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RESOURCE CHARACTERIZATION FOR URANIUM MINERALIZATION IN THE MONTROSE 1° x 2° QUADRANGLE, COLORADO

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ABSTRACT

A data-classification scheme was developed to detect potential uranium mineralization in the Montrose 1° x 2° quadrangle, Colorado. The methodology developed is a rapid and efficient method of resource evaluation on a reconnaissance scale. The necessary techniques were developed and refined to digitize, integrate, and register various large geological, geochemical, and geophysical data sets for the Montrose quadrangle, Colorado, using a grid resolution of 1 km. All data sets for the Montrose quadrangle were registered to the Universal Transverse Mercator projection. The data sets include hydrogeochemical and stream sediment analyses for 23 elements, uranium-to-thorium ratios, airborne geophysical survey data, the locations of 90 uranium occurrences, and a geologic map (scale 1:250 000). Geochemical samples were collected from 3965 locations in the 19 200 km^2 quadrangle; aerial data were collected on flight lines flown with 3-5 km spacings. These data sets were smoothed by universal kriging and interpolated to a 179 x 119 rectangular grid (each grid block is 1 km^2). A mylar transparency of the geologic map was prepared and digitized.

All possible combinations of three, for all data sets, were examined for general geologic correlations by utilizing a color microfilm output. Subsets of data were further examined for selected test areas. A classification scheme for uranium mineralization, based on selected test areas in the Cochetopa uranium district, is presented. Areas favorable for uranium mineralization, based on this scheme, were identified and are discussed.

INTRODUCTION

The objective of this report is to characterize known uranium occurrences for the Cochetopa uranium district in the Montrose 1° x 2° quadrangle and to find other areas in the quadrangle with similar characteristics. It has been accomplished by integrating, in the computer, available National Uranium Resource Evaluation (NURE) geochemical reconnaissance data, geologic map information, uranium occurrence data, and radiometric and magnetic data from the NURE airborne geophysical survey.

This technology was developed to interpret the large quantity of data available for many of the 1° x 2° quadrangles in the continental U.S. When several data sets are integrated into one large data set a wealth of information can be extracted. Only one aspect of this project, that of uranium characterization, is covered in this report--other applications, detailed descriptions of the methodology, statistical manipulations, enhancement techniques, and display options are discussed in Bolivar et al., 1981.

GEOLOGY AND URANIUM OCCURRENCES

General Information

The Montrose quadrangle comprises about 19 200 km^2 in southwestern Colorado. It includes sections of the Southern Rocky Mountain and Colorado Plateau physiographic provinces (Fig. 1). The West Elk mountains, San Juan mountains, and Sawatch Range are the dominant drainage divides within the quadrangle.

A wide variety of igneous, metamorphic, and sedimentary rocks, representing most major geologic periods crop out in the Montrose quadrangle. A generalized geologic map, Fig. 2, shows the distribution of major rock units. Lithology and regional geology of this region have been described in detail by many investigators (e.g., Weimer and Haun, 1960; Haun and Kent, 1965; Epis, 1968; Tweto, 1968 and 1975; Mallory, 1972; Tweto et al., 1976a). Only a brief summary is given herein.

The Montrose quadrangle consists of three major physiographic/geologic provinces: the Sawatch-Gunnison crystalline terrane, the San Juan-West Elk volcanic field, and the Western Plateau area. The Sawatch-Gunnison crystalline terrane is underlain principally by Precambrian igneous and metamorphic rocks and, to a lesser extent, by Paleozoic sedimentary formations and Tertiary plutonic rocks. The San Juan-West Elk volcanic province is underlain by mid-Tertiary intermediate to felsic volcanic rocks, whereas the Western Plateau is underlain by gently dipping Mesozoic sedimentary formations.

Radioactive Mineral Occurrences

There are approximately 90 separate known locations where uranium mineralization has been identified or where anomalous radioactivity occurs in the Montrose quadrangle (Fig. 3). The mineralization at these occurrences appears to be fracture and or stratigraphically controlled. Mineralization is also commonly associated with shear zones, fault breccias, fractures, and vein fillings.

Over half of the known uranium occurrences in the quadrangle are found in three major uranium districts: the Cochetopa, Marshall Pass, and Powderhorn districts (Fig. 3). In fact, nearly 600 000 tons of uranium ore containing between 0.11 and 1.17 per cent U_3O_8 have been produced from the Montrose quadrangle (compiled from Nelson-Moore et al., 1978). Most production is from mines in the Cochetopa and Marshall Pass districts. These mining districts and other uranium occurrences in the quadrangle are briefly described in Table I and their locations are

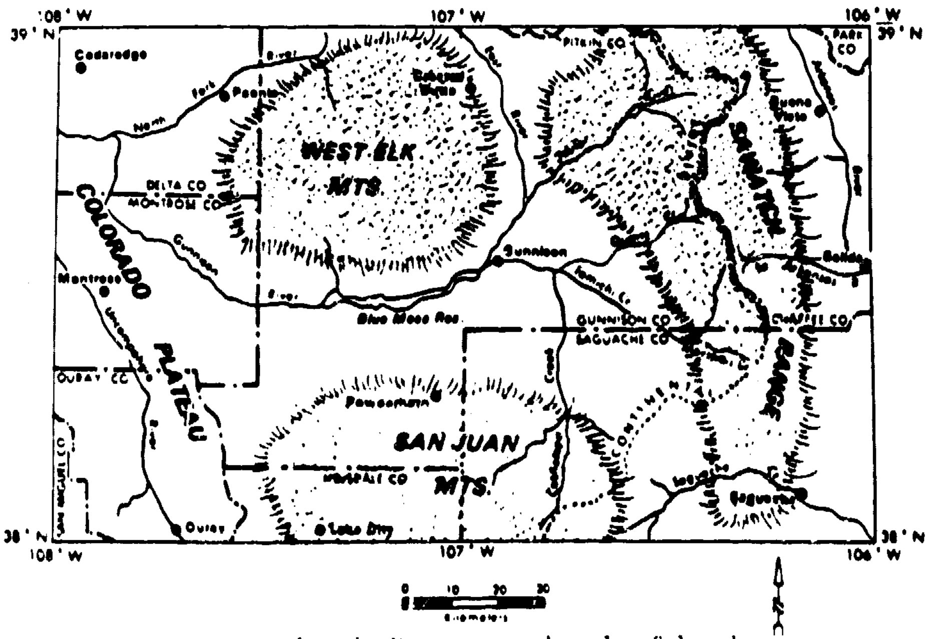


Figure 1. Location map for the Montrose quadrangle, Colorado.

