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NURE GEOCHEMICAL INVESTIGATIONS IN THE EASTERN UNITED STATES

by

V. Price

Savannah River Laboratory
E. I. du Pont de Nemours & Company
Aiken, S. C. 29801

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V. Price
Savannah River Laboratory
E. I. du Pont de Nemours & Company
Aiken, South Carolina 29801

ABSTRACT

The Savannah River Laboratory (SRL) is conducting a hydrogeochemical and stream sediment reconnaissance of the eastern United States as part of the National Uranium Resource Evaluation (NURE) program of the United States Department of Energy (DOE). An extensive development program is underway to provide field techniques and interpretive models for the reconnaissance survey. Manuals for subcontracted sample collection, based on SRL development work, have been published. SRL reports, together with information developed by other DOE subcontractors, will be used to define areas for detailed resource appraisal. All NURE program information will be released to the public by the Grand Junction, Colorado, office (GJ) of DOE. In addition to their value in minerals exploration and resource appraisal, these reports will provide an environmental data base of unprecedented scope.

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Stream samples are collected at a density of one per 13 square kilometers in crystalline rock areas and 25 square kilometers in sedimentary rock areas. Stream sediment (-40 mesh) is taken at each site, and stream water is concentrated on ion exchange resin in some areas. Ground water samples are collected at an average density of about one site per 20 square kilometers.

Measurements made at each site include alkalinity, pH, and conductivity of water. Dissolved ions are recovered quantitatively in the field from one liter of water with ion exchange resin. Sample preservation problems are avoided by this method.

Measurements of the radon and helium contents of ground water samples were made on a semiregional scale in pilot studies.

Samples are analyzed at SRL by neutron activation techniques. Concentrations of uranium and about 20 other elements are determined in concentrated water samples. Automated pneumatic transfer of samples and automated data processing permit analysis of up to 4000 samples per week.

Results from several orientation studies are discussed including: a Triassic Basin area near Sanford, North Carolina; the North and South Carolina Coastal Plain; and from reconnaissance studies in the Carolinas-Virginia Piedmont and Blue Ridge areas.

In the Sanford Triassic Basin area, uranium content averaged 0.035 ppb in ground water from the organic-rich Cumnock formation and 1.8 ppb in the arkosic Pekin formation. Tuffaceous metavolcanics in the adjacent Carolina Slate Belt yielded water averaging about 0.1 ppb U.

Studies in the Carolina Piedmont and Coastal Plain include helium, He/Ne, and radon determinations in ground water. Background helium contents average about 5 ppm; anomalous samples range up to over twenty times background.

During the next several years, an extensive data base will be established and published for elemental concentrations in stream sediment and surface and ground waters over much of the United States.

Development is in progress in field methods, analytical methods, data management, interpretation of geochemical data, and models for the use of regional and semiregional geochemical data in resource appraisal.

INTRODUCTION

The National Uranium Resource Evaluation (NURE) Program was established to evaluate domestic uranium resources in the continental United States and to identify areas favorable for uranium exploration. The Grand Junction Office (GJ) of the Department of Energy (DOE) is responsible for administering and coordinating NURE program efforts. The NURE program consists of five parts: 1) Hydrogeochemical and Stream Sediment Reconnaissance Survey, 2) Aerial Radiometric Survey, 3) Surface Geologic Investigations, 4) Drilling for Geologic Information, and 5) Geophysical Technology Development. Inputs to the NURE program come from DOE prime contractors, DOE-sponsored research and development, the uranium industry, U. S. Geological Survey, U. S. Bureau of Mines, other federal and state government agencies, and independent sources.

The Savannah River Laboratory (SRL) has responsibility for hydrogeochemical and stream sediment reconnaissance (HSSR) of 2.2 million square kilometers in 30 eastern states. Other DOE laboratories are responsible for similar reconnaissance in the rest of the continental United States, including Alaska (Figure 1).

On Figure 2A, the area sampled is indicated by cross hatching. Areas for which reports have been issued through March 1978 are shaded. Figure 2B shows the area scheduled to be sampled and reported by October 1978 by hatching and shading, respectively.

The Savannah River Laboratory has conducted and is maintaining an extensive development program to support the regional geochemical reconnaissance in its area of responsibility. Sampling densities, sampling equipment and techniques, analytical techniques (including the types of analyses required), and results obtained from sampling of different media have been evaluated (SRL a-1). Orientation or pilot studies have been conducted in model areas of known uranium mineral occurrences or where geologic conditions seem favorable for the accumulation of uranium. Results of those studies have been useful in designing and conducting the regional reconnaissance.

The primary objective of this paper is to summarize the technical status and results of SRL pilot and reconnaissance studies in the eastern United States. References to more-detailed technical papers acknowledge a few of the people who developed methods and provided guidance for the work summarized here.

In the introduction to his classic textbook *Economic Mineral Deposits*, Bateman (1950) states: "With waning discovery of obvious mineral outcrops, search must be directed to the less obvious deposits, of which vast numbers must be hidden by the ubiquitous overburden. Every art of geology must be employed to this end, and it promises to become the important work of the economic geologist."

When Bateman's statement was written, geochemical exploration was a new and little known art — his book scarcely notes its existence. Today geochemistry offers the geologist a powerful tool in the study of the geology of an area. Elemental distributions are sensitive to thermal and pressure gradients in the earth (Carpenter, 1968). And elemental ratios (e.g., K/Rb) may be used to determine subtle but important differences between rocks of similar gross mineralogy and composition.

Just as there is scarcely a stream that has not been panned for gold, there is scarcely an outcrop that was not checked for radioactivity during the great uranium search of the late 1940's and early 1950's when there was such a market for geiger counters that Sears, Roebuck and Co. sold their own "Tower Brand." It is logical to assume that, in accessible areas, most uranium deposits with significant surficial expression have been found.

Thus, the art of geochemistry must be as sophisticated as our science allows. If geochemistry does not help the geologist to "see into the ground," it will be of little value. SRL's responsibility is not merely to complete a sampling program, but to produce results useful in uranium resource assessment.

I was recently approached by two prospectors who had transferred their attentions from the Arctic Islands to the piedmont of Georgia. "Uranium," they stated knowingly, "like gold, is where you find it." Surely the art of geology passed this stage with Werner and Agricola. With modern exploration comes the underlying assumption that deposits of useful commodities do not occur independently of the rocks that encompass them. If this assumption is true, then an integrated approach using field geology, geophysics, and geochemistry should allow the knowledgeable geologist to predict the presence or absence of a given sort of mineral deposit. But the geologist must constantly remember that each of his tools measures only a fragment of the whole, and his own scientific intuition and experience must supply much of the integration.

SAMPLE COLLECTION AND QUALITY ASSURANCE

Reconnaissance sampling is subcontracted by SRL to firms and individuals on the basis of competitive bidding. Reconnaissance sampling personnel are required to have completed at least one year's courses in geology and chemistry and are trained by SRL staff members according to procedures in the SRL documents *Field Manual for Stream Water and Sediment Reconnaissance* (Ferguson and others, 1977) and *Field Manual for Ground Water Reconnaissance* (Ferguson and others, 1976). Sampling personnel for pilot studies are normally professional geologists and often contribute substantially to the design of the study.

A minimum of five sediment subsamples are composited from each stream site. Approximately 400 g of sediment passing a 420-μm (U.S. Std. 40-mesh) screen are collected. The nominal stream sampling density in crystalline rock areas is one site per 13 square kilometers (5 sq mi) and in areas of relatively undisturbed sedimentary rocks, one site per 25 sq km (10 sq mi). Stream water is also collected in most areas.

Ground water sampling sites are spaced at about one per 20 to 25 sq km in crystalline and 15 to 20 sq km in sedimentary terranes. Sampling densities are increased where there is thought to be uranium potential.

Field measurements made at each reconnaissance site include pH, alkalinity, and conductivity of water. Pilot sites include other measurements, including Eh and field determination of anion concentrations.

Water samples are filtered (0.8 μm) in the field using a pressure filter developed at SRL. After filtration, the water sample is stirred with 10 g of ion exchange resin, using a battery-driven stirrer. The resin is collected and returned to the laboratory for analysis.

Two to five percent of the sampled sites are routinely checked by SRL personnel or by separate subcontractors to assure the reported field locations are accurate. Based on these quality assurance checks, more than 98% of the sampled sites have been judged to be located as accurately as they could be plotted on county road maps. No evidence has been discovered of malfeasance by the sampling teams. Most sites that were mapped incorrectly were found to be within 300 meters of their correct locations. Thus, the goals of a regional reconnaissance have not been compromised by mapping errors. Details of the quality assurance program are given elsewhere (SRL i-1).

SAMPLE ANALYSIS

Reconnaissance sediment samples are dried at 105°C, sieved to <149 μm, blended, coned, and quartered. Half-gram aliquots of the <149-μm material are packed in ultrapure polyethylene capsules for neutron activation analysis (NAA). The encapsulated samples in batches of 25, including one standard and one blank, are loaded into an NAA pneumatic system. Transport into the irradiation assembly and counting stations and the collection and processing of data are computer-controlled. Samples from pilot studies are sieved into several fractions and may be analyzed by alternative methods (e.g., emission spectroscopy).

Calibration standards for NAA include accepted reference materials such as rocks distributed by the U.S. Geological Survey and the Spectroscopy Society of Canada. Standards run routinely with samples are prepared and blended by SRL and then are calibrated by independent and government laboratories. Appropriate standard data are published with each SRL NURE data release.

Resin samples are handled only under ultraclean conditions. They are dried at 105°C, sealed in ultrapure polyethylene capsules, and analyzed by NAA similarly to sediment samples. SRL and DOE interlaboratory standards are used to maintain quality assurance.

The ion exchange resin used in this work is specially prepared, mixed cation-anion resin which collects all dissolved ions, including uranium (Baucom, et al., 1977). The resin is ultrapure to permit NAA for uranium and other elements. Resin of 100- to 200-mesh size is used because coarser sizes require too much field time for complete ion exchange, and finer mesh is difficult to recover quantitatively.

