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The Los Alamos Scientific Laboratory
Approach to Hydrogeochemical and
Stream Sediment Reconnaissance for
Uranium in the United States

University of California

LOS ALAMOS SCIENTIFIC LABORATORY

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THE LOS ALAMOS SCIENTIFIC LABORATORY APPROACH TO
HYDROGEOCHEMICAL AND STREAM SEDIMENT RECONNAISSANCE FOR URANIUM
IN THE UNITED STATES

by

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ABSTRACT

The Los Alamos Scientific Laboratory of the United States is conducting a geochemical survey for uranium in the Rocky Mountain states of New Mexico, Colorado, Wyoming, and Montana and in Alaska. This survey is part of a national hydrogeochemical and stream sediment reconnaissance in which four Department of Energy laboratories will study the uranium resources of the United States to provide data for the National Uranium Resource Evaluation program. The reconnaissance will identify areas having higher than background concentrations of uranium in ground waters, surface waters, and water-transported sediments.

The Los Alamos Scientific Laboratory bases its reconnaissance on an extensive literature review on geochemical sampling, the results of pilot studies, and similar sampling programs in Canada, France, Sweden, New Zealand, and the United Kingdom. The reconnaissance consists of standardized field procedures, data acquisition and evaluation, and publication of results. Water and sediment samples are collected at a nominal density of one sample location per 10 km² except for lake areas of Alaska where the density is one sample location per 23 km². Water samples are analyzed for uranium by fluorometry which has a 0.02 parts per billion lower limit of detection. Concentrations of 12 additional elements in water are determined by plasma-source emission spectrography. All sediments are analyzed for uranium by delayed-neutron counting with a 20 parts per billion lower limit of detection, which is well below the range of uranium concentrations in natural sediment samples. Elemental concentrations in sediments are also determined by neutron activation analysis for 31 elements, by x-ray fluorescence for 9 elements, and by arc-source emission spectrography for 2 elements. The multielement analyses provide valuable data for studies concerning pathfinder elements, environmental pollution, elemental distributions, dispersion halos, and economic ore deposits other than uranium. An average of 350 samples are analyzed by each analytical method each working day.

To date, all of four Rocky Mountain states and about 80% of Alaska have been sampled. About 220 000 samples have been collected from an area of nearly 2 500 000 km². The philosophy, sampling methodology, analytical techniques, and progress of the reconnaissance are described in several published pilot study, reconnaissance, and technical reports. The Los Alamos program was designed to maximize the identification of uranium in terrains of varied geography, geology, and climate and is one of the largest geochemical programs of this type in the world. This program technology could be adopted for regional studies of economic commodities in almost any country.

I. INTRODUCTION

In 1973, the United States Atomic Energy Commission initiated a National Uranium Resource Evaluation (NURE). The NURE program, now administered by the Department of Energy (DOE), consists of hydrogeochemical and stream-sediment reconnaissance, airborne radiometric surveys, and topical geologic studies (US DOE, 1979).

This paper describes the role of the Los Alamos Scientific Laboratory (LASL) in the Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) for the period 1975 to 1980. The original objective of the HSSR program was to complete a systematic reconnaissance of the nation's surface waters, ground waters, and stream sediments. In all likelihood, data from the HSSR program will not identify ore bodies, but rather, they will help outline geochemical provinces favorable for detailed follow-up studies. Recently, the objective appears to have shifted to emphasize more detailed evaluations in areas of potential favorability. Four DOE laboratories have conducted the hydrogeochemical program.

The LASL is conducting the HSSR program for the DOE in the Rocky Mountain states of New Mexico, Colorado, Wyoming, Montana, and Alaska, as well as in parts of Arizona, Utah, and Idaho (Fig. 1). To date, approximately 220,000 locations have been sampled within an approximate 2.5 million km² land area.

II. THE APPROACH TAKEN

Most procedures and ideas presented in this paper are a direct consequence of similar programs developed in Canada, Finland, France, Norway, United Kingdom, and the USSR (Sharp and Bolivar, 1980) and of standard geochemical practices summarized by Hawkes and Webb (1972) and Levinson (1974).