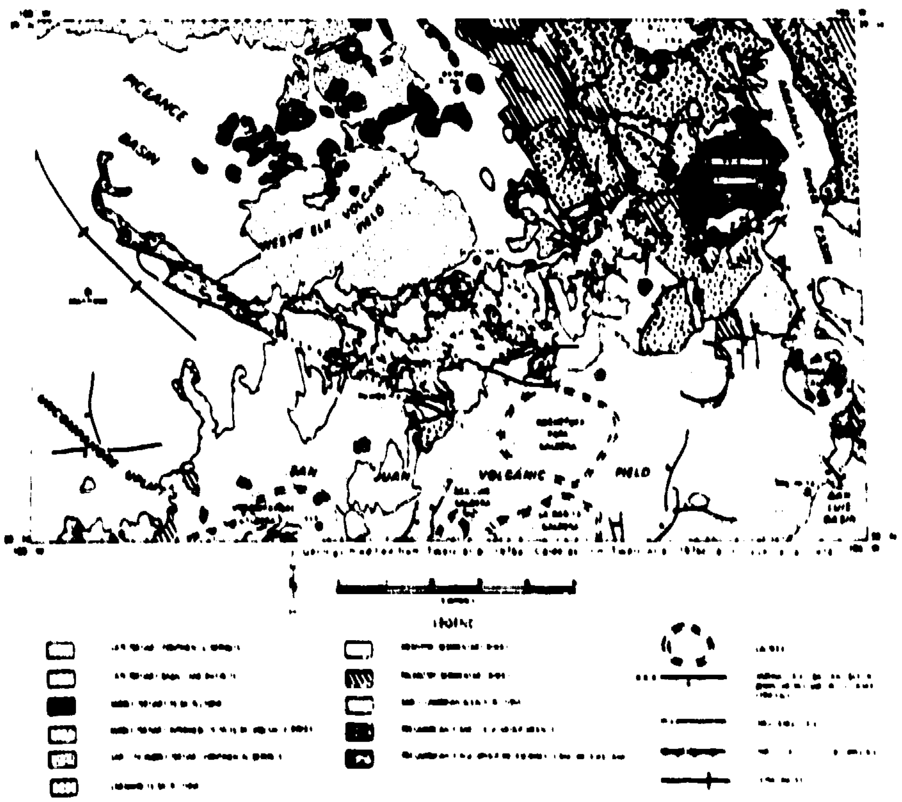
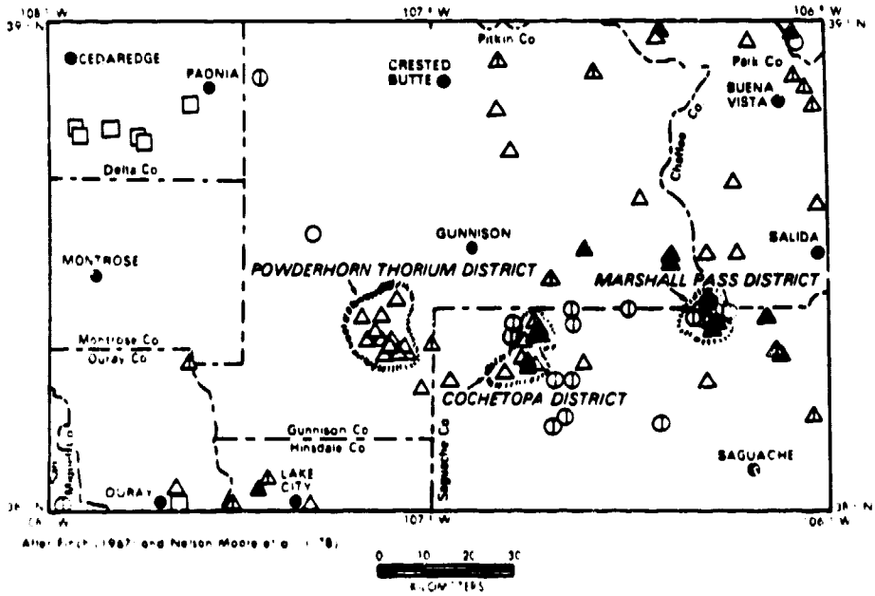


Figure 2. Generalized geologic map of the Montrose quadrangle, Colorado.



LEGEND

One symbol may represent several occurrences or claims

△ Vein, pegmatite, breccia zone, and related types, uranium mineralization strongly suspected (usually because of abnormal radioactivity) but not megascopically visible

△ Vein, pegmatite, breccia zone, and related types, uranium mineralization documented but no past production

▲ Vein, pegmatite, breccia zone, and related types, uranium ore production documented

Figure 3. Uranium occurrences in the Montrose quadrangle, Colorado.

shown in Fig. 3. More detailed descriptions of the individual uranium occurrences are summarized in Finch (1967), Olson (1976), and Nelson-Moore et al., (1978).

The Cochetopa district is located about 25 km southeast of Gunnison, and mineralization occurs in an 11-km diameter region. In this district, uranium mineralization is localized along fault breccias of the Los Ochos fault where Morrison sandstones and shales are faulted against Precambrian X age granites and schists. The principal ore bodies are associated with intensely altered areas in the fault breccia and in adjacent wall rocks, although mineralization can occur in quartz-calcite-barite veins and shear zones that cut Precambrian schists (geoMetrics, 19[illegible]). Although no mines are active in this area at the present time, 486 000 tons of ore yielding [illegible] lb of U_3O_8 have been produced, mainly from the Los Ochos and T-2 mines (Nelson-Moore et al., 1978).

DATA SET DESCRIPTION, DIGITIZATION, AND REGISTRATION

In order to efficiently integrate large volumes of data, it is necessary to get the various data sets into spatially comparable formats. Therefore, after data sets are obtained, they are digitized and geometrically registered to the Universal Transverse Mercator (UTM) projection. The UTM coordinate system is a rectangular equal area projection and the coordinate boundaries chosen are slightly larger than the Montrose quadrangle boundaries.