A novel feature of the cation-anion resin is that it is used in the hydronium and hydroxide forms, respectively. All exchange reactions with the resin yield water, and the chemical driving force for quantitative exchange is very great. Not only charged uranium species but also neutral complexes can be collected on this resin. The amount of filtered water allowed to react with the resin is normally exactly 1 liter. It is possible for 1 liter of water to contain more dissolved solids than can be removed by the resin. Conductivity indicates the concentration of dissolved material present and is used to estimate the volume of water to be ion exchanged.

Table 1 summarizes the efficiency with which various elements are concentrated by the ion exchange resin. Samples (100 mL each) of filtered natural water before and after ion exchange were slowly evaporated to dryness on spark source mass spectrometry electrodes in "Class 100" clean benches. Greater than 90% of all elements detected were removed by the resin. Uranium recovery was greater than 99.9% from natural water containing several parts per billion uranium. Fission-track analyses were made before and after ion exchange. Hundreds of tracks were counted from residues of unexchanged water, while no tracks above background were observed from residues of exchanged water.

In other tests, natural waters doped with trace ^{233}U and 3 meq/L each of sodium, calcium, chloride, and sulfate ions were exchanged and measured radiometrically. Uranium recovery was greater than 99%, and total ion recovery was 99.9% despite the fact the resin was 70% saturated.

The results of reproducibility tests of uranium concentration and analysis are summarized in Figure 3. Multiple samples were taken from 10 sites in North Carolina. The filtered water samples (1 liter each) were concentrated on ion exchange resin in the field. The recovered resins were activated, and uranium was determined by counting the delayed neutrons. A 10-mL sample of filtered water from one site was also analyzed by NAA. Recovery of uranium was quantitative within experimental error. These and other features of the SRL field and analytical development program have been reported in more detail in SRL quarterly reports issued during 1975 through 1977 (SRL a-1).

RADON AND HELIUM MEASUREMENTS

Radon and helium are being measured in pilot studies of ground water samples. They appear to be promising candidates for followup or anomaly verification studies. Helium will be measured on a reconnaissance basis in some areas. Radon is measurement by alpha scintillometry using equipment described by Allen (1975) and Korner and Rose (1977).

Samples for helium determinations are collected in soft drink bottles. A 2-cc air gap is produced by using a syringe to withdraw water from the filled bottle. The bottle is then capped and inverted. Approximately 90% of dissolved helium in the water will exsolve into the air gap. The air gap was found to be essential to prevent bursting of bottles as ground water warmed from about 12°C to over 30°C in vehicles. Helium and neon are measured by mass spectrometry as described elsewhere (SRL k-1). Work of the Geologic Survey of Canada (Dyck, et al., 1976) was valuable to the development of a helium sampling capability at SRL.

DATA REPORTING

Reports from SRL fall into three main categories: 1) quarterly summaries reporting technical and sampling progress and plans; 2) data releases from reconnaissance and pilot studies. (These are processed and released as rapidly as possible and contain little technical interpretation.); 3) technical papers discussing the relation of hydrogeochemical and stream sediment reconnaissance (HSSR) geochemical data to regional and local geology and emphasizing features of the data which appear to be related to uranium occurrences.

RESULTS

Kings Mountain, NC, Orientation Study

Detailed results of this study are presented by Price and Ferguson (1977). In summary, uranium concentrations in stream sediments were high in an area known to contain abundant monazite. Uranium in ground and surface water was low in this area but high in an area where uraninite had been reported in a mica pegmatite. Surface water also showed elevated uranium concentrations downstream from a pegmatite mineral processing plant.

When the ratio U/(Hf•Th•Dy) for sediment samples is plotted on a map, the highs in this ratio correspond to areas of high dissolved uranium. Thus, a correction may be introduced for the presence of uranium in common resistate minerals such as zircon, monazite, and xenotime.

Figure 4 shows the distribution of ground water uranium and the outcrop area of the Cherryville Quartz Monzonite. Points on the map indicate helium sampling localities. Helium anomalies show an areal distribution similar to the previously published dissolved uranium distribution.

A radon survey of this area has not been completed. However, Sasser and Watson (in press) in a survey of the radon content of public water supplies in North Carolina recorded their two highest values, 46,000 and 35,000 pCi/L, in the Kings Mountain area and probably in samples from the Cherryville Quartz Monzonite (Kent Sasser, personal communication, 1978).

Oconee, SC, Orientation Study

Magnetic stream sediments were collected in the Oconee area, SC, orientation study (Price, 1976). The bulk magnetic samples contained a few ppm U in background areas and 20 to 50 ppm U near the radioactivity anomaly.

An electron microprobe study was made of the distribution of uranium in one anomalous sample. In reflected light, the grains in a polished grain mount showed bright and brighter grey areas, probably magnetite and hematite. Intragranular fractures made up ∿10% of the area observed. Grain exteriors were not observable in the mounts used because of polishing relief.

Five analyses of the material ranged from 67 to 73% Fe, confirming the presence of magnetite and/or hematite. The uranium content of the ground mass was below detection (less than about 50 ppm). In intragranular fractures, uranium was generally present in the range 200 to 500 ppm. Thus, it appears that uranium observed in fractures could explain a bulk analysis of several tens of parts per million. Further study of this material is in progress.

Weathering magnetite could be expected to accumulate limited amounts of uranium from ground water. The equilibrium between magnetite and hematite intersects the stability field of UO_2 under certain conditions in the pH range of about 3 to 7 (Garrels and

Christ, 1965; Langmuir and Appling, 1977). Thus, magnetite weathering out of rocks containing significant amounts of soluble uranium should immobilize traces of this uranium and provide a viable and readily collected medium for anomaly verification.

In a study of high-uranium granites of the St. Francois Mountains, Nash (1977) obtained autoradiographs of rock thin-sections. Uranium was noted in several types of sites in the rocks. Of particular interest was the fact that magnetite grains were outlined by high-uranium borders. Magnetic separates from these rocks contained about 50 ppm uranium. Concentrations of uranium on the surfaces of the magnetite grains were estimated, by track density, to be about 500 ppm. These values are nearly identical to results of the SRL study, and we suggest that uranium is being immobilized in the weathering rocks by reduction and adsorption along magnetite grain boundaries. Presumably, as the rock continues to weather, fluids will gain access to the interior of magnetite grains and deposit uranium along intragranular fractures as seen in the Oconee County, SC, magnetic stream sediments.

Williamsport, PA, Orientation Study

Thirty-two stream sites in the Sonestown, PA, 7-1/2 minute quadrangle duplicated samples reported by Rose, et al. (1976). Figure 5 summarizes some results of the SRL study of dissolved uranium. Circles mark sites which yielded >150 pptr dissolved uranium. (This "anomaly threshold" is defined as samples which exceed the 99th percentile of the lowest or background population.)

Figure 6 compares results of the SRL study of surface water with the Rose study of extractable uranium in sediments at the same sites. Analyses for extractable uranium and direct analyses of stream water with SRL techniques yield similar results.

Uranium concentrations in ground water predominantly from the Catskill formation ranged from below detection (<.02 ppb) to about 20 ppb and averaged about 1 ppb. This distribution is similar to that for Triassic sandstones discussed below.

Moore County, NC, Area (Triassic Basin)

Sediment samples contained from 1.9 to 526 ppm uranium in this study (Ferguson, Baucom, and Price, 1977). High uranium in all samples was accompanied by high Ce, Th, and Hf, indicating that the uranium is primarily in resistate minerals. Highest uranium in sediment values were in areas where the basal sands of the upper Cretaceous Tuscaloosa formation are being eroded by present streams.

The distribution of dissolved uranium in ground water is somewhat more interesting. Samples ranged from below detection (<.02 ppb) in areas of Pleistocene windblown sands (Pinehurst fm) to 3.5 ppb in Triassic red beds (Pekin fm). Table 2 summarizes the uranium content of ground water samples for eight geologic units (geology from Conley, 1962).

Note that the uranium content of ground water in the Triassic formations sampled is similar to that in the Devonian Catskill formation where uranium deposits are known to occur. Suppose ground water from the Pekin formation, at an average of 1.8 ppb U, flowed at a rate of 1 cm per day into an environment which reduced and precipitated uranium to a concentration of 0.04 ppb as seen in the Cumnock formation. If the reducing front were 100 by 1000 meters in area (10^9 cm^2), then 1.8 grams of uranium would be precipitated each day. This is about 650 tons per million years. Thus, within a geologically short time, a significant ore body could be formed. Of course, the proper subsurface conditions for concentration of the dissolved uranium may exist only very locally, and the sites of any existing ore bodies may be difficult to find.

North Carolina Coastal Plain Helium Survey

Helium analyses from ground water samples at a 13 sq km spacing in six North Carolina counties are shown on Figure 7. Contours are 100 γ magnetic contours from Zietz and others, 1968. Many anomalous samples are aligned with magnetic contours, suggesting a relation to basement geology. Other high-helium samples do not seem to be aligned with magnetic lineaments. In 23 samples, where dissolved U and He have been measured (Table 3), three of the four highest He measurements are accompanied by U anomalies.

Leesville, SC, Study Area

This area is at the coastal plain-piedmont boundary and is underlaid by 0-100 meters of poorly consolidated Cretaceous sands and clays. It was chosen for study because of high radioactivity levels in a town water supply (Jacqueline Michel, personnel communication, 1977).

Several media exhibited mildly-to-strongly anomalous levels in this study area (Price and Jones, 1978). Ground water uranium concentrations ranged from a background of less than 0.1 ppb to a high of 29 ppb. (Regional reconnaissance samples collected on a 25-square-kilometer grid detected the anomaly areas and are included in the data used to generate Figure 8.) Field radon determinations and dissolved helium outlined similar but slightly displaced anomaly areas (Figures 9 and 10).

Surface water samples analyzed for uranium ranged from background (∿0.02 ppb) to a high of 0.120 ppb. The cumulative frequency plot shows a break at ∿0.06 ppb. The area included within a 0.060 ppb contour is similar to the area outlined as anomalous in ground water sampling.