Fig. 1. Index map for the LASL area of responsibility for the HSSR.

Because uranium deposits seldom occur under simple geochemical conditions, to develop a successful HSSR program, a thorough test of all sampling methodologies and philosophies is necessary. This is done by means of pilot (orientation) studies. The pilot studies completed by the LASL are shown in Fig. 1 (Sharp and Aamodt, 1976; Olsen, 1977; Aamodt, 1978; and Sharp et al (1979).

The LASL compiled a field procedures manual that explains the purpose of the program; the care, calibration, and use of field equipment; and the general procedures to be followed for all aspects of the program (Sharp and Aamodt, 1978).

Priority areas are assigned by the DOE each year. Samples are then collected by subcontractors according to systematic and standardized sampling procedures as outlined in the sample collection manual. All field equipment necessary to collect samples, including sample vials and data forms, and to take and record the required measurements are provided by the LASL. Subcontracted field personnel are required to attend a short training course during which the objectives of the program, sampling methodology, and care and calibration of field equipment are taught. Laboratory personnel are present in a supervisory capacity to monitor the sampling and provide help with equipment malfunctions and obtaining access to private property.

Contract areas generally cover one or more National Topographic Map Series (NTMS) quadrangles; each NTMS quadrangle consists of an area of 1° latitude and 2° or 3° longitude. Access normally requires four-wheel drive vehicles, which usually are provided by the subcontractor. Most areas in Alaska are sampled by use of helicopters.

III. FIELD OBSERVATIONS

In a reconnaissance program, chances are high that any particular sample location will not be revisited. Therefore, it is essential to record all field measurements and observations at the collection site. To do this, the LASL has developed a data form on which the sampler can record the sample type, location, weather, relief, possible contaminants, field measurements, and geologic observations (Fig. 2). Field observations are number coded and can be recorded in minimal time. Each form has additional space for comments or clarification of information. Coded prenumbered adhesive stickers are attached to each data form and are placed on all samples so that the state and quadrangle from which the sample was taken can be identified easily.

Fig. 2. The LASL data form.

(0-2000 $\mu\text{mho/cm}$, $\pm 5 \mu\text{mho/cm}$), pH (0 to 14, ± 0.1 pH), and dissolved oxygen (0 to 20 parts per million (ppm), ± 1.0 ppm) can be measured.

All temperatures are measured with precalibrated thermometers. The air temperature in the shade is recorded to the nearest Celsius degree. The water temperature is usually recorded to the nearest 0.5°C . Ground radioactivity is measured with portable scintillometers.

V. SAMPLE COLLECTION

The LASL uses separate collection procedures for samples collected either in the Rocky Mountain states or in Alaska (Sharp and Aamodt, 1978).

Water samples. In the Rocky Mountain states, about 50 ml of water are collected in two 25-ml polyethylene vials that have been prewashed with dilute nitric acid. Ground-water samples are collected from either wells and springs as near the emergence source as possible. Holding tanks are not sampled. Stream waters are collected from the flowing current away from the bank. All waters are filtered through a $0.45\text{-}\mu$ membrane and acidified to pH ≤ 1.0 with 8 M reagent-grade nitric acid. All water quality measurements are made with instruments previously discussed.

In Alaska, 50 ml of water are collected; however, due to the high purity of the water and the high transportation costs per sample location, the time-consuming operation of filtration is omitted.

Sediment samples. About 1 kg of sediment is collected from at least three adjacent spots at each location. The sediment must be water transported and taken below water level (if water is present) and must contain enough organic-rich, fine-grained particles to fill a 25-ml polyethylene vial. In lake areas in Alaska, the sediment is collected with a specially designed 11-kg, suction-operated bottom sampler that can be dropped from the side of a

helicopter. The sample is usually collected with a polyethylene scoop and put into a rip-top polyethylene bag which is labeled both inside and out. The subcontractor dries the samples at $\leq 100^{\circ}\text{C}$ and sieves the samples, retaining only the fraction that passes through a 100 mesh screen, which the LASL has determined is optimum for detection of uranium anomalies (Olsen, 1977).