For the Montrose quadrangle, the reference grid selected has a grid spacing (and resolution) of one kilometer, exactly coinciding with the UTM grid for this part of Colorado. The 1-km spacing is also the smallest reasonable choice for concordance with the kriging interpolation schemes used for airborne and geochemical data. Because the corners of the Montrose 1° x 2° quadrangle do not form a perfect rectangle on the UTM projection, the smallest rectangle that can be defined on the sample grid that will cover the entire quadrangle was selected. This results in an index set of 119 rows and 179 columns to cover the 1° x 2° sheet--a total of 21 [illegible] grid cells. All data sets are keyed to grid cell locations.

Data integration requires resampling each data set to the selected grid. Point data (such as NURE data) are statistically smoothed and interpolated to the rectangular grid. Data available on a finer resolution, such as geologic information, are subsampled to the 1 km UTM grid. Ideally, the finished product gives computer access to all data sets simultaneously for any desired location.

Once the data sets are integrated and spatially registered, they can be examined statistically for relationship between data sets and individual variables and also for significant patterns derived from the data. Individual data sets can be analytically and visually overlain. All possible combinations of

TABLE I

MAJOR URANIUM AND THORIUM DISTRICTS IN THE MONTROSE QUADRANGLE, COLORADO

(Locations of specific occurrences are shown in Fig. 3)

County	District or Area	Description	References
Delta	Gunnison River Area	The five occurrences in this area are radioactive spring deposits that are found in the Dakota sandstone. One is associated with a fault. No uranium mineralization is visible; abnormal radium contents have been reported.	Cadigan et al., 1976.
San Miguel Ouray Hinsdale	Southwest Montrose Quadrangle	On a 18 tons of ore of average grade 0.20% U_3O_8 are reported from these three counties (Nelson-Moore et al., 1978). Most uranium occurrences are in veins in Tertiary volcanics; one radioactive spring deposit is known. Uranium mineralization is associated with rhyolite-latite intrusives and breccia zones. The dominant uranium minerals are uranophane and pitchblende. In San Miguel county tabular ore bodies are found in the Entrada sandstone. Average ore grade is 0.05% U_3O_8 and is closely associated with vanadium. One such occurrence is reported in the extreme southwest corner of the Montrose quadrangle.	Burbank, 1940; Burbank and Pierson, 1953; Larsen and Cross, 1956; US AEC, 1966d; Fischer et al., 1968.
North Gunnison Chaffee Park	Northeast Montrose Quadrangle	About 300 tons of ore, with average grades of 0.12 to 0.22% U_3O_8, have been taken from deposits in this area (Nelson-Moore et al., 1978). Most uranium occurrences are vein types found in pegmatites in Precambrian granitic rocks; some are associated with veins, dikes, and fault breccias of Tertiary intrusives; a few are found along Paleozoic quartzite-Precambrian granite fault contacts. Deposits are usually small in size. Uranium mineralization is associated with faults, fractures, alteration zones, carbonaceous trash (especially in fault zones), and base-metal mineralization. Autunite, columbite, pitchblende, brannerite, and monazite are the dominant uranium minerals. These types of occurrences are not restricted to these three counties, but are found throughout the Montrose quadrangle.	Guillotte, 1945; Adams, 1953; Heinrich, 1958; Baillie, 1962; US AEC, 1966a; US AEC, 1966b; Gallagher et al., 1977.
Gunnison	Powderhorn Thorium District	Most of the thorium occurrences in this district consist of radioactive anomalies in veins. These veins are found in Precambrian granite, schist, and gneiss. Deposits consist of thorite, minor amounts of uranium, quartz, barite, hematite, and sulfides.	Larsen, 1942; Olson and Wallace, 1956; US AEC, 1966a; Murphy et al., 1978; Nelson-Moore et al., 1978; Armbrustmacher, 1979.
Saguache	Cochetopa District	Production totals for this district to 1971 are about 486 000 tons of ore containing 0.11 to 0.30% U_3O_8 (Nelson-Moore et al., 1978). Uranium mineralization generally occurs in fault breccia or shear zones between the Morrison formation (or to a lesser extent the Dakota sandstone) and Precambrian rocks, or in veins cutting Precambrian rocks. Uranium mineralization may also be associated with malachite, azurite, or other base metal mineralization. The Morrison formation is comprised predominantly of sandstone and mudstone, whereas the Precambrian rocks are generally granite or schist. Primary uranium-bearing minerals include pitchblende, uranophane, autunite, torbernite, and zippeite.	Derzay, 1956; Malan and Ranspot, 1959; Eckel, 1961; US AEC, 1966c; Finch, 1967; Olson, 1976.
Saguache	Periphery of Cochetopa District	Around the periphery and southeast of the Cochetopa district, several uranium occurrences are reported in the Miocene Potosi Volcanic Series, or in Cretaceous rocks which are overlain by these volcanics.	Malan and Ranspot, 1959; Nelson-Moore et al., 1978.
Saguache Gunnison	Marshall Pass District	Over 105 000 tons of ore ranging from 0.25 to 1.17% U_3O_8 have been produced from this district. All occurrences in this area are related to the Chester fault or Indian Creek anticline. Principal host rocks include the Ordovician Harding quartzite and Pennsylvanian Belden shale, which are in fault contact with Precambrian rocks. The Harding quartzite is a porous sixty sandstone, whereas the Precambrian rocks include highly fractured granites, schists, and pegmatites. Uranium mineralization is associated with iron-stained, fossiliferous, and carbonaceous zones. Sulfides may or may not be present. Primary uranium minerals include pitchblende, uraninite, and uranophane with minor amounts of gummite, autunite, and zippeite. Several occurrences, not within this district but with similar types of uranium mineralization, are found to the southeast.	Malan and Ranspot, 1959; Ranspot and Spengler, 1957; Gross, 1965; Nelson-Moore et al., 1978.

three, for all data sets, were examined for general geologic correlations by utilizing a color microfilm output (Bolivar et al., 1981).

Small test areas containing known uranium occurrences, predominantly from the Cochetopa uranium district, were extracted and examined. A preliminary classification scheme, based on characteristics of the known occurrences in this district, was then generated and iteratively refined. This classification will be tested for the entire Montrose quadrangle to determine if similar uranium occurrences can be found.