The distribution of uranium in three stream sediment size fractions is shown on Figure 11. Note that the median concentration of uranium is higher (14 ppm) for the intermediate (75-150 µm) size fraction than for the coarser or finer (150 µm at 4 ppm, <75 µm at 9 ppm). This supports previously published (Ferguson and Price, 1976) data from a geologically different area, indicating that -100 mesh (<150 µm) stream sediment was the size fraction of choice for a uranium reconnaissance.

RECONNAISSANCE DATA

At this writing, reconnaissance data have been released for four quadrangles (shaded on Figure 2A). Figure 12 is a composite showing stream water alkalinity in three areas — Winston-Salem, Charlotte, and Spartanburg (80-82°W, 34-37°N; Baucom, et al., 1977; Heffner and Ferguson, 1978, a,b). Strong geologic control of stream water quality is evident. High alkalinity values are concentrated in the Valley and Ridge, whereas low values outline the sands of the upper Coastal Plain. Detailed correspondence between geology and water quality is seen when these data are compared to more-detailed geologic maps. In some areas, most stream pH values are outside the range of 5 to 9.5 generally accepted for industrial and recreational water supplies.

Figure 13 gives the areal distribution of uranium in stream sediments from the Charlotte 1° x 2° quadrangle (80-82°W, 35-36°N). Almost all high samples come from the area known as the "Southeastern Monazite Belt" (Mertie, 1953; outlined on Figure 13). Cerium, thorium, and dysprosium (Figures 14A, B, and C) are similarly distributed.

The areal distribution of uranium in ground water of the Charlotte quadrangle is given on Figure 15 as the ratio: (U, pptr/conductivity, μmho). Note that the distribution of dissolved uranium is quite different from the distribution of uranium in sediments (Figure 13).

The areal distribution of the ratio U/(Th•Hf•Dy) is shown on Figure 16. When anomalous areas (highest 10% of samples) on this map are compared with anomalous areas on the dissolved uranium map, several overlapping anomalies are revealed. The largest area of overlapping anomalies corresponds to the Cherryville Quartz Monzonite discussed above. Other areas are suggested as promising exploration targets.

This discussion is intended as an example of one approach to interpreting the data. It is not intended to imply that the anomaly areas selected have more or less proven potential for commercial uranium deposits than other areas at this time.

DATA INTERPRETATION

Interpretation of analytical data from NURE geochemical reconnaissance samples is not expected to be straightforward. Price and Ferguson (1977) demonstrated that in crystalline terranes the total uranium content of a stream sediment sample alone may bear little or no relation to any occurrence of a commercially viable uranium mineral. Many factors must be considered.

The SRL-NURE HSSR geochemical data base contains many measurements for a large number of samples collected in regional reconnaissance. Enough data are collected to provide a statistically reliable data base. Models are being developed to relate this data base to the geology of uranium deposits. The word "model" as used here defines a set of criteria or relationships (causal, associative, or chance) with predictive value. Such models will relate analytical data to sample mineralogy and ultimately to mineralogical or geochemical patterns associated with known mineral deposits. The model will be used to propose areas for further field study based on reconnaissance data. The objective is to reduce the number of false anomalies that might be pursued in the absence of effective models.

Data from several sources are being used to develop models. Orientation studies conducted in areas of known uranium mineral occurrences are critical. Anomalous analytical results from reconnaissance data are used to select a few field areas for detailed geologic study. Geologic information provides the basis for detailed sampling and analysis. This detailed study (or anomaly verification) contributes to model development as discussed previously (SRL, 1).

Literature descriptions of known uranium deposits will also provide input to SRL models. The models ultimately developed will probably be applied through computer screening of the SRL-NURE data base without input from supplemental field surveys or detailed geologic observations.

One facet of the modeling in progress is an attempt to predict sample mineralogy directly from reconnaissance analytical data. Electron microprobe data are being used to determine the mineralogy in density/magnetic susceptibility splits of samples from the Kings Mountain, NC, pilot study and in apparently anomalous reconnaissance samples.

SUMMARY

A number of geochemical sampling media, field measurements, and laboratory analyses have been evaluated for their efficacy in uranium resource appraisal. Each medium and measurement tested offers some advantages and provides some useful data. Some analytical data, such as those for iron, titanium, and other elements not specifically discussed above, provide a measure of ground truth for geologic maps which may be compiled from conflicting sources.

SRL has chosen to collect ground water and stream sediments routinely. Orientation and reconnaissance experience indicate that these media can be collected and analyzed reproduceably and that they provide meaningful geochemical data.

Ground water samples for helium determination can be readily collected and analyzed. As discussed above and in the published literature (Dikun, et al., 1976), the helium concentration of near-surface ground water is not merely a function of proximity to accumulations of uranium as thorium but also a function of structural control of helium migration from diffuse sources. In addition, the volatility of helium makes samples from shallow wells suspect. SRL is collecting samples for possible helium analysis in areas where normal ground water circulation is not expected to reach possible buried uranium accumulations.

Radon should be an ideal pathfinder for uranium deposits. Korner and Rose (1977) report anomalous radon in ground water samples from an area with known uranium deposits even though the samples did not contain anomalous uranium. Radon is less volatile than helium so that nonpressurized water systems may be sampled. Unfortunately, valid radon measurements can only be obtained immediately after sample collection, and the field instrumentation is expensive and requires a skilled operator. For this reason, radon measurement is not considered practical for regional reconnaissance. However, radon measurements should be a powerful tool in anomaly verification studies. Field instrumentation provides the geologist with a measurement which can be directly applied to planning the next day's work.

An underlying assumption of SRL's sampling and analysis is that uranium deposits do not occur independently of their host rocks. It follows logically that detailed geochemical characterization of samples should be done insofar as practical and that this sample characterization should be integrated, through a set of derived relationships (models), with other knowledge (of the sampled area, of uranium deposits) to produce an estimate of the likelihood that uranium deposits occur in an area.

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b. DPST-75-138-2, GJBX-6(76)
c. DPST-75-138-3, GJBX-7(76)
d. DPST-75-138-4, GJBX-8(76)
e. DPST-76-138-1
f. DPST-76-138-2
g. DPST-76-138-3
h. DPST-76-138-4
i. DPST-77-138-1
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TABLE 1

Elements Removed from Ground Water Samples by Ion Exchange Concentration

Element	*Concentration of Elements in Ground Water, ppm*[a] *Before Ion Exchange*	 *After Ion Exchange*	 *% Removed by Resin*
B	3	0.003	99.9
F	1	<0.09	>91
Na	4	0.04	99
Mg	0.7	0.0008	99.9
Al	0.01	<0.001	>90
Si	0.07	0.002	97
P	0.007	0.0007	90
S	0.2	0.003	98
Cl	1	0.02	98
K	2	0.02	99
Ca	2	0.006	99.7
Cr	0.02	0.0002	99
Mn	0.07	0.001	98.5
Fe	0.3	0.02	93
Ni	0.05	<0.002	>96
Br	0.09	<0.003	>97

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[a] Analyses by spark source mass spectrometry of residue.

Table 2

Uranium content of ground water samples for 8 different geologic formations, pptr

	ft	mt	ant	Kt	Ꞧp	Ꞧc	Ꞧs	Pp
$\bar{x}$	77	155	18	53	1780	36	550	15
σ	88	150	13	52	1270	17	640	20
n	6	4	7	10	4	4	5	5

a. ft, mt, ant: felsic mafic and andesitic tuffs, pЄ to early paleozoic
Kt : Tuscaloosa formation, fluvial to littoral sands and clays
Ꞧp: Pekin formation, predominantly red beds
Ꞧc: Cumnock formation, organic-rich shales with some coal
Ꞧs: Sanford formation, red beds, fanglomerate
Pp : Pinehurst formation unconsolidated fine sands at higher elevations, probably windblown.

Table 3

Concentrations of U and He in North Carolina Coastal Plain

Sample No.	U (pptr)	He (ppm)
603	14	5.3
604	3	5.9
605	21	5.7
606	99	5.6
607	35	5.5
608	51	5.8
609	14	5.6
610	113	5.5
611	18	5.8
612	39	5.1
613	14	6.1
614	46	5.2
615	94	5.8
616	60	5.1
617	43	5.3
618	511	400
619	278	75
621	58	5.0
622	94	4.6
623	811	70
624	67	5.7
625	58	5.7
626	59	40

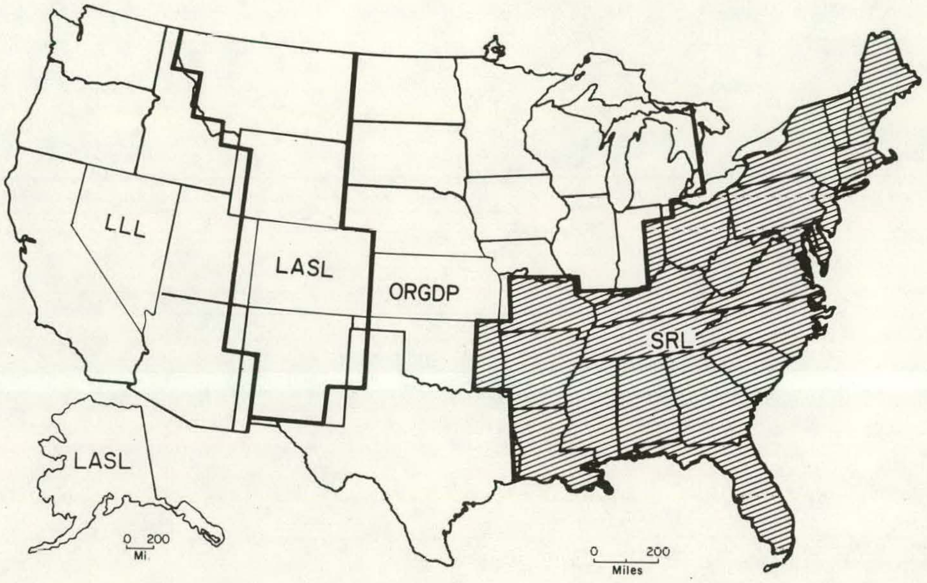

FIGURE 1. Areas of Responsibility for the NURE Hydrogeochemical Reconnaissance Program