Sampling densities. Based on extensive literature research of reconnaissance programs in similar terrains and based on the results of pilot studies (Sharp and Aamodt, 1976; Olsen, 1977), the LASL selected a nominal sample density of one location per 10 km^2 for the Rocky Mountain states. While it may be argued that this sampling density may not be favorable for some areas, it has proven adequate for uranium reconnaissance work aimed simply at delineating areas favorable for exploration (Dall'Aglia, 1972; Dyck, 1975; Sharp, 1977). The sampling of both waters and sediment wherever possible also enhances the adequacy of coverage (Sharp, 1977). All sample locations in the Rocky Mountain states are preselected by LASL personnel. Surface streams are selected to represent drainage areas of about 10 km^2 . Sites which cannot be reached in the field are reselected to approximate the original drainage area as closely as possible. For sampling in Alaska, a pattern containing 23-km^2 grids is marked on field maps, and helicopter pilots select all sample locations from lakes as near as possible to the center of each grid square. Alaskan streams are sampled at twice this density or two sample locations per 23 km^2 .

VI. SAMPLE AND DATA VERIFICATION

Occasionally LASL personnel collect control samples in the field. However, field supervision consists primarily of teaching samplers correct sampling procedures and checking to insure these procedures are followed. After

samples arrive at LASL, they are checked against the respective data form to make sure they are complete and properly labeled as described. Samples are sorted and then sent to the respective laboratories for analysis.

The LASL digitizes all sample locations from the field maps. The digitized results are generated by computer overlays to the field maps (usually 1:24 000 scale). Any locations plotted incorrectly are corrected and entered into the appropriate data base.

VII. ANALYTICAL PROGRAM

Ancillary Elements

Elements other than uranium may form a much wider dispersion halo resulting from their chemical behavior and weathering characteristics and may act as supplemental indicators of uranium. The indicators or pathfinder elements most commonly used in uranium exploration are molybdenum, sulphur, lead, arsenic, vanadium, zinc, copper, nickel, and cobalt (Hawkes and Webb, 1962). Other elements, such as gold, tin, and tungsten can be analyzed for their own worth. Rare-earth elements provide a basis for in-depth geochemical studies, particularly with respect to the association of uranium with resistate minerals such as monazite. The particular elements selected for analysis depend on pilot surveys, analytical facilities, and funding constraints. In addition to the elements listed in Table I, LASL also reports molybdenum, arsenic, selenium, and zirconium (by x-ray fluorescence) in sediment, and vanadium (by plasma-source emission spectroscopy) and arsenic and selenium (by atomic absorption spectrometry) in water for certain areas, as requested by the DOE.

Fluorometry Facility

All water samples are initially analyzed for uranium by fluorometry. Duplicate 0.20-ml water sample aliquots are transferred to special fabricated

TABLE I

LIMITS OF DETECTION AND METHODS OF ANALYSES FOR MULTIELEMENT ANALYSES
(detection limits are ppm for sediment and ppb for water)

