Rep. Copy

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Interpretation of data from an aerial gamma-ray survey in the Cripple Creek district, Teller County, Colorado

by

James A. Pitkin and Carl L. Long

U.S. Geological Survey, Denver, Colorado 80225

Open-File Report 77-534

1977

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature

Contents

Illustrations

Tables

Interpretation of data from an aerial gamma-ray survey in the Cripple Creek district, Teller County, Colorado

by

James A. Pitkin and Carl L. Long

U.S. Geological Survey, Denver, Colorado 80225

Introduction

An aerial gamma-ray survey has been flown in part of the Cripple Creek gold mining district of Teller County, Colorado. The survey was made to map the surficial lithologic pattern as defined by the distribution of the radioelements potassium (K), uranium (U), and thorium (Th). Rock sampling and laboratory analysis has documented K concentrations of more than 10 percent in the area (Gott and others, 1969, p. A4), and it was thought that the radioactivity data could lead to a better understanding of the surface geochemistry.

Method

The gamma-ray flux in the air column at and near the earth's surface results from the radioactive decay of the radioelements K, U, and Th. Their distribution at the surface is dependent on bedrock composition modified by the geologic processes of weathering, erosion, and transportation.

Aerial measurements of natural gamma energy are made with scintillation instruments mounted in aircraft which must follow the contour of the ground at flight altitudes of no more than 200 m in order to make statistically valid measurements. The gamma photons from the uppermost 45 cm of rock and soil are measured in this manner.

System

The scintillation instrument used in the Cripple Creek survey was a 4-channel spectrometer which detected gamma energy with six thallium-activated sodium iodide crystals, each 10 cm thick and 12.5 cm in diameter. Detected energy was electronically sorted into four measurements of natural radioactivity as shown in Figure 1. Gross count data were obtained by measuring the span 0.40- to 2.80-MeV (million electron volts). Elemental data were obtained by measuring (1) the 1.46-MeV photopeak of potassium-40 for K, (2) the 1.76-MeV photopeak of bismuth-214 for eU, and (3) the 2.62-MeV photopeak of thallium-208 for eTh. The e (equivalent) prefix is used because of the potential for disequilibrium in the U and Th decay series.

The four channels of the spectrometer, each operated with an integrating time constant of 1-second, were sampled every 0.4 second by an analog-to-digital converter and recorded on a digital magnetic tape recorder. These channels were also continuously-recorded, for immediate visual reference, on a pen-and-ink strip-chart recorder. Both recorders received a signal representing flight altitude from a radar altimeter. A 35 mm frame camera, activated at 1.5 second intervals, photographed the flight path of the aircraft. Operation of the recorders and the camera was synchronized by an intervalometer clock and a manually-operated fiducial edgemark system.

 (FOLLOWED BY PAGE 2-A)

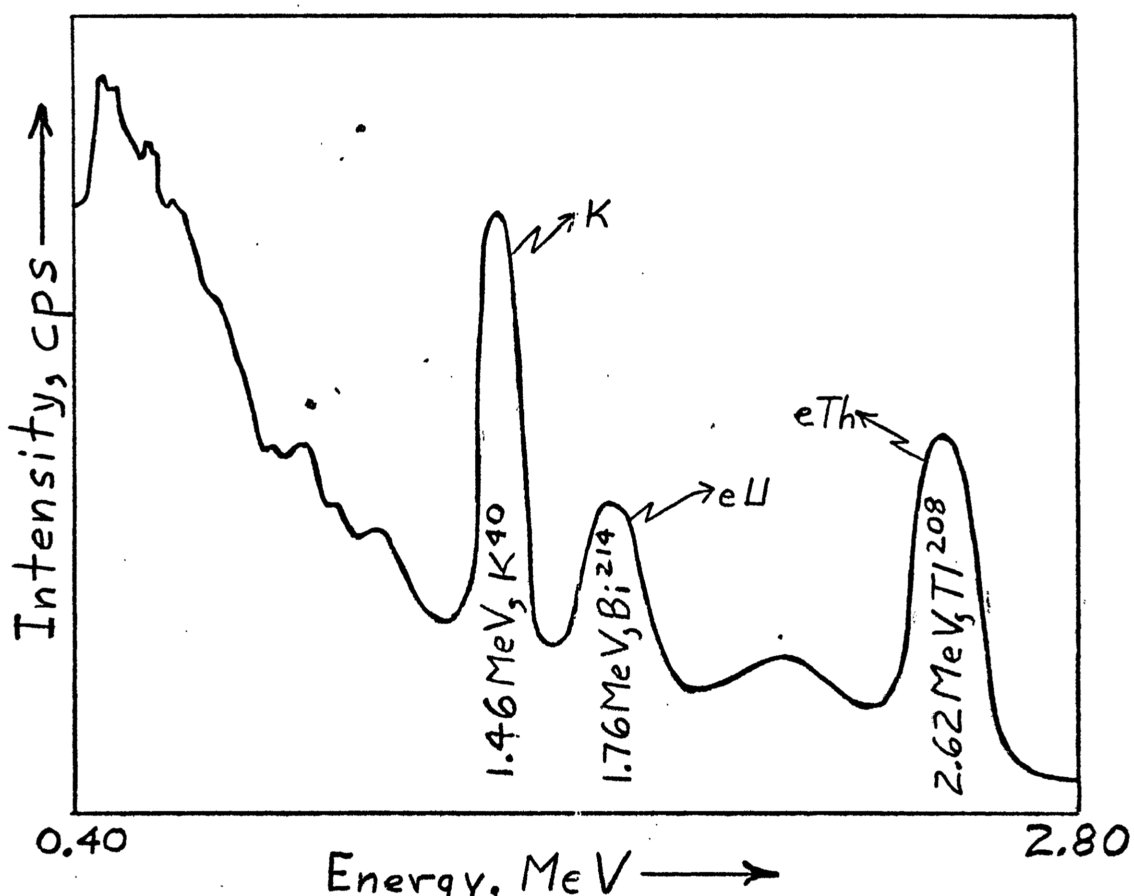

Figure 1. Natural gamma spectrum showing calibration of spectrometer used during Cripple Creek survey.

Survey

The aerial gamma-ray survey of the Cripple Creek area was flown on July 23, 1971. The aircraft used was a single-engine deHavilland[1/] Otter which averaged 160 km/hr at a nominal flight altitude of 122 m. The effective area measured by the spectrometer was a strip 244 m wide. Pre-flight planning had detailed 20 northeast-trending flight lines spaced 0.4 km apart and averaging 8 km in length. The flight lines were designed to provide complete spectrometric coverage of the gold-bearing area, topography permitting. The lines were not precisely parallel as individual lines were oriented away from topographic extremes. Nevertheless, it was found that the survey could not be flown as planned because of the topography, and also because of less than optimum handling of the aircraft in the thin air which occurs at more than 3 km above sea level. Plate I shows the lines flown, numbers 10 through 20, and a part of number 9.

Data Reduction

The 35 mm photography obtained during the survey was used to plot flight path locations on topographic maps at 1:24,000. At least two precise positions were determined for each flight line, as near as possible to each end of the line. These positions are referred to as documentation points and were processed with an X-Y digitizer which digitized their latitude and longitude coordinates. The digitized documentation points were processed via an IBM 360/65 computer

[1/] Use of brand names in this report is for descriptive