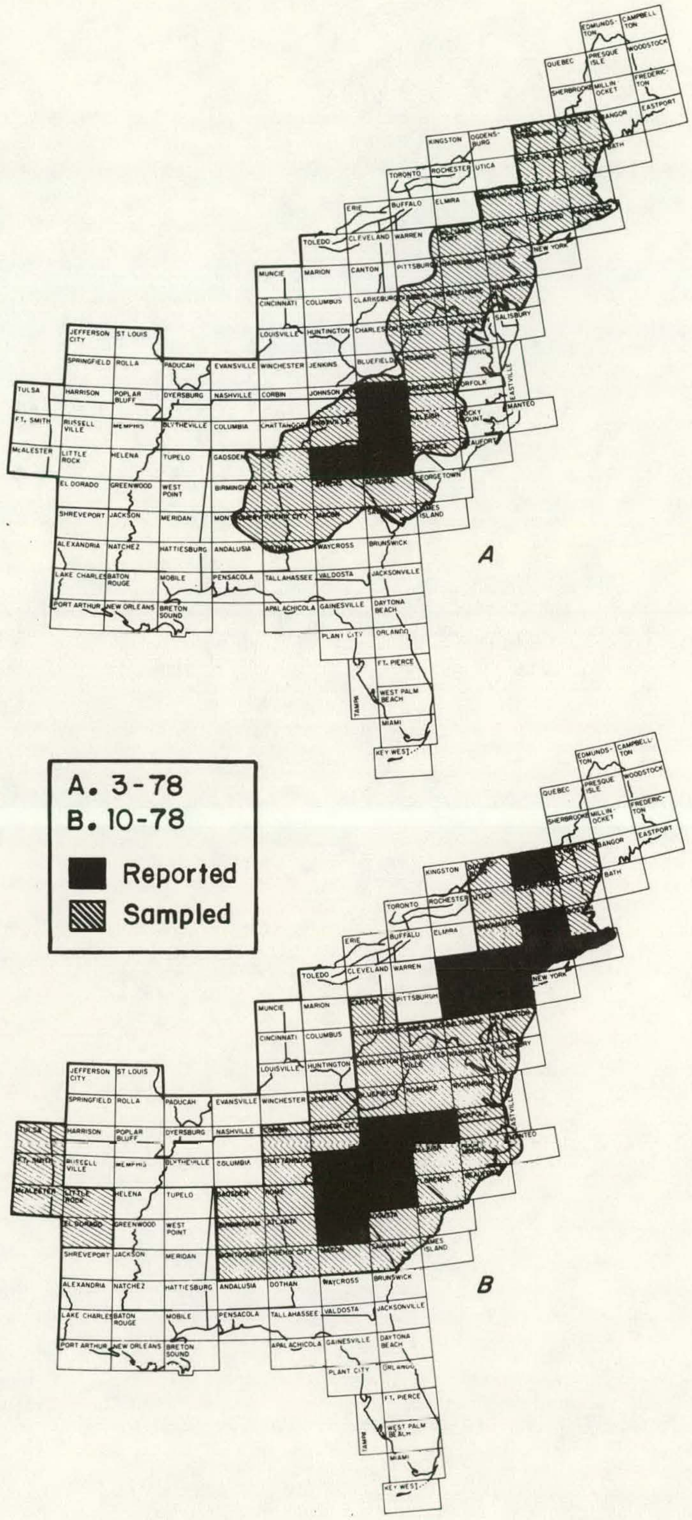

FIGURE 2. SRL Sampling and Reporting Schedules Through 1978

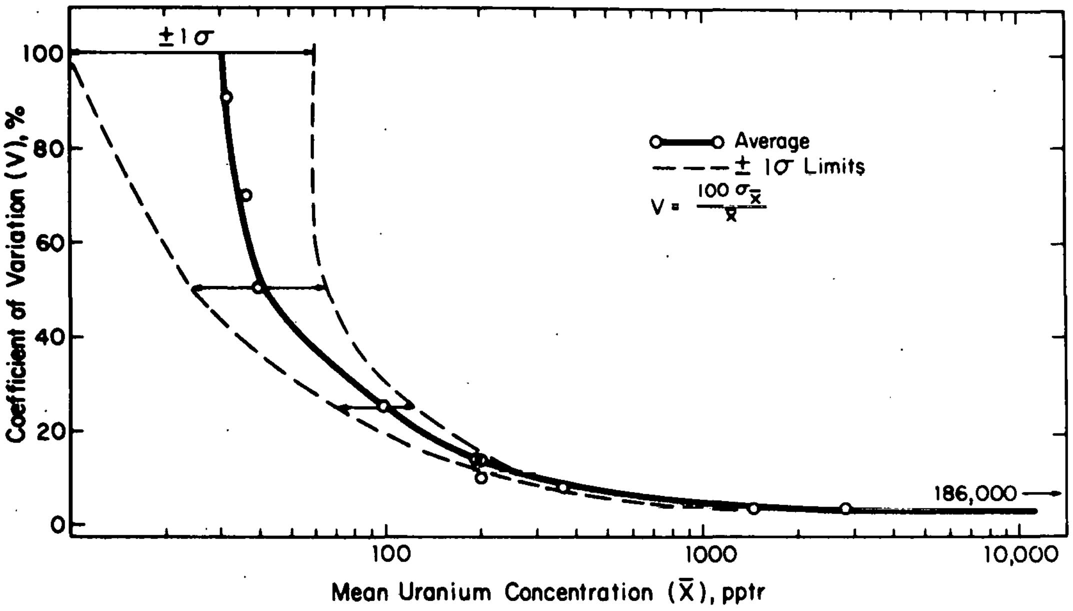

FIGURE 3. Precision of Resin Method

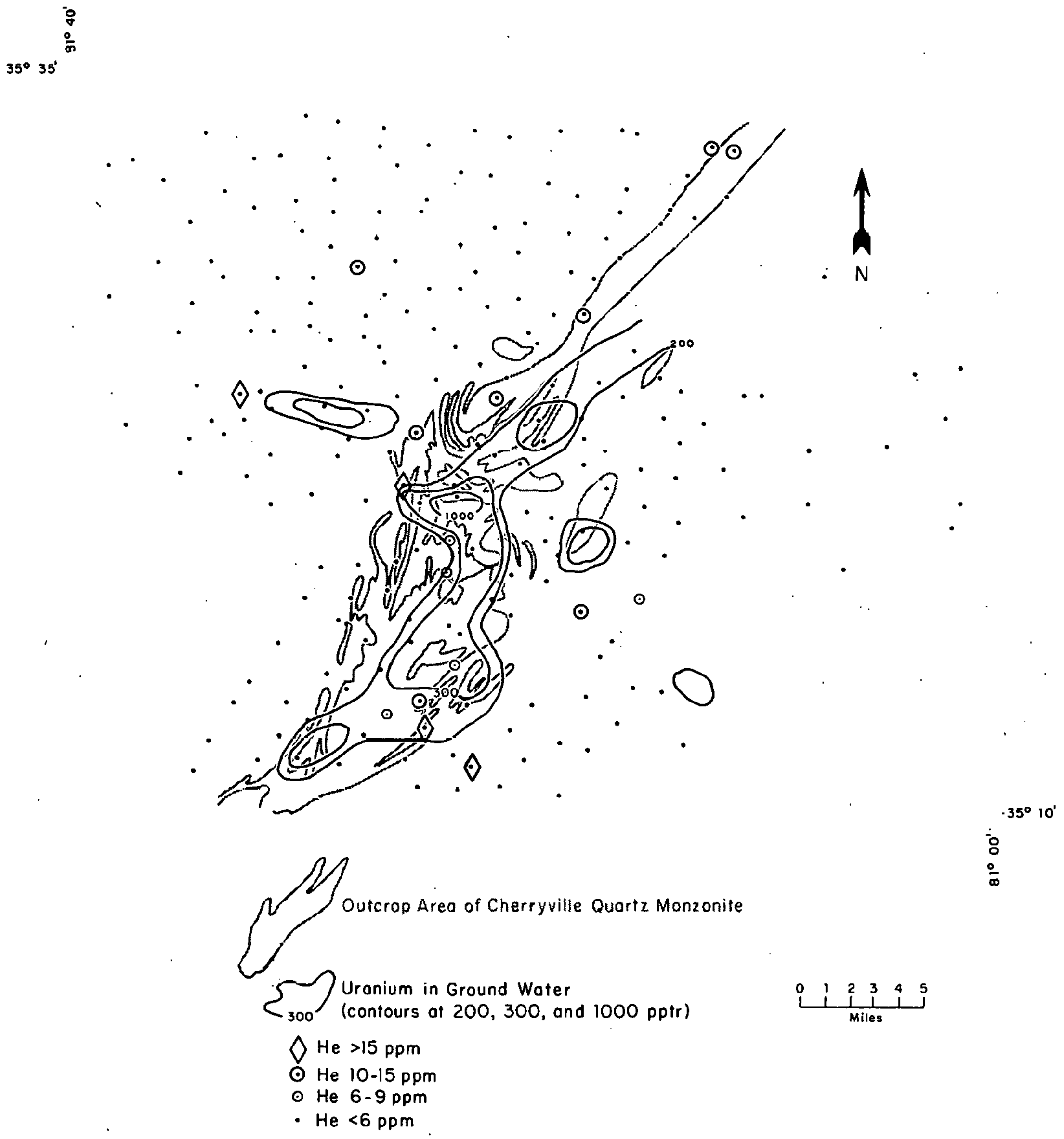

FIGURE 4. Ground Water Uranium Concentrations and Helium Anomalies in the Kings Mountain, N.C., Area

