13 ± 0.16	3.47 ± 0.19
Ce-141	45.5 ± 1.6	27.3 ± 1.1	28.0 ± 1.0
Nd-147	< 8.6	14.2 ± 3.2	23.3 ± 5.3
Eu-152	0.601 ± 0.045	0.578 ± 0.041	0.648 ± 0.043
Tb-160	0.518 ± 0.070	0.285 ± 0.046	0.325 ± 0.046
Lu-177	0.302 ± 0.017	0.223 ± 0.012	0.238 ± 0.012
Hf-181	10.03 ± 0.25	7.05 ± 0.18	8.44 ± 0.21
Ta-182	0.587 ± 0.087	0.441 ± 0.075	0.534 ± 0.085
Th-233	6.89 ± 0.21	4.37 ± 0.14	4.88 ± 0.15

	qoa-195	qoa-200	qoa-194 r1
Na- 24	5380 ± 130	6760 ± 160	6150 ± 150
Mg- 27	4320 ± 450	5460 ± 590	4310 ± 520
Al- 28	41400 ± 1400	49200 ± 1600	44100 ± 1500
Cl- 38	< 40	< 46	< 44
K - 42	18900 ± 1300	17900 ± 1300	19600 ± 1400
Ca- 49	2930 ± 520	8350 ± 920	34100 ± 2300
Ti- 51	2330 ± 150	2060 ± 160	1960 ± 150
V - 52	36.1 ± 2.4	40.4 ± 2.6	34.0 ± 2.8
Mn- 56	215.7 ± 5.2	271.9 ± 6.5	372.3 ± 8.9
Sr- 87	< 130	< 150	< 160
Ba-139	586 ± 32	523 ± 37	519 ± 35
Dy-165	2.32 ± 0.16	2.53 ± 0.21	1.87 ± 0.16
U -235	2.340 ± 0.066	1.978 ± 0.055	1.554 ± 0.044
Ga- 72	< 10.7	< 14	< 11.6
As- 76	1.38 ± 0.19	3.32 ± 0.36	1.98 ± 0.28
Br- 82	1.64 ± 0.24	3.20 ± 0.41	1.02 ± 0.24
Sb-122	0.283 ± 0.067	< 0.29	0.369 ± 0.097
La-140	14.16 ± 0.47	19.49 ± 0.62	14.61 ± 0.51
Sm-153	1.915 ± 0.080	2.38 ± 0.10	1.905 ± 0.088
Yb-175	1.51 ± 0.12	1.73 ± 0.16	1.07 ± 0.12
W -187	< 1.43	< 1.53	< 1.37
Sc- 46	3.477 ± 0.052	4.476 ± 0.067	3.672 ± 0.055
Cr- 51	23.14 ± 0.74	25.74 ± 0.93	22.90 ± 0.82
Fe- 59	12460 ± 200	12850 ± 220	12300 ± 210
Co- 60	3.80 ± 0.10	4.72 ± 0.13	3.80 ± 0.12
Zn- 65	< 2.5	< 5.0	< 3.9
Rb- 86	66.9 ± 3.5	64.9 ± 4.2	64.3 ± 3.9
Zr- 95	383 ± 40	331 ± 44	205 ± 30
Sb-124	0.341 ± 0.089	0.62 ± 0.17	< 0.27
Cs-134	3.56 ± 0.17	4.86 ± 0.23	3.53 ± 0.19
Ce-141	27.99 ± 0.84	36.3 ± 1.1	28.7 ± 1.2
Nd-147	22.2 ± 4.5	12.4 ± 3.3	16.5 ± 3.6
Eu-152	0.593 ± 0.039	0.615 ± 0.043	0.521 ± 0.039
Tb-160	0.258 ± 0.039	0.569 ± 0.080	0.276 ± 0.048
Lu-177	0.294 ± 0.013	0.280 ± 0.016	0.202 ± 0.012
Hf-181	12.98 ± 0.29	7.50 ± 0.19	6.84 ± 0.18
Ta-182	0.631 ± 0.079	0.604 ± 0.088	0.419 ± 0.065
Th-233	4.45 ± 0.13	5.55 ± 0.17	4.35 ± 0.13

NOTE:

Qoa-194 rl is a replicate analysis of qoa-194.

	qoa-201 r1	
Na- 24	6630	± 160
Mg- 27	3640	± 430
Al- 28	38400	± 1300
Cl- 38		< 37
K - 42	17700	± 1200
Ca- 49	3560	± 590
Ti- 51	1680	± 130
V - 52	27.7	± 2.4
Mn- 56	215.9	± 5.2
Sr- 87		< 110
Ba-139	442	± 29
Dy-165	2.14	± 0.16
U -235	1.593	± 0.045
Ga- 72		< 10.3
As- 76	1.92	± 0.33
Br- 82		< 1.07
Sb-122		< 0.21
La-140	13.14	± 0.45
Sm-153	1.665	± 0.067
Yb-175	1.37	± 0.12
W -187		< 1.41
Sc- 46	2.671	± 0.043
Cr- 51	16.76	± 0.62
Fe- 59	7670	± 140
Co- 60	2.645	± 0.087
Zn- 65	24.1	± 2.2
Rb- 86	46.7	± 2.9
Zr- 95	251	± 29
Sb-124		< 0.19
Cs-134	2.78	± 0.14
Ce-141	18.35	± 0.59
Nd-147		< 3.5
Eu-152	0.391	± 0.030
Tb-160	0.251	± 0.042
Lu-177	0.1662	± 0.0095
Hf-181	7.36	± 0.18
Ta-182	0.384	± 0.061
Th-233	3.24	± 0.10

NOTE:

Qoa-201 rl is a replicate analysis of qoa-201.