Geochemical Data

Our geochemical data sets are compiled from two separate studies done as part of the US Department of Energy's NURE program (Bolivar, 1980a). As part of this program (Bolivar, 1980b), the Los Alamos National Laboratory conducted a hydrogeochemical and stream sediment reconnaissance for uranium in the Montrose quadrangle, Colorado, during which 1365 water and 1857 sediment samples were collected from 1877 locations (Broxton et al., 1979). Water samples came from streams, springs, and wells and were analyzed for uranium by fluorometry. Sediment samples were taken from streams and springs and were analyzed for uranium by delayed-neutron counting, for 31 additional elements by neutron activation analysis, for 9 elements by energy dispersive x-ray fluorescence, and for 2 elements by arc-source emission spectrography. Standard sampling procedures as defined by Sharp and Aamodt (1978) were used in the field. Sample densities were nominally one sample location per 10 km². All samples were collected during July 1976 and July and August of 1977. A sample location overlay (scale 1:250 000) can be found as Plate I of Broxton et al. (1979).

In the summer of 1979, Los Alamos conducted a detailed follow-up hydrogeochemical and stream sediment survey in a portion of the Montrose quadrangle. A total of 2088 stream sediment samples were collected at a nominal density of one sample location per km² (note: 1034 water samples were also collected). Samples were analyzed for uranium and for 45 other elements (Maassen, 1980). The majority of samples were from, or near, the Sawatch Range.

By combining these two data bases, we obtain a geochemical data base with 3965 sample locations (some locations have sediment samples only, some have water samples only, however most have both a water and sediment sample). We then selected elements believed most beneficial as an aid in identifying uranium mineralization. The report of Reyth et al. (1980b) examines the data of Broxton et al. (1979) by using multivariate statistical analyses. Reyth's results helped to identify those elements that would be most favorable for our work. We tried to select elements that had a minimal number of values below our analytical detection limit (Bolivar, 1980b). Also included are the elements arsenic and zirconium which the Department of Energy required for the follow-up study (Maassen, 1980). Table II is a list of elements selected. The U/Th ratios (not shown in Table II) comprise a separate data set.

The elemental concentration analyses represent point data at irregularly spaced sample locations; therefore, it is necessary to get these data into a spatially comparable format with the other data sets. This was done by universal kriging on a moving window average, interpolated to a regular grid. Universal kriging is a statistical method (Olea, 1974) used to obtain spatially interpolated values from a set of irregularly spaced data points. The standard assumption is that the spatial covariance in small regions is dependent only on the distance between points. If this covariance function were known, an unbiased estimate of the elemental concentration at an unsampled location can be formed, together with an estimate of the variance. In practice, the spatial covariance function (actually, a related function, the variogram) must be estimated as well.

Thus an estimate of the elemental concentration was formed for each grid center on the 1-km grid as a weighted average of nearby samples. The nearest five samples were used, provided there were five within a 5-km radius of the grid point; also, all samples within 500 m were used, even when the total was greater than 5. When there were two or less samples within 5 km of a grid point, no estimate was computed and the grid point was assigned a zero value. The weighting of those samples depended on their distance from the grid point and on the estimated variogram. No provision was made for stream drainages. Because some elemental concentrations can be below detection limits (explained in Table II), such values are downweighted.

TABLE II

DETECTION LIMITS AND ANALYTICAL METHODS FOR SELECTED ELEMENTS
(from Bolivar, 1980b)

Element	Symbol	Minimum Detection Limit in ppm[a]	Method of Analysis[b]
Aluminum	Al	200	NAA
Arsenic	As	5	XRF
Barium	Ba	400	NAA
Calcium	Ca	5000	NAA
Cerium	Ce	10	NAA
Cobalt	Co	2	NAA
Chromium	Cr	20	NAA
Copper	Cu	10	XRF
Dysprosium	Dy	2	NAA
Iron	Fe	2000	NAA
Hafnium	Hf	1	NAA
Potassium	K	3000	NAA
Lithium	Li	1	ES
Manganese	Mn	10	NAA
Lead	Pb	5	XRF
Scandium	Sc	0.1	NAA
Thorium	Th	0.8	NAA
Titanium	Ti	200	NAA
Vanadium	V	5	NAA
Zirconium	Zr	5	XRF
Zinc	Zn	30	NAA
Uranium (in sediment)	U	0.01	DNC
Uranium (in water)[c]	U	0.02 (in ppb)	F

[a] Because of elemental interference, detection limits will shift as a function of sediment composition.

[b] NAA = neutron activation analysis, XRF = x-ray fluorescence, ES = arc-source emission spectroscopy, DNC = delayed neutron counting, F = fluorometry.

[c] All water samples with uranium concentrations 40 ppb are reanalyzed by DNC.

Airborne Radiometric and Aeromagnetic Data

In fall 1978, as part of the NURE program, an airborne radiometric and aeromagnetic survey was made of western Colorado and eastern Utah. Data processing methods, regional geology, and evaluation techniques for this regional survey are summarized in geoMetrics (1979a); geoMetrics (1979b) is a geologic summary and evaluation of the Montrose quadrangle. A summary of the characterization of all uraniferous provinces by aerial spectrometry can be found in Saunders (1979).

Surface gamma radiation is produced primarily by the radioactive decay of potassium-40, thorium 232, and uranium-238. Gamma-ray intensities are measured by an airborne spectrometer from the potassium-40, thallium-208, and bismuth-214 peaks. Because the parent heavy nuclides do not have distinct gamma-ray peaks, daughter thallium and bismuth intensities are read; the daughter products bismuth-214 (for uranium-238) and thallium-208 (for thorium-232) are assumed to be in equilibrium with their parent nuclides (Adams and Gasparini, 1970).

Moving at a standard ground speed of 110 kmph (70 mph), the airborne spectrometer measures gamma radiation from only the top 20-50 cm of ground surface (Gregory and Horwood, 1963). Each data point is an integrated measurement of gamma rays taken normally from a helicopter and accumulated over a fixed period of time, usually one second. For the Montrose quadrangle, a one-second sample corresponds to a 215-m (700-ft) long by 185-m (600-ft) oval on the ground, i.e., one data point represents about a 40 000 m^2 area (geoMetrics, 1979a). The Montrose quadrangle contains over 200 000 points for each of the aerial radiometric and aeromagnetic bands.

East-west profiles were flown at 4.8-km (3-mile) spacing for the southeast quarter of the Montrose quadrangle and 3.2 km (2 miles) for the rest of the quadrangle. North-south tie lines were flown at 19.2-km (12-mile) spacing. Flight lines were flown at a 122-m (400-ft) mean terrane clearance.