<u>Element</u>	<u>* Minimum Detection</u>	<u>Sample Medium</u>	<u>Element</u>	<u>Minimum Detection</u>	<u>Sample Medium</u>
<u>NEUTRON ACTIVATION ANALYSIS</u>			<u>X-RAY FLUORESCENCE</u>		
Al	200	Sediment	Ag	5	Sediment
Au	0.1	Sediment	Bi	5	Sediment
Ba	400	Sediment	Cu	10	Sediment
Ca	5000	Sediment	Nb	20	Sediment
Ce	10	Sediment	Ni	15	Sediment
Cl	200	Sediment	Pb	5	Sediment
Co	2	Sediment	Sn	10	Sediment
Cr	20	Sediment	W	15	Sediment
Cs	2	Sediment	Cd	5	Sediment
Dy	2	Sediment			
Eu	0.5	Sediment			
Fe	2000	Sediment	<u>ARC-SOURCE EMISSION SPECTROSCOPY</u>		
Hf	1	Sediment	Be	1	Sediment
K	3000	Sediment	Li	1	Sediment
La	4	Sediment			
Lu	0.2	Sediment			
Mg	3000	Sediment	<u>PLASMA SOURCE EMISSION SPECTROSCOPY</u>		
Mn	10	Sediment	Ca	20	Water
Na	150	Sediment	Co	55	Water
Rb	25	Sediment	Cu	4	Water
Sb	1	Sediment	Cr	25	Water
Sc	0.1	Sediment	Fe	25	Water
Sm	0.5	Sediment	Mg	2	Water
Sr	300	Sediment	Mn	3	Water
Ta	1	Sediment	Mo	25	Water
Tb	1	Sediment	Ni	25	Water
Th	0.8	Sediment	Pb	200	Water
Ti	200	Sediment	Ti	4	Water
V	5	Sediment	Zn	50	Water
Yb	2	Sediment			
Zn	30	Sediment			
<u>DELAYED NEUTRON COUNTING**</u>			<u>FLUOROMETRY**</u>		
U	0.02	Sediment	U	0.02	Water
U	0.2	Water			

* Because of elemental interference, the detection limits for those elements determined by NAA will shift as a function of the composition of the sediment.

** All water samples having uranium concentrations >40 ppb are reanalyzed by delayed neutron counting.

platinum dishes. Each set of samples is dried under heat lamps, then a LiF-NaF flux is added to each dish and the samples are fused. The fused pellets are transferred to one of four fluorometers, excited with ultra-violet radiation, and the fluorescence is recorded. The uranium concentrations are determined using a computer routine which compares the fluorescence from each pellet with those of pellets from standard uranium solutions and blanks run in the same set (Hues et al, 1977).

The lower limit of detection by normal procedures is 0.2 ppb. However, an evaporative concentration step can provide a 10X concentration factor. This step reduces the lower limit of detection of uranium in natural waters to 0.02 ppb. When a uranium concentration is <0.02 ppb, the sample is arbitrarily assigned a value of 0.01 ppb. Samples having greater than 40 ppb are sent to the reactor group for reanalysis by delayed neutron counting (DNC).

Determinations are stored on a magnetic tape cassette and later transferred to the central computing facility. Throughput is presently 200 samples per day. The throughput for 1979 was about 40 000 analyses (Aamodt et al, 1979).

Energy Dispersive X-Ray Fluorescence

An energy-dispersive x-ray fluorescence system is used to determine nine elements in sediments (Table I). Two x-ray fluorescence analyzers have a throughput of 180-200 samples per day including blanks and standards (Morris et al, 1979). A third analyzer is used for special elements (such as molybdenum, arsenic, selenium, and zircon).

Each system consists of an automatic 20-position sample changer, a lithium-drifted silicon detector, a pulsed molybdenum transmission-target x-ray tube, a multichannel analyzer, and a minicomputer. Sample splits are prepared

for analysis by grinding 6 g of each sample to a minus 325-mesh powder. A computer program positions the samples in the x-ray beam, unfolds overlapping peaks, determines peak intensities for each element, and calculates the ratio of the intensity of each peak to that of the molybdenum K α Compton peak. Concentrations of each element are then calculated using equations obtained by analyzing prepared standards. Detection limits are given in Table I. The relative standard deviation is 10% or less at the 100-ppm level and 20% or less at the 20-ppm level. Details of the method and equipment used are described by Hansel and Martell (1977).