Appendix I-D: Elemental concentrations in rock standards

	gxr-2	gxr-1	sl-1
Na- 24	598 ± 29	5910 ± 150	1469 ± 68
Mg- 27	3750 ± 490	9570 ± 870	8400 ± 1800
Al- 28	84100 ± 2500	219700 ± 5900	122600 ± 3900
Cl- 38	130 ± 16	< 67	< 126
K - 42	< 2900	11900 ± 1700	8700 ± 2500
Ca- 49	8290 ± 990	7500 ± 1000	< 2100
Ti- 51	< 520	3490 ± 280	5360 ± 640
V - 52	74.8 ± 4.4	56.6 ± 4.3	179 ± 11
Mn- 56	829 ± 19	1062 ± 24	3649 ± 84
Sr- 87	< 210	< 300	< 610
Ba-139	1161 ± 58	2400 ± 100	< 310
Dy-165	4.32 ± 0.28	3.18 ± 0.25	3.49 ± 0.74
U -235	30.45 ± 0.85	2.959 ± 0.083	3.92 ± 0.11
Ga- 72	15.1 ± 3.9	28.4 ± 5.7	24.0 ± 6.4
As- 76	347.6 ± 7.3	23.12 ± 0.76	27.80 ± 0.95
Br- 82	< 1.1	2.95 ± 0.39	4.26 ± 0.51
Sb-122	96.2 ± 2.9	39.7 ± 1.2	0.92 ± 0.13
La-140	7.51 ± 0.31	25.15 ± 0.75	48.9 ± 1.4
Sm-153	2.14 ± 0.20	3.36 ± 0.13	6.77 ± 0.26
Yb-175	1.59 ± 0.17	1.43 ± 0.14	2.82 ± 0.20
W -187	114 ± 17	< 1.8	< 1.8
Sc- 46	1.283 ± 0.023	6.86 ± 0.10	17.70 ± 0.27
Cr- 51	9.47 ± 0.95	41.7 ± 1.2	124.7 ± 2.9
Fe- 59	168600 ± 2200	19610 ± 290	68040 ± 950
Co- 60	5.69 ± 0.15	8.88 ± 0.20	19.99 ± 0.38
Zn- 65	489 ± 30	484 ± 30	185 ± 13
Rb- 86	< 15	76.9 ± 4.7	107.5 ± 7.8
Zr- 95	< 150	189 ± 34	< 240
Sb-124	100.6 ± 3.1	50.2 ± 1.8	1.35 ± 0.26
Cs-134	2.04 ± 0.20	5.36 ± 0.25	7.96 ± 0.41
Ce-141	8.40 ± 0.32	53.5 ± 1.6	108.6 ± 3.3
Nd-147	< 7.2	23.2 ± 4.6	< 16
Eu-152	0.437 ± 0.042	0.702 ± 0.051	1.571 ± 0.080
Tb-160	0.89 ± 0.12	0.538 ± 0.078	1.23 ± 0.17
Lu-177	0.226 ± 0.020	0.309 ± 0.017	0.531 ± 0.030
Hf-181	0.887 ± 0.090	7.83 ± 0.20	4.56 ± 0.18
Ta-182	< 0.55	0.92 ± 0.12	0.98 ± 0.13
Th-233	1.754 ± 0.091	8.73 ± 0.24	13.70 ± 0.40

NOTE:

Gxr-2 is a soil standard from the USGS.

Gxr-1 is a jasperoid standard from the USGS. The second analysis for gxr-1 is a replicate.

Sl-1 is an IAEA standard supplied by Carl Popp.

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                 gxr-1

Na- 24          5760 ± 160
Mg- 27          9490 ± 920
Al- 28        216600 ± 5800
Cl- 38               < 71
K - 42         11300 ± 1700
Ca- 49          8600 ± 1200
Ti- 51          2610 ± 230
V - 52          51.4 ± 4.6
Mn- 56          1050 ± 24
Sr- 87               < 320
Ba-139          2380 ± 110
Dy-165          3.52 ± 0.29
U -235         2.902 ± 0.081
Ga- 72          26.8 ± 5.9
As- 76         23.21 ± 0.84
Br- 82          3.40 ± 0.50
Sb-122          41.2 ± 1.3
La-140         25.69 ± 0.82
Sm-153          3.25 ± 0.13
Yb-175          2.30 ± 0.27
W -187          2.56 ± 0.69
Sc- 46          6.84 ± 0.10
Cr- 51          42.2 ± 1.3
Fe- 59         19500 ± 310
Co- 60          8.64 ± 0.21
Zn- 65           478 ± 30
Rb- 86          72.8 ± 4.9
Zr- 95           265 ± 42
Sb-124          49.4 ± 1.8
Cs-134          5.62 ± 0.28
Ce-141          53.3 ± 1.6
Nd-147          16.1 ± 5.0
Eu-152         0.730 ± 0.056
Tb-160         0.382 ± 0.078
Lu-177         0.273 ± 0.017
Hf-181          8.05 ± 0.21
Ta-182          1.19 ± 0.15
Th-233          8.75 ± 0.25
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