The first step in getting from densely sampled flight lines to the 1-km rectangular grid is to smooth and subsample the noisy aerial radiometric data along flight lines. This is done using an automated kriging procedure, where the parameters of the variogram are estimated locally, depending on the local signal-to-noise ratio. The result is an adaptive filter. In regions where the data are not changing much, relative to the noise, the smoothed estimate is almost an unweighted average of measurements in a relatively long segment of the flight line (about 1.5 km); in a region where the signal is changing rapidly, nearby measurements are much more heavily weighted than more distant ones. These kriged estimates (together with error estimates) were computed every 0.4 km along each flight line, that is, at about one-tenth the density of the original one second measurements.

From this point, interpolation onto the rectangular grid proceeds much as for the hydrogeochemical data. A variogram is computed and used to form an estimate at each grid center point as a weighted average of the smoothed data (with associated errors). All of the smoothed data within 3.5 km of a given grid center point were used in forming an estimate at that center point; a circle of this radius intersects at least two flight lines, except when centered at a few points in the southeast part of the quadrangle.

The aeromagnetic data were similarly treated, except that along flight lines, because there is very little noise in these data, values at 0.4-km intervals were determined by linear interpolation between the two nearest measurements.

Known Uranium Occurrences

About 90 uranium occurrences or areas with abnormal radioactivity are known for the Montrose quadrangle (Fig. 3). These occurrences are described in Table I.

In order to combine this information, which is essentially point data, with other data sets, it was necessary to digitize the occurrences and assign each a UTM coordinate. Each known occurrence was assigned a coded number from which one could identify the deposit type. Each occurrence was also assigned a grid cell location in the 179 x 119 rectangular grid. This allowed us to examine any one occurrence by simply identifying the coordinates for that grid cell. The occurrences, their coded identification numbers, and their grid cell coordinates are given in Appendix A.

Geologic Map

The reconnaissance geologic map of Tweto et al. (1976a), scale 1:250 000, was used as a base map. Tweto's map contains 57 mapable formations. To facilitate interpretation efforts and because many of these units are depositionally similar, the 57 formations of Tweto were grouped into 13 selected geologic "units."

A mylar transparency was then made for this map by assigning each unit a separate mylar color. Care was taken to assign colors that could easily be resolved by a computer when the primary colors are examined. The mylar transparency was used in an attempt to assign each unit a consistent color density.

The mylar transparency was then photographed onto 70-mm color film. The color film was digitized on a PDS microdensitometer to obtain three 512 x 340 digital arrays corresponding to the green, red, and blue exposures, respectively, on magnetic tape. The three digital arrays were inserted into a COMTAL 8000 digital display unit to form a color image of the geological map. Training sets were then defined for each of the 13 geological units from inspection of the color display. Finally, each grid cell was classified as belonging to one of the geologic units by using a simple minimum distance classifier. Then the classified 512 x 340 array was subsampled, using a nearest neighbor algorithm interpolation, to the 179 x 119 UTM grid.

Because the contacts between mylar cutouts (each cutout corresponding to contiguous geologic units) do not fit perfectly, most classification errors occurred along boundaries between geologic units. This problem was alleviated somewhat by a median filter operating both as a preprocessor and a postprocessor. Final cleanup of the map was accomplished manually on the 179 x 119 array.

Classification Schemes for the Cochetopa Test Areas

In this section, the procedures and methods used to determine a classification scheme by using test areas from the Cochetopa uranium district are outlined. A preliminary, albeit crude, classification scheme was successfully developed.

We are looking for regional patterns that may indicate uranium mineralization. These patterns may be independent of any individual high or low value for any given data set. It is the combinations of various data sets that we believe will ultimately help to identify the regional patterns.

TABLE III

KRIGED VALUES FOR SELECTED GRID CELLS CONTAINING KNOWN URANIUM OCCURRENCES
(Code numbers are explained in Appendix A; cumulative percent in parenthesis.)

Code Number	Grid Cell Location	Al	As	Ba	Ca	Ce	Co	Cr	Cu	Dy
100402	49-10	76802(90)	--	762.3(33)	19919(14)	76.7(9)	16.01(40)	21.9(12)	31.19(1)	3.22(9)
200616	110-38	54530(71)	14.54(21)	854.7(37)	15651(11)	110.7(13)	12.01(30)	49.3(27)	31.19(1)	5.72(16)
200619	112-43	50348(59)	11.77(17)	623.7(27)	11382(8)	93.7(11)	11.61(29)	56.6(31)	31.19(1)	6.43(18)
200631	113-45	50348(59)	20.77(30)	646.8(28)	22765(16)	85.2(10)	9.21(23)	40.2(22)	31.19(1)	5.72(16)
100506	124-62	49495(58)	17.31(25)	554.4(24)	17074(12)	[illegible].6(7)	12.01(30)	42.0(23)	62.37(2)	6.43(18)
200503	143-59	67415(79)	14.54(21)	739.2(32)	8537(6)	17[illegible].4(20)	8.01(20)	29.2(16)	93.56(3)	8.22(23)
200515	151-50	57175(67)	11.08(16)	554.4(24)	18496(13)	110.7(13)	16.41(41)	133.4(73)	31.19(1)	6.43(18)
100[illegible]1	152-45	7168[illegible](84)	9.69(14)	900.9(39)	22765(16)	136.3(16)	12.41(31)	84.1(46)	31.19(1)	11.08(31)
40062	152-47	70829(83)	9.00(13)	831.6(36)	19919(14)	85.2(10)	11.21(28)	89.5(49)	62.37(2)	9.65(27)
100[illegible]8	153-45	69976(82)	9.69(14)	877.8(38)	18496(13)	93.7(11)	12.81(32)	89.5(49)	62.37(2)	10.72(30)
100[illegible]	164-46	73389(86)	6.92(10)	993.3(43)	14228(10)	119.2(14)	10.41(26)	45.7(25)	31.19(1)	5.36(15)
100649	167-47	63149(74)	19.38(28)	1570.9(68)	4268(3)	187.4(22)	12.01(30)	31.1(17)	842.05(21)	4.65(13)
200801	171-110	58882(69)	--	6[illegible]4.8(28)	21342(15)	110.7(13)	12.01(30)	64.0(35)	31.19(1)	5.36(15)