Arc-Source Emission Spectrography

In sediments, two elements, beryllium and lithium, are analyzed by emission spectrography. A 7.5-mg portion of the minus 325-mesh sample that has already been analyzed by x-ray fluorescence is mixed with a graphite-silica buffer. This mixture is placed into a graphite electrode that is used as the anode of a dc arc. A 6-s exposure of the resulting spectrum is made on a direct-reading spectrograph. Photomultiplier tubes are used to measure the spectra lines of Be, Li, and V and the background spectra near these lines. The signals from the photomultiplier tubes are interfaced to a data acquisition system. Stabilization of the spectrograph is achieved by maintaining rigid temperature control of the grating and the focal curve containing the exit slits, and by providing two mercury reference lines between each sample analysis. Vanadium is monitored in order to correct for its interference with the beryllium determination. The results are simultaneously printed on paper and written on cassette tape for later transmission to a computer data file. The elemental concentrations of Be and Li are determined from the spectra, based on the results of previously run calibration standards. The lower detection limit for both elements is 1 ppm. Precision at the lower detection

limit is $\approx 50\%$ for both and improves to $\approx 25\%$ at one order of magnitude above the lower limit. The throughput of this system is 200 analyses per day. In 1979, the throughput was more than 50 000 samples (Morris et al, 1979).

Plasma-Source Emission Spectrography

All water samples are now analyzed for 12 elements (Table I) by inductively coupled plasma emission spectroscopy. To allow complete system equilibration, the inductively coupled plasma and photomultiplier tubes are warmed up for at least 1 h prior to making any analyses. Argon coolant and sample carrier gas lines are adjusted and calibrated using a zinc standard. The sample solution is taken up from its container, nebulized, and injected into the plasma source at a rate of $9.2 \times 10^{-9} \text{ m}^3/\text{s}$.

A plasma-therm inductively coupled plasma is used as the source. After the computer determines that the photomultiplier tubes have stabilized, a 15-s exposure of the resultant spectrum is made on a direct-reading spectrograph. Stabilization of the spectrograph is achieved by maintaining rigid control of the grating and exit slit focal curve temperatures, and by profiling two mercury reference lines between each sample analysis. The resulting signals are read directly into a computer, and converted automatically to give the elemental concentrations. In addition, beryllium, sodium, and silicon are monitored. Interelement effects for each of the 15 elements monitored on the other elements are determined and used in correcting values for the 12 elements reported. Background corrections are made by running blanks, and control samples are run regularly. When high (off-scale) results are obtained, the computer calls for the insertion of a filter between the plasma source and the spectrograph, repeats the readings, and then converts and stores the corrected elemental concentrations. Analytical precision for the elements as determined for water by this method is $\approx 50\%$ at the lower detection limit, improving to

$\approx 10\%$ one order of magnitude above the lower detection limit and to $\approx 5\%$ two orders of magnitude above the detection limit.

The throughput of this system is 100 samples per 9-h day for samples exclusive of standards and controls. In 1979, the throughput was about 17 000 samples (Morris et al, 1979).

Certain elements analyzed by plasma-source emission spectrography are subject to analytical interferences. For example, large concentrations of calcium in a water sample may cause abnormal concentration readings for lead and molybdenum resulting in a bias of lead and molybdenum values. Consequently, a dual-grating, high-resolution, direct reading spectrograph is under construction. This instrument will permit monitoring of 200 spectral lines and permit more accurate interelement-effect corrections.

Neutron-Activation Analysis

The neutron-activation analysis (NAA) system at the LASL represents a state-of-the-art system which produces precise values for uranium and 31 other elements in sediment samples. All samples are run through one of two computer-coordinated pneumatic sample-handling systems. Each sample is irradiated twice and counted a total of three times (Table II): once for delayed neutron counting (DNC) for uranium and twice for gamma-ray spectrum counts for 31 other elements. Both sample transfer and data acquisition are entirely automated (Nunes and Weaver, 1978).