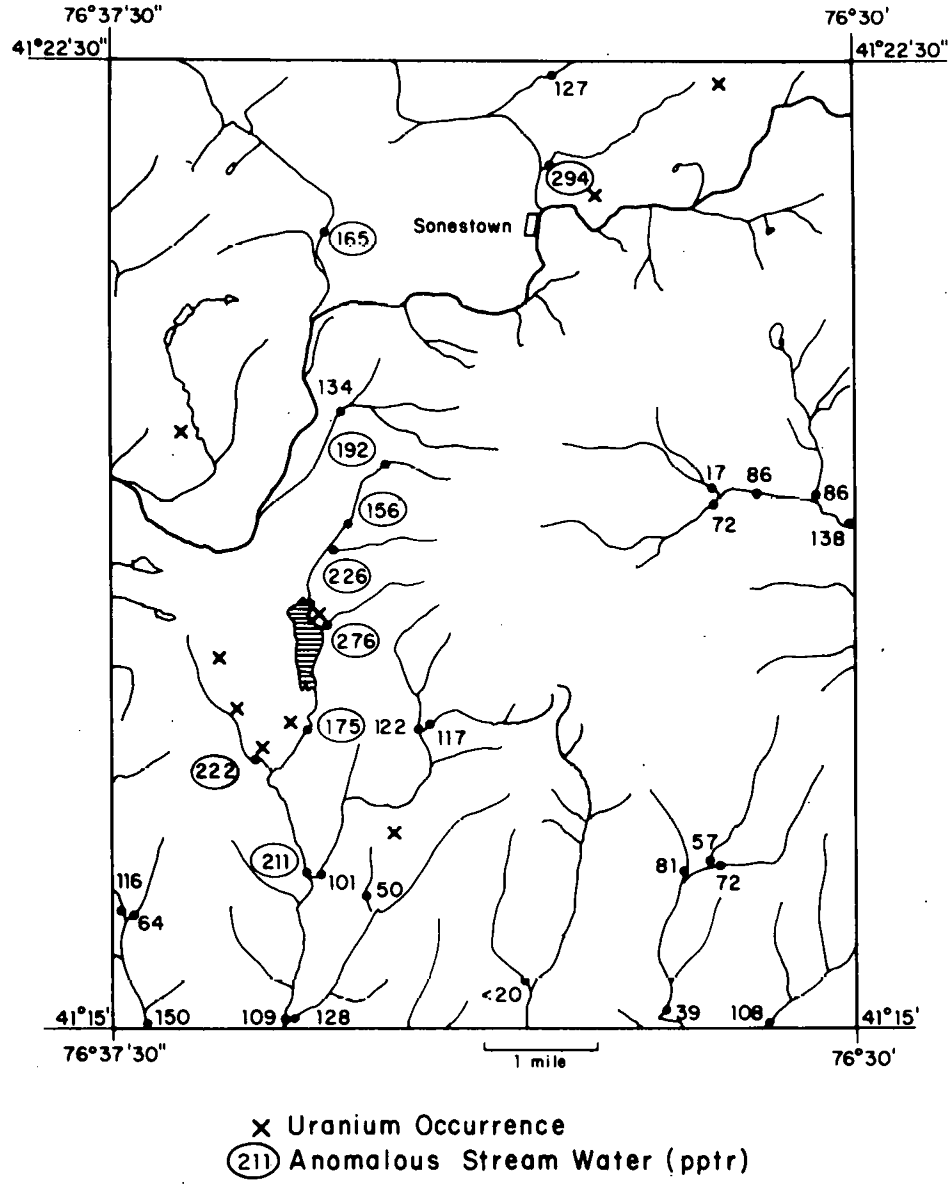

FIGURE 5. SRL Sampling Sites in the Sonestown, Pa., Quadrangle

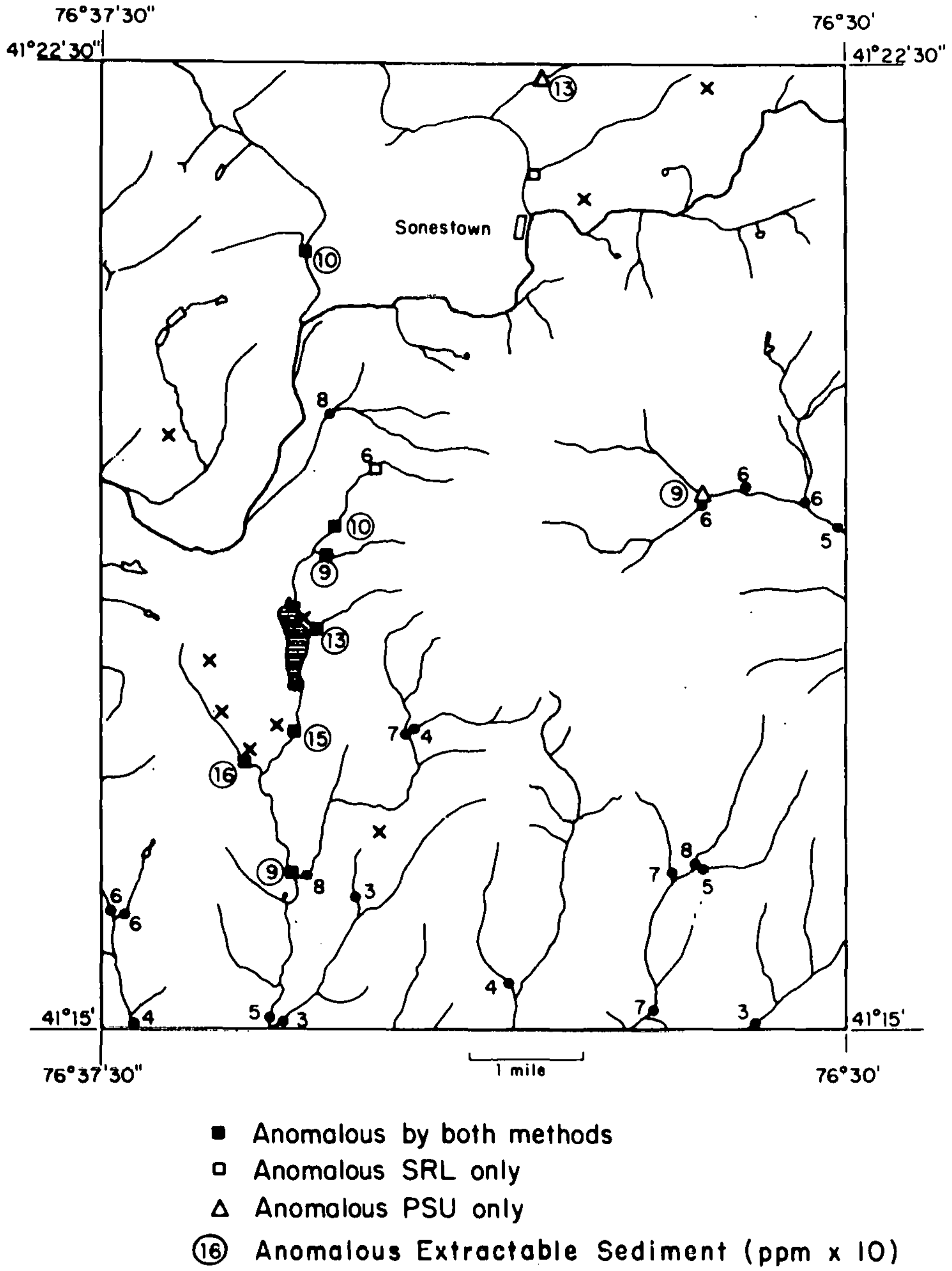

FIGURE 6. Comparison of Extractable Uranium Anomalies and Stream Water Uranium Anomalies in the Sonestown, Pa., Quardrangle

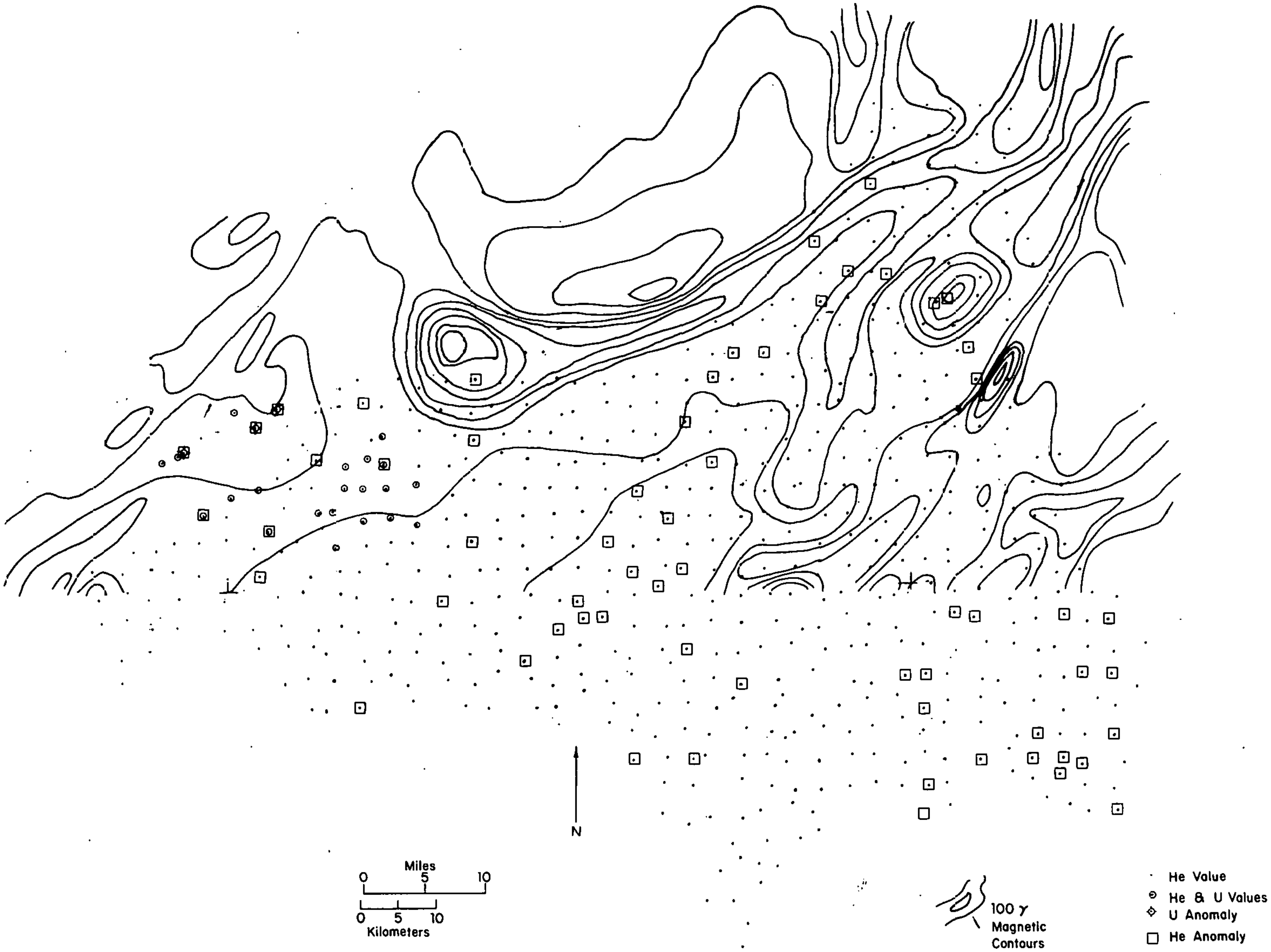

FIGURE 7. Helium Anomalies and Magnetic Contours for a North Carolina Coastal Plain Area