Code Number	Grid Cell Location	Fe	Hf	K	Li	Mn	Pb	Sc	Th	Ti
1[illegible]	49-1[illegible]	3[illegible](20)	6.55(4)	16716(49)	25.26(16)	1044(18)	10(0)	10.30(32)	11.56(6)	4597(33)
2[illegible]	110-38	3[illegible](1)	14.75(9)	18[illegible](55)	36.31(23)	848(13)	10(0)	12.62(39)	11.56(6)	4319(31)
2[illegible]	1[illegible]-43	11592(21)	14.75(9)	18[illegible](54)	44.21(26)	1109(17)	10(0)	11.33(35)	7.71(4)	3622(26)
2[illegible]	113-45	27193(17)	9.83(6)	17[illegible](50)	48.94(31)	914(14)	10(0)	9.06(28)	7.71(4)	3065(22)
1[illegible]	1[illegible]-62	22[illegible](14)	8.19(5)	13987(41)	26.84(17)	718(11)	20(1)	12.95(40)	7.71(4)	5015(36)
[illegible]	1[illegible]	[illegible]	1[illegible]	24[illegible]	5[illegible](32)	979(15)	14(1)	[illegible]	3[illegible](19)	[illegible]
[illegible]	1[illegible]-50	[illegible]	[illegible]	2[illegible]	33.2[illegible](21)	2284(35)	10(0)	26.83(5[illegible])	11.5[illegible]	68[illegible](49)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8[illegible](19)	1109(17)	20(1)	11.98(37)	17.[illegible](9)	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	2[illegible](9)	36.31(23)	914(14)	10(0)	12.40(38)	9.63(5)	40[illegible](29)
1[illegible]	1[illegible]	[illegible]	6.55(4)	13[illegible](5[illegible])	36.31(23)	1438(22)	20(1)	13.2[illegible](41)	11.56(6)	4179(30)
1[illegible]	[illegible]	10791(2[illegible])	11.1[illegible]	2[illegible](21)	37.89(24)	914(14)	20(1)	10.68(33)	11.56(6)	5156(37)
1[illegible]	1[illegible]-47	5[illegible](1[illegible])	9.83(6)	19[illegible](57)	37.89(24)	4[illegible](66)	9.5(46)	1[illegible]	17.1[illegible](9)	4[illegible]
2[illegible]	171-110	1499[illegible]	[illegible]	1[illegible]	25.26(16)	783(12)	20(1)	[illegible]	9.[illegible]	[illegible]

Code Number	Grid Cell Location	[illegible]	Lu	V	Zn	Zr	eTh	[illegible]	[illegible]	U/Th
1[illegible]	49-1[illegible]	[illegible](2)	0.77(0)	117.19(28)	[illegible](1)	24.1(0)	19.5(49)	[illegible](2)	2.73(5[illegible])	[illegible](2)
2[illegible]	110-38	[illegible]	0.77(0)	87.89(21)	41.71(1)	38[illegible](8)	7.6(19)	2.6[illegible](29)	1.8[illegible]	[illegible]
2[illegible]	11[illegible]-43	[illegible](2)	2.29(5)	66.96(16)	87.41(2)	38[illegible](8)	7.2(18)	[illegible](27)	1.97(19)	[illegible]
2[illegible]	113-45	[illegible]	1.54(1)	58.59(14)	87.41(2)	316.7(7)	7.9(20)	7.56(8[illegible])	[illegible]	[illegible]
1[illegible]	12[illegible]-62	[illegible](2)	0.77(0)	87.69(21)	87.41(2)	288.6(6)	6.[illegible]	1.89(5)	1.52(30)	[illegible]
2[illegible]	143-59	1[illegible](2)	0.77(0)	50.22(12)	611.88(14)	432.5(9)	19.9(50)	4.9[illegible](5)	3.19[illegible]	[illegible]
2[illegible]	151-50	19.[illegible](9)	0.77(0)	133.93(32)	87.41(2)	240.5(5)	6.4(16)	3.1[illegible](35)	1.52(30)	[illegible]
1[illegible]	15[illegible]-45	10.2(5)	1.54(1)	92.07(22)	87.41(2)	288.6(6)	11.1(28)	3.5(39)	2.08(41)	[illegible]
[illegible]	15[illegible]-47	16.32(8)	3.08(2)	87.89(21)	87.41(2)	240.5(5)	5.6(14)	3.50(39)	1.42(28)	1.58(8)
[illegible]	15[illegible]	16.32(8)	3.08(2)	104.63(25)	131.12(3)	240.5(5)	11.5(29)	3.41(38)	2.13(42)	1.18(7)
1[illegible]	16[illegible]-4[illegible]	6.12(3)	0.77(0)	96.26(23)	43.71(1)	348.8(8)	13.1(33)	3.1[illegible](35)	2.63(52)	[illegible]
1[illegible]	167-47	8.16(4)	0.77(0)	96.26(23)	2884.6(66)	316.7(7)	20.2(51)	4.69(50)	3.09(61)	[illegible]
2[illegible]	171-110	4.08(2)	1.54(1)	104.63(25)	87.41(2)	144.3(3)	12.3(31)	3.05(3[illegible])	1.52(30)	[illegible]

For a first approach, potential data sets can be selected by examining the range of values in each data set for those grid cells containing known uranium occurrences. Such data are shown for a selected number of grid cells containing known occurrences in the Cochetopa and Marshall Pass uranium districts in Table III. Each occurrence in this table is designated by both grid cell location and code number (from Appendix A). The values in Table III represent kriged data. Classification criteria (i. e., intervals for each data set) were then selected from this table. Criteria for Cochetopa-type uranium mineralization were selected primarily (but not solely) from occurrences 200616, 200619, and 200631. Criteria for Marshall Pass-type mineralization (primarily occurrences 200515, 100621, 400627, and 100618) are included for comparison.

Intervals for each of the 28 data sets were selected from Table III. Grid cells satisfying the selected intervals for each of 28 data sets were then selected by the computer. Grid cells containing data sets that fulfilled all 28 criteria, 27 of 28, 26 of 28, etc., are thus identified. It was hoped that this procedure might create a halo effect around the test areas and other areas favorable for uranium mineralization.

Classification

Two sets of criteria were selected for test areas in the Cochetopa uranium district; based on these criteria, two separate classification schemes were completed, COCH-1 and COCH-2 (Table IV).

Data set intervals selected for COCH-1 are relatively wide, i.e., the difference between the upper and lower limits for each data set resulted in several areas of potential favorability for uranium mineralization. Figure 4 shows the grid cells satisfying 28, 27 of 28, 26 of 28, and 25 of the 28 intervals. Care must be taken to optimize window criteria both to include all training set grid cells and yet be small enough to avoid obtaining the entire quadrangle as an area of favorability. Therefore, a second iteration, whereby the COCH-1 data set intervals were narrowed, particularly with respect to Al, Ba, Ce, Cr, Cu, Ti, and Us, was run.