All sediment splits (regardless of which facility analyzes the sample) are made in a "clean room." Four-ml rabbits, the containers in which the sample undergoes irradiation, are loaded with approximately 5 g of sample, although as little as 0.5 g may be used. These rabbits are then loaded into a 50-sample transfer clip. The reactor pneumatic transfer system and background

TABLE II

STEPS INVOLVED IN IRRADIATION OF A SAMPLE
FOR NEUTRON ACTIVATION ANALYSIS

<u>Steps</u>	<u>Operation</u>	<u>Elapsed Time (seconds)</u>
1	20-s irradiation	20
2	10-s delay	30
3	20-s delayed neutron counting	50
4	20-min delay	1250
5	500-s γ -ray count (day shift) for Al, Ba, Ca, Cl, Dy, K, Mg, Mn, Na, Sr, Ti, V	1750
6	120-s irradiation	1820 ($\approx$ 30 min)
7	2 week delay	2 weeks
8	900-s γ -ray count (night shift) for Au, Ce, Co, Cr, Cs, Eu, Fe, Hf, La, Lu, Rb, Sb, Sn, Sm, Ta, Tb, Th, Yb, Zn	

Note: There are two separate analytical systems. Each system has one delayed neutron counter and 4 Ge(Li) detectors and is capable of analyzing 200 samples per working day. A sample enters each system every 126 seconds.

radiation levels are checked, and standards are run for calibration. The transfer clip is installed and the samples are cycled through the system.

The uranium concentration is automatically measured after 30 s by DNC, converted to ppm, and entered into the data base. The lower limit of detection of this method is 20 ppb (not ppm) uranium, which is below the range of uranium concentrations in natural sediment samples. Above the 1-ppm level, the uranium values in sediment measured by DNC at the LASL have a one-sigma error of less than 4% (Aamodt et al, 1979). The specially designed delayed-

neutron detectors, built by the LASL and used for these analyses, are described by Balestrini et al (1976).

After uranium is counted by DNC, 12 elements are determined by gamma counting. The remaining 19 elements are determined by γ -ray counting following re-irradiation and two week delay. The γ -ray counting is done by lead-shielded Ge(Li) detectors; the 4096-channel γ -ray data are recorded and subsequently analyzed for each individual element by computer. The analytical data for each sample are automatically printed out along with the associated statistical errors. Current "typical" lower detection limits for the elements determined by NAA are in the ppm range as reported in Nunes and Weaver (1978); however, the actual detection limit for an element depends upon the composition of the sample, so this limit may be higher or lower than the "typical" value. At concentration values one order of magnitude above the lower detection limits, the relative errors are generally less than 10%.

Both systems have a combined total throughput of 400 samples per day. The yearly throughput greatly exceeds 50 000 samples.

Uranium Determination in Water Samples by DNC

Only waters with >40 ppb uranium (as determined by fluorometry) or those with impurities that cause interference with uranium-induced fluorescence are analyzed using DNC. Samples are transferred to clean rabbits before being analyzed. Each water sample is weighed, then loaded into a 25-sample transfer clip. The reactor pneumatic transfer system and background radiation levels are checked and four standards are run for calibration. The transfer clip is installed on the pneumatic feed line and the samples are cycled through the system. Typically, a 60-s irradiation, 30-s delay, and 60-s count cycle is used. The neutron count rate is automatically measured, converted to ppb uranium, and entered into a computer data base. The lower detection limit for

uranium in water by DNC as used at the LASL is 0.2 ppb. The statistical error of this method is $\approx 20\%$ at a uranium concentration of 1 ppb, $\approx 6\%$ at 10 ppb, and $<4\%$ at 40 ppb or greater. Statistical treatments of uranium concentrations obtained from the same suites of samples analyzed both by fluorometry and DNC have shown that there is no significant difference between the results of the two analytical methods as used at the LASL. This analytical comparability is rechecked periodically.

Central Computer Facility

The LASL data-base management group employs a general-purpose, data-base management system to maintain and organize the field and analytical data for the HSSR project. The data-base management system is used with about 75 programs to load the field data, check the data for consistency, and load analytical results (Cheadle, 1977 and 1978).