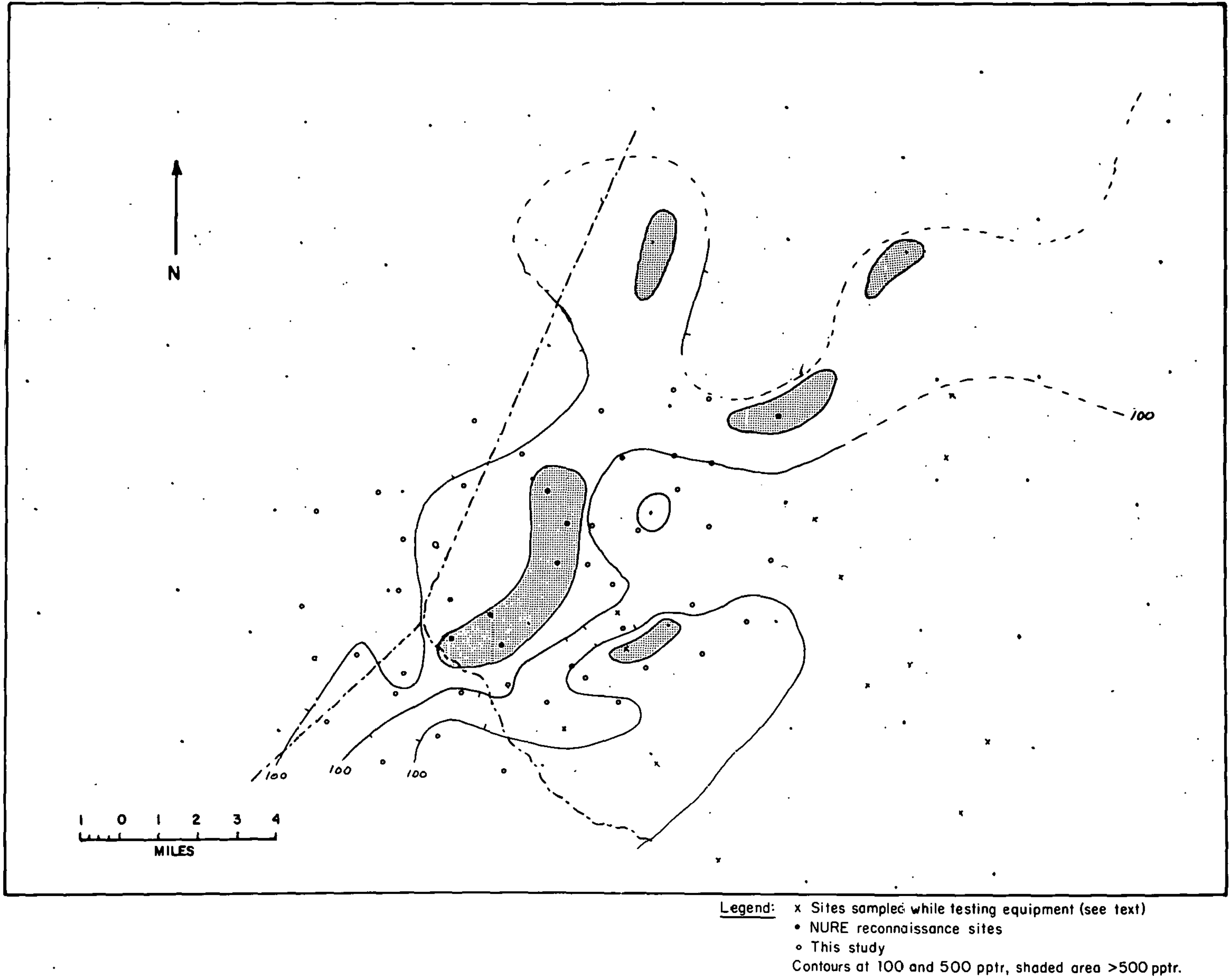

FIGURE 8. Uranium Concentrations in Ground Water, Leesville, S.C., Area

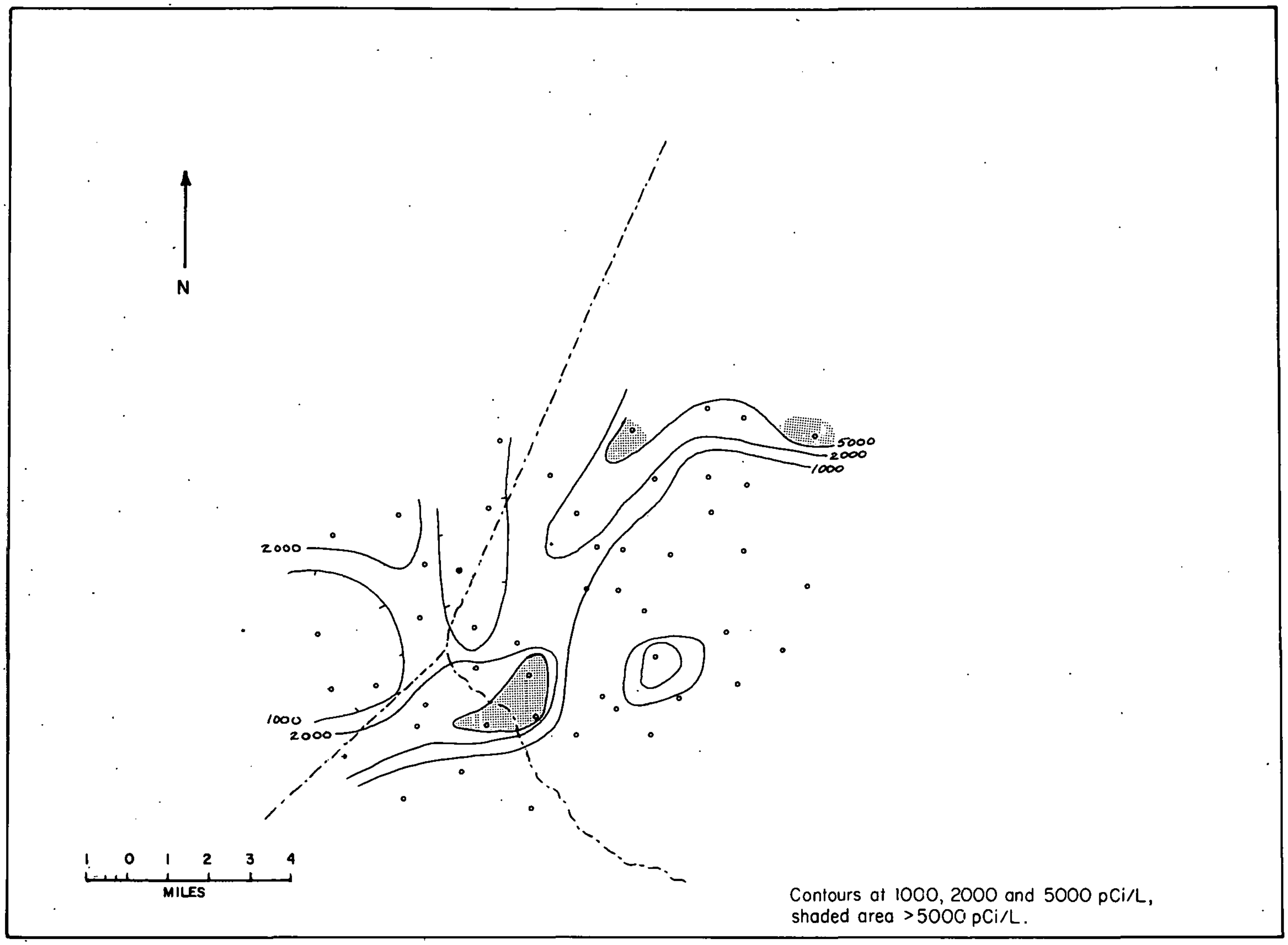

FIGURE 9. Radon Concentrations in Ground Water, Leesville, S.C., Area

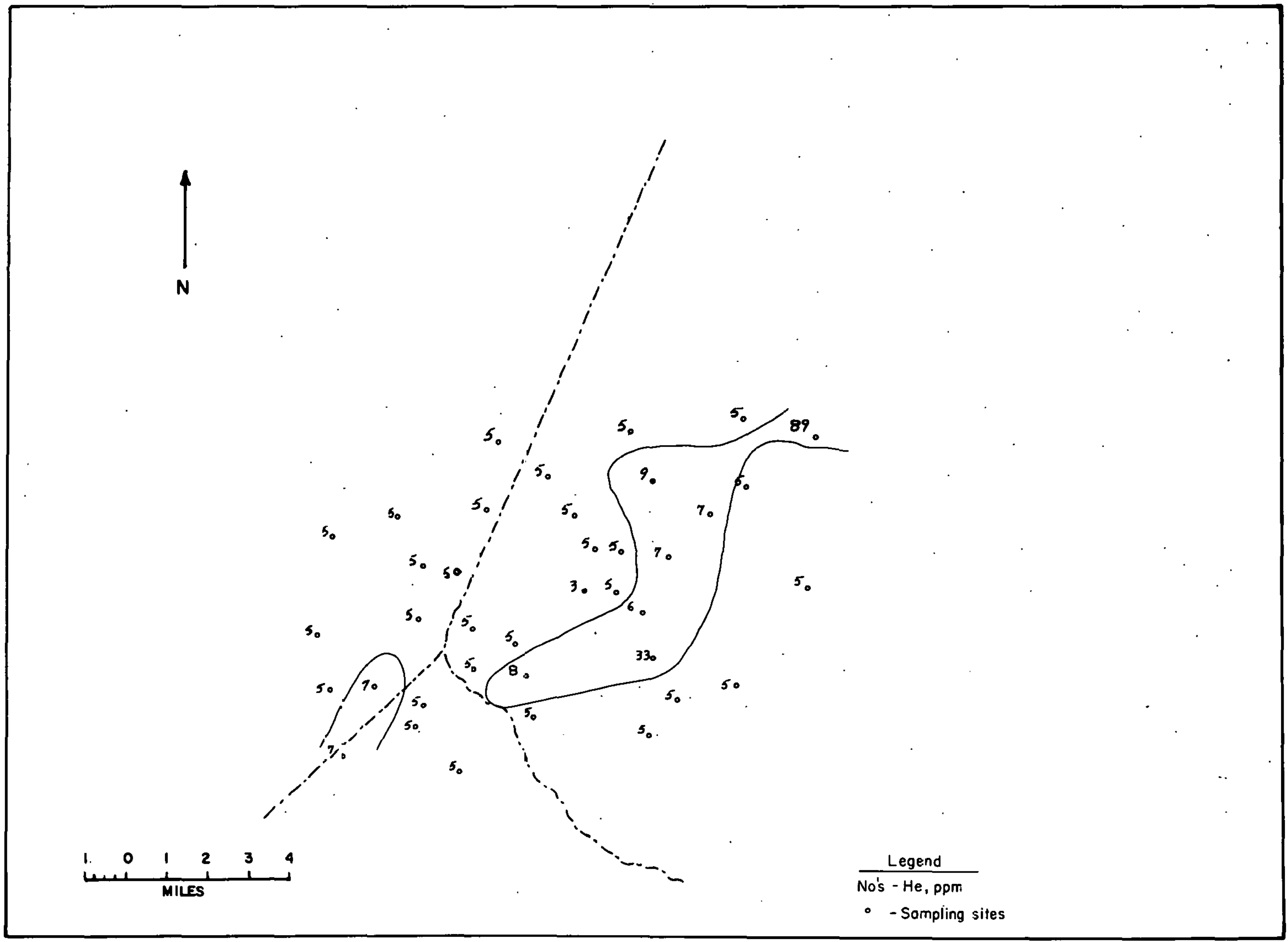

FIGURE 10. Helium Concentrations in Ground Water, Leesville, S.C., Area