There are nine areas that satisfy 25 or more of the 28 selected intervals for COCH-2 (Fig. 5). Area A contains the Cochetopa mining district, and 46 grid cells cluster in this region. Here, only 3 of the 11 grid cells containing known uranium occurrences were primarily used as test areas, yet 6 (including the three test areas) of the 11 show up as favorable grid cells. All uranium occurrences in this district are surrounded by grid cells of favorability.

Seven cells cluster in Area B, and this is a large number of grid cells relative to all other areas except Area A. Thus, Area B may have good potential for uranium mineralization. Most of these grid cells are from the drainages of Tomichi Creek (USGS, 1956), just north of the Cochetopa district, and are underlain by either Oligocene ash flow tuffs or Precambrian metamorphic units or are on the contact zone between the two (Tweto et al., 1976a). Potential uranium deposits in this area would probably be fault or vein-controlled (Nelson-Moore et al., 1978).

Area C in Fig. 5 consists of four scattered grid cells. Three of these are underlain by the Mancos formation and would probably not be prime areas of favorability for uranium mineralization. However, the Mancos does contain uranium-rich, coal-bearing units, and these may be influencing the selection of grid cells; radioactive springs have been reported in Cretaceous units in this quadrangle (Cadigan et al., 1976). One grid cell in this cluster is in alluvium but also occurs in an area that drains Precambrian granitic and metamorphic rocks and is near a fault zone. One known occurrence of vein-type mineralization is in this region (Nelson-Moore et al., 1978).

TABLE IV

DATA SET INTERVALS FOR THE COCHETOPA (COCH) CLASSIFICATION SCHEMES*

DATA SET	COCH-1	COCH-2
Al	45000-75000	50000-70000
As	10-22	10-22
Ba	550-1000	600-900
Ca	10000-25000	8000-20000
Ce	<120	75-120
Co	9-16	9-15
Cr	<75	10-60
Cu	<90	10-75
Dy	5-7	5-7
Fe	20000-35000	22000-36000
Hf	8-16	9-16
K	12000-20000	15000-20000
Li	25-50	30-50
Mn	700-1200	800-1200
Pb	<30	1-30
Sc	9-14	8-13
Th	>6	>6
Ti	2500-5500	2800-4500
Us	>3	>4
Uw	0-10	>0.1
V	50-150	<90
Zn	40-120	<150
Zr	300-500	250-450
U/Th	>0.35	>0.35
K40	1.5-2.1	1.5-2.5
eTh	7-9	7-9
eU	>2.5	>2.5
Mag	<-300	<-400

*All values in ppm except for Uw, which is in ppb; U/Th, which is a ratio; K40, which is in percent; and Mag, which is in gammas.

The third most favorable area delineated by this scheme is Area D. Four grid cells occur along the eastern tributaries of Flag Creek (USGS, 1956) and are underlain by Middle Tertiary Oligocene granitic intrusives and Paleozoic formations. Several fault zones are located near this cluster. Paleozoic rocks in fault contact with Precambrian rocks or Tertiary intrusives are favorable for vein- or fault-controlled uranium mineralization in this area. Examples are found in the Marshall Pass district (Malan and Ranspot, 1959; Nelson-Moore et al., 1978).

One grid cell in Area H contains similar geology, and occurs within a few kilometers of two known uranium occurrences (US AEC, 1966b) and, consequently, can be considered as favorable for uranium mineralization.

Area E contains only three grid cells, all of which occur in alluvium that drains Precambrian granitic rocks. Uranium mineralization in this area would probably be in veins or fractures. Area F contains four grid cells also underlain by Precambrian granitic rocks. Two of these cells are also near a fault zone. The other two grid cells

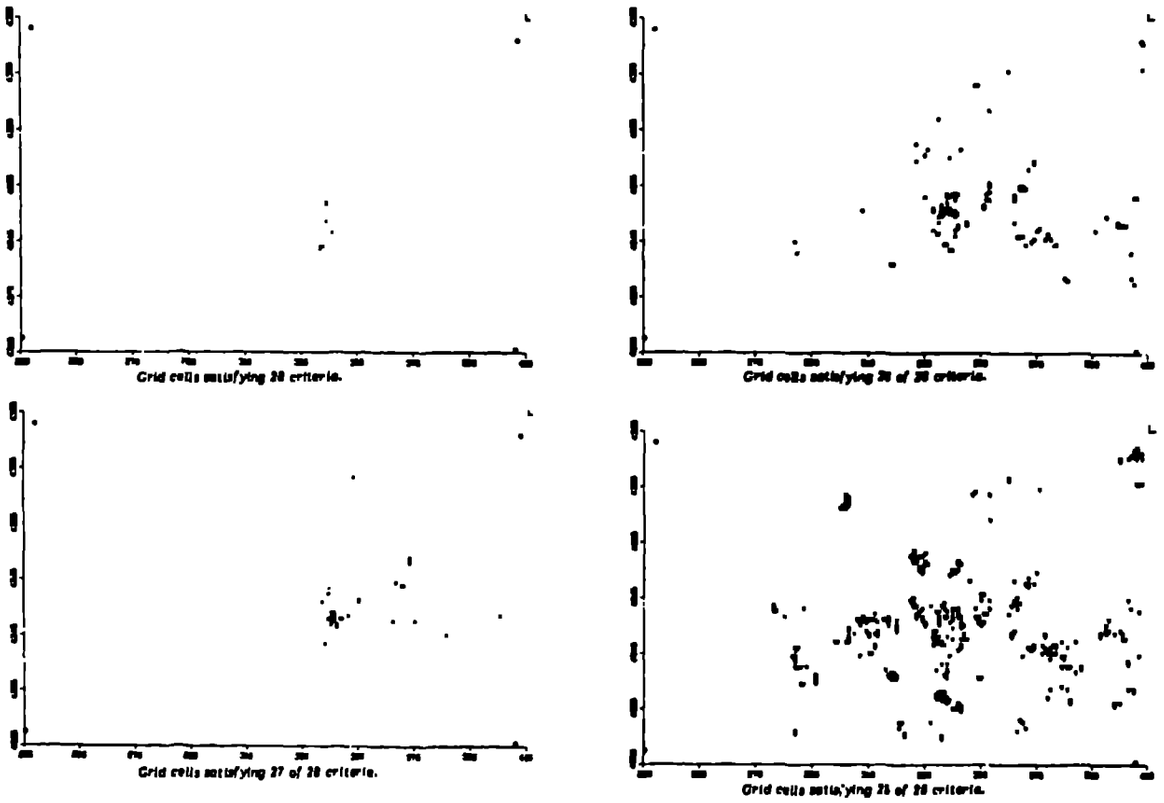


Figure 4. Results for COCH-1 classification scheme. Criteria (data set intervals) are listed in Table IV).