The samples and analytical data are grouped into data bases according to NTMS quadrangle boundaries (Sharp, 1977). Each data base stores about 138 variables for each sample and occupies about 125K words of core. At present, there are about 220 000 sample locations stored in 158 data bases. Each sample location is associated with a number of coded field measurements and observations and up to 13 water and 43 sediment analyses. There are about 25 million pieces of information in readily available form (C. McInteer, personal communication, LASL, 1980).

VIII. EVALUATION OF DATA

Once all samples from an area have been analyzed for uranium and other elements, the measured concentrations are entered into the appropriate data base at the central computing facility. A maximum effort is made by all LASL

personnel to check the data to make sure they are analytically correct before being released.

Each report contains a suite of standard histograms for each sample type (stream waters, stream sediments, etc.). These histograms are used both to evaluate the data and to establish reasonable limits in selecting intervals for the various concentration overlays, which are also included with each report. These concentration overlays are all produced at a 1:250 000 scale to be used in conjunction with the appropriate 1:250 000-scale geologic and topographic maps. Geologic maps, when not available at this scale, are compiled and included with the reports. Concentration overlays, one each for a sample location, a uranium concentration in waters, conductivities in waters, uranium concentrations in sediments, and thorium concentrations in sediments, are included with the report. An example of a uranium concentrations overlay for sediment is shown in Fig. 3. Appendixes include listings of field data and elemental concentrations for both waters and sediments and a summary of standard LASL HSSR procedures and codes.

Standard reports also contain approximately 15 pages of text that includes sections on geography, geology, hydrology, geochemical considerations, and known uranium occurrences in the area. Empirical and statistical evaluations are concise and generally refer to uranium data only; however, all analytical data are included in every report. Data releases are an abbreviated type of report and include only histograms, overlays, and data listings. All reports are made available to the public in both magnetic tape or report form.

Potential Uses of Data

The LASL personnel are now examining the analytical data in great detail and have been employing several multivariate statistical programs as an aid in their evaluation. For example, Bolivar and Hill (1979), in an HSSR report of

Fig. 3. A reduction of a uranium concentrations in sediments overlay (plate IV in Bolivar and Hill, 1979).

the Craig NTMS quadrangle, Colorado, were able to delineate several areas favorable for uranium mineralization using empirical evaluation methods. Planner and Campbell (1980) show a correlation between structure and uranium concentrations in this quadrangle by employing a "moving average" method of data evaluation. Also, by using both a moving average and kriging techniques, they were able to identify a known area of mineralization that the evaluation of Bolivar and Hill (1979) did not detect.

By use of correlation coefficients, scattergram plots, and factor analysis, Beyth et al (1980) were further able to identify and pinpoint areas in the Craig quadrangle favorable for uranium and base-metal mineralization. Some areas have characteristic low uranium concentrations in waters and sediments and casual examination of data from these areas may not reveal potential exploration regions. However, sophisticated statistical treatment of the data helps to identify these areas.

IX. SUMMARY

Since April 1975, the LASL has established an effective and capable hydrogeochemical and stream sediment reconnaissance program. Based on an extensive review of world literature (Sharp and Bolivar, 1980), the results of several pilot studies (Sharp and Aamodt, 1976; Olsen, 1977; Aamodt, 1978; Sharp et al, 1979), and in keeping within funding constraints, the LASL has developed standardized sampling procedures (Sharp and Aamodt, 1978) that emphasize the determination of uranium concentrations in both natural waters and waterborne sediments. Water and/or sediment samples are collected from approximately each nominal 10 km^2 , except in lake areas of Alaska where samples are collected every nominal 23 km^2 . The LASL area includes the states of New Mexico, Colorado, Montana, Wyoming, and Alaska in which 165 000

waters and 185 000 sediments have been collected (as of May 1980) from 220 000 locations (Bolivar, 1979).

The LASL HSSR program has been developed to aid in a national uranium resource evaluation. Because many elements are analyzed in addition to uranium and because the LASL program employs standard geochemical sampling techniques and analytical methodology, this program technology could be adopted for regional studies of economic commodities in almost any country.

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