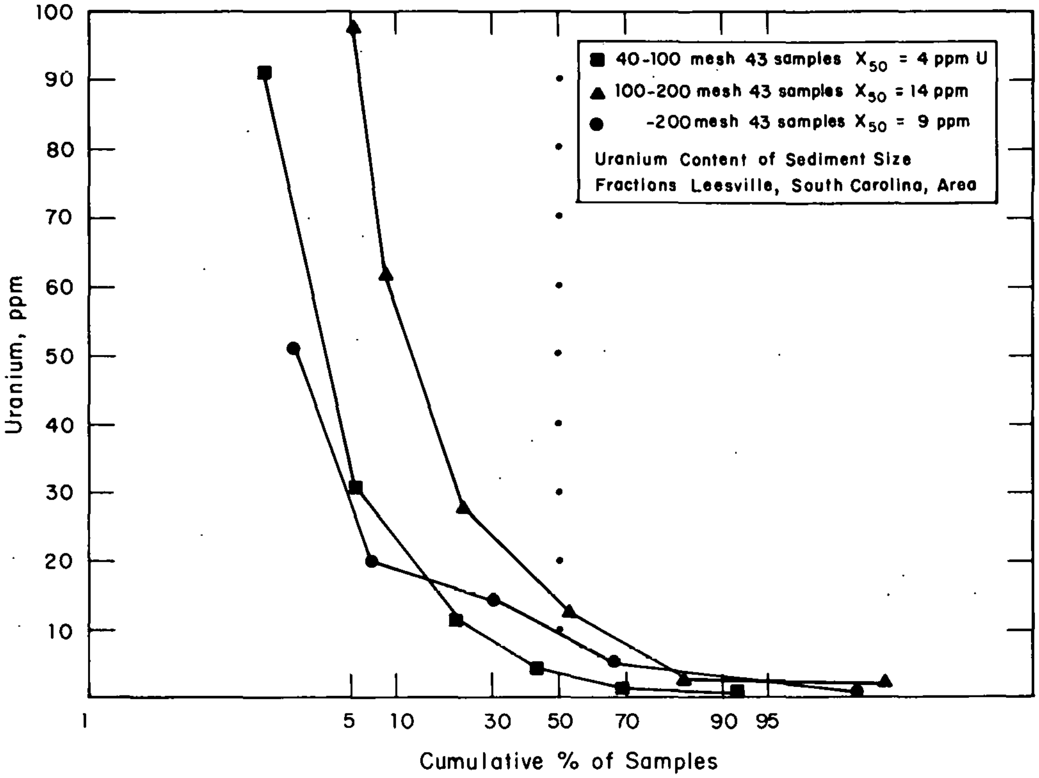

FIGURE 11. Uranium Distribution in Different Grain-Size Fractions of Stream Sediments from the Leesville, S.C., Area

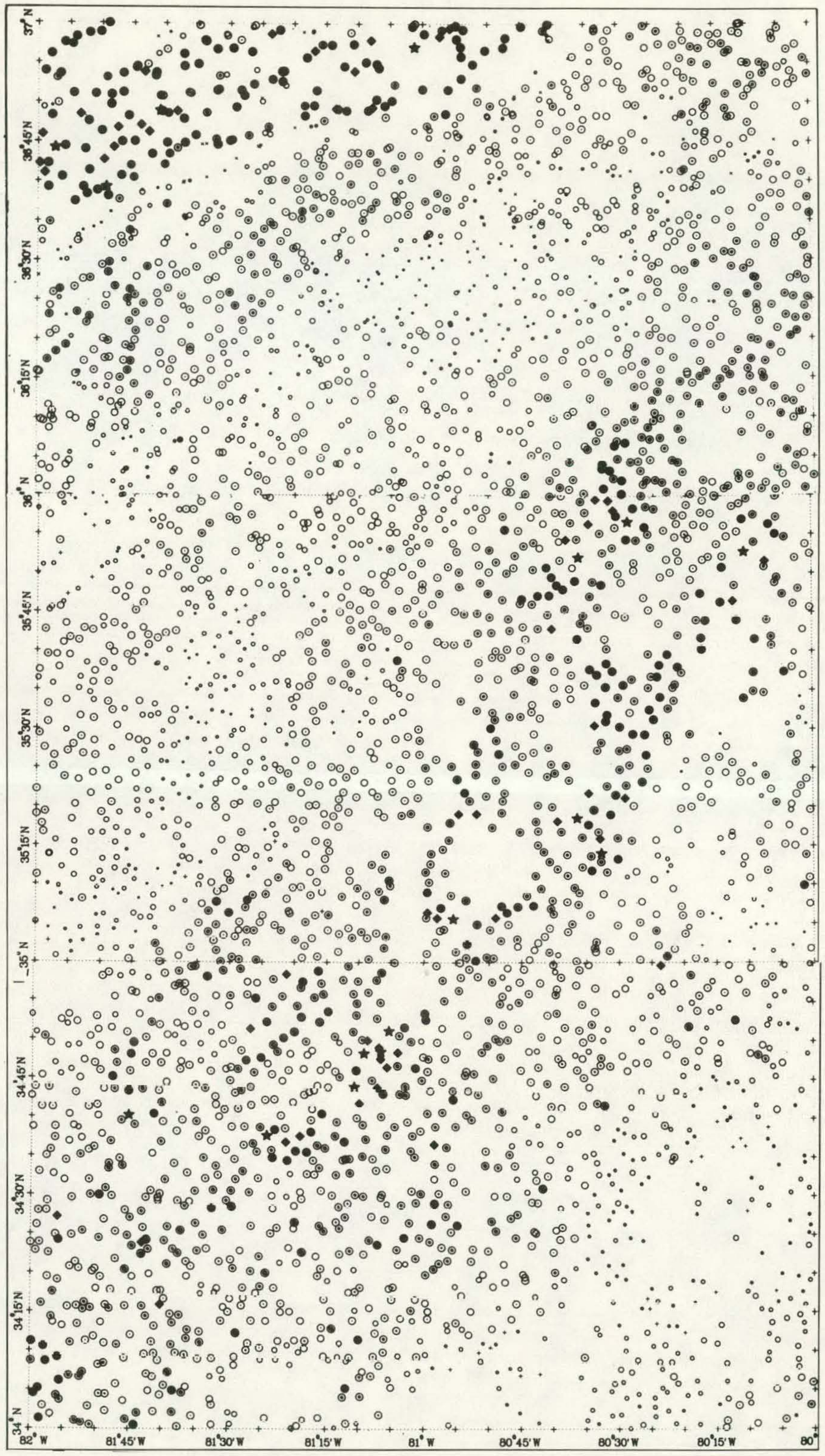

FIGURE 12. Areal Distribution of Stream Water Alkalinity Values: 34° to 37° N; 80° to 82° W.

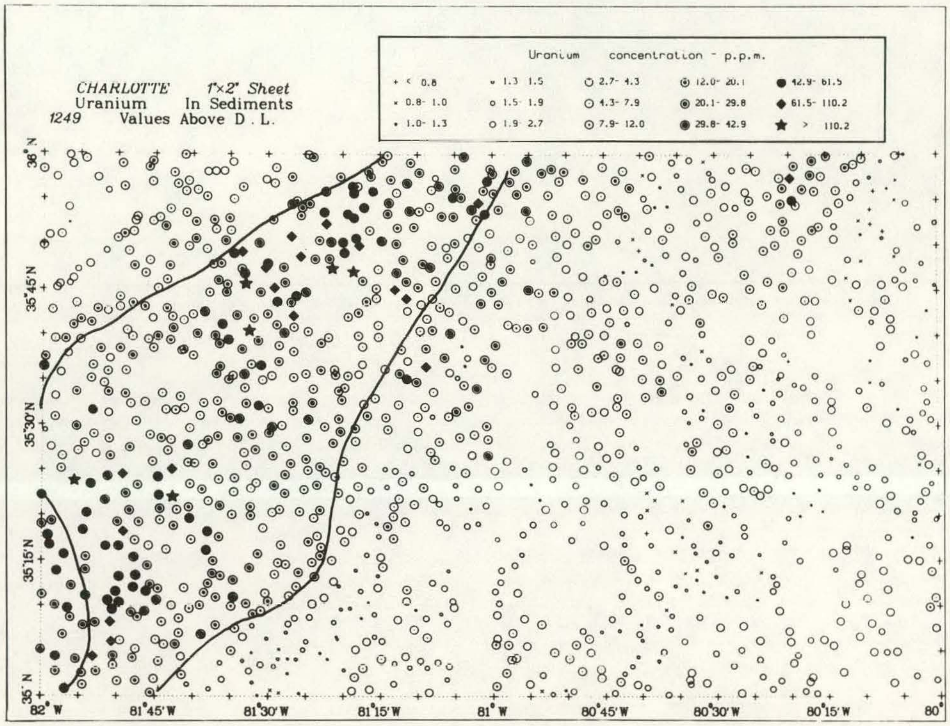

FIGURE 13. Areal Distribution of Uranium in Stream Sediments, Charlotte 1° x 2° Quadrangle

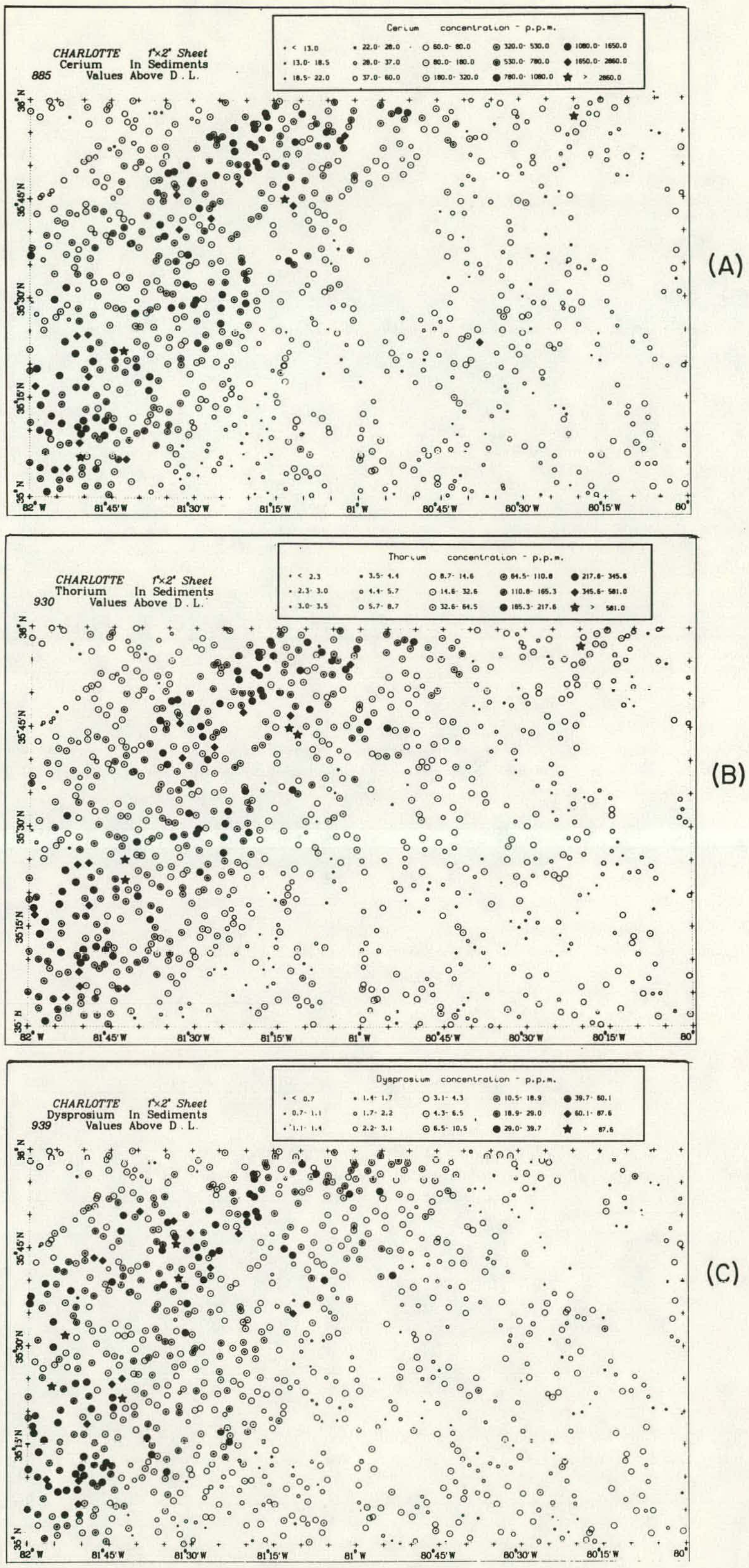

FIGURE 14. Areal Distribution of Cerium (A), Thorium (B), and Dysprosium (C), Charlotte 1° x 2° Quadrangle

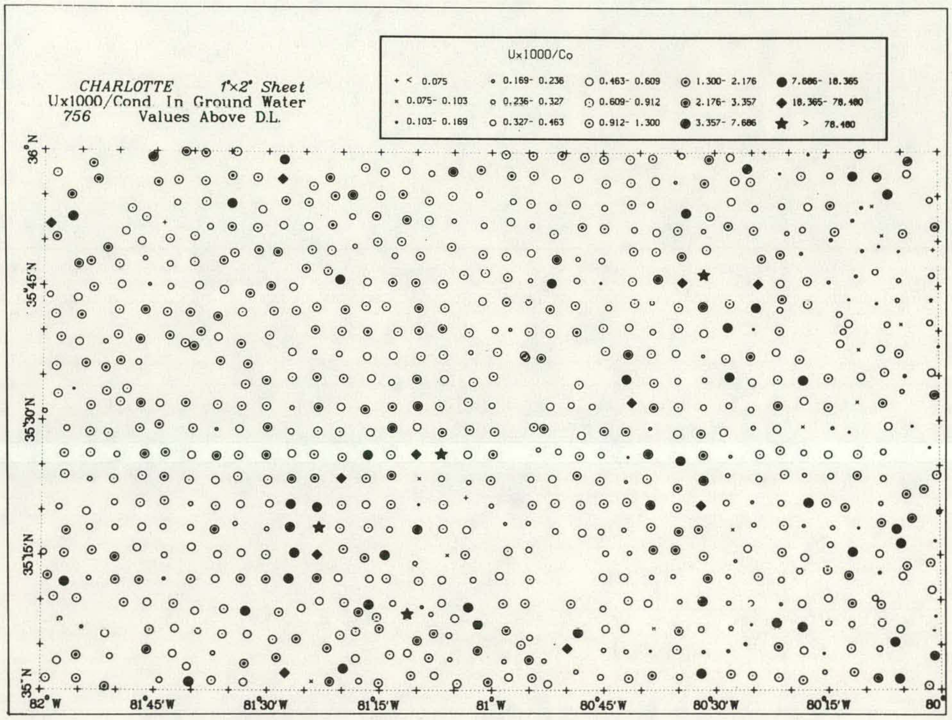

FIGURE 15. Areal Distribution of Uranium in Ground Water, Charlotte 1° x 2° Quadrangle

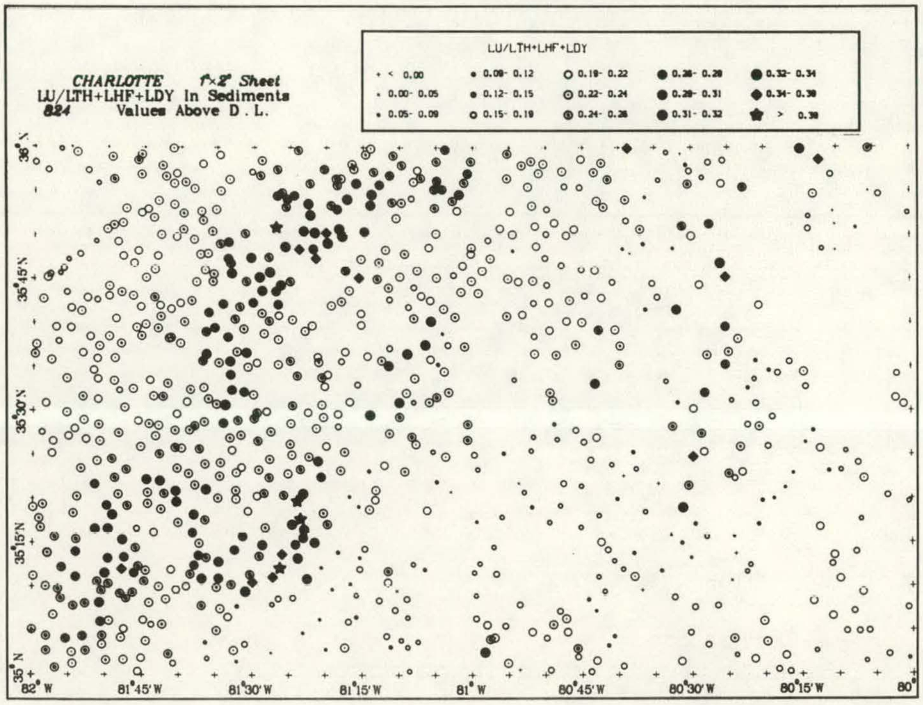

FIGURE 16. Areal Distribution of (U/Th·Hf·Dy) in the Charlotte 1° x 2° Quadrangle