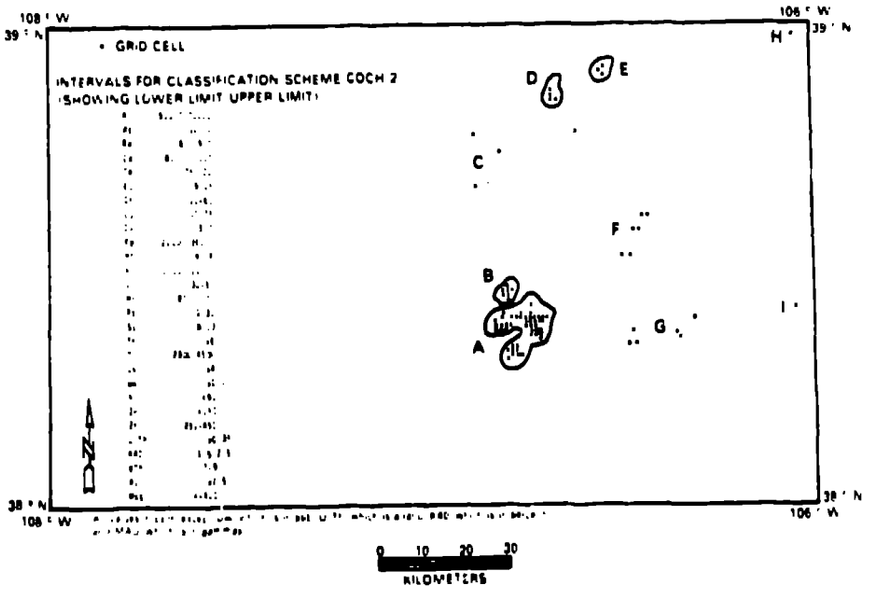


Figure 5. Schematic Diagram for COCH-2 classification scheme. Nine areas of favorability are delineated based on the criteria in Table IV.

border the Mancos formation. In general, any grid cells located in the Precambrian crystalline terrain have some favorability for uranium mineralization and the presence of a fault increases that favorability (Nelson-Moore et al., 1978). This includes the grid cells in Areas D, E, F, H, and I.

The remaining group G contains six grid cells, one of which is located within the Marshall Pass uranium district. The other five grid cells are underlain by, or are in drainages of, Oligocene andesitic lavas and breccias. Although these lavas are not a major host rock for uranium mineralization, they do host several reported uranium occurrences and minor deposits (US AEC, 1966c).

SUMMARY OF MAJOR RESULTS

This report describes a program developed at Los Alamos National Laboratory to integrate various large geological, geochemical, and geophysical data bases for the Montrose 1° x 2° quadrangle, Colorado. The techniques necessary to digitize, register, and integrate multiple data sets for a 1 km grid resolution are described. The primary purpose of the project was to identify, in the computer, areas favorable for uranium mineralization in the Montrose quadrangle. Classification schemes described are based on test areas from the Cochetopa uranium district. Several regions that seem to contain some potential for uranium mineralization are identified. Detailed examination of selected data sets and data set intervals (e.g., the techniques of Beyth et al., 1980a and b; Koch et al., 1979; Howarth and Martin, 1979; and Lankston and Lankston, 1979; and Bolivar et al., 1981) must be coupled with field verification to validate these areas as truly favorable for uranium mineralization. However, the methodology developed is a rapid and efficient method of resource evaluation on a reconnaissance scale.

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APPENDIX A
LIST OF DIGITIZED URANIUM OCCURRENCES, MONTROSE QUADRANGLE, COLORADO
APPENDIX A

The following lists the grid cell coordinates for each coded uranium occurrence. The occurrence locations are shown in Fig. 4 and described in Table I. The code is as follows.

The first three digits refer to the host rock as defined by Nelson-Moore et al. (1978). A 100 is an igneous or metamorphic host; a 200 is a sandstone, arkose, conglomerate, siltstone, or lake sediment; a 300 is a spring deposit or ground water occurrence; a 400 designates a coal, shale, or limestone host; 500 is undetermined. The fourth digit identifies the county.

1 = Delta	4 = Hinsdale	7 = Chaffee
2 = San Miguel	5 = Gunnison	8 = Park
3 = Ouray	6 = Saguache	

The fifth and sixth digit are location numbers from Plate 7 of Nelson-Moore et al. (1978). The pixel coordinates are given column first (179 maximum) and line second (119 maximum).

Code Number	Grid Cell Column	Grid Cell Line
100301	34	39
100402	49	10
100403	43	7
100405	51	11
100406	60	6
100502	80	43
100505	[illegible]	32
100506	124	62
100508	76	45
100509	78	43
100510	78	49
100511	108	85
100512	81	40
100514	80	41
100516	83	40
100517	127	103
100518	78	40
100519	83	40
100520	81	52
100521	105	85
100523	89	42
100525	73	48
100526	75	43
100525	73	38
100526	7	43
100527	63	68
100601	123	36
100603	15[illegible]	32
100605	111	43
100608	164	46
100609	111	37
100610	105	35
100618	153	45
100620	109	38
100621	152	45
100626	166	38
100630	109	42
100637	155	48
100639	116	23
100640	118	24
100641	140	23
100642	116	33
100646	120	33
100649	167	37
100704	162	109
100705	156	61
100710	157	77
100712	176	94
100713	177	72
100717	141	112
100718	141	112
100720	174	98
100722	171	101
200214	4	6
200501	52	103
200503	143	59
200504	143	60
200515	151	50
200524	116	56
200602	148	47
200606	149	47
200611	152	48
200615	174	24
200616	110	48
200617	149	48
200619	112	43
200623	110	37
200631	113	45
200635	120	49
200636	120	46
200638	133	49
200644	107	43
200645	107	46
200646	114	44
200801	171	119
300101	18	91
300102	36	98
300103	[illegible]	93
300104	11	92
300105	24	91
300106	25	90
300111	31	[illegible]
300112	30	11
400522	136	74
400607	152	47
400708	151	61
400803	172	109
500507	105	105
500651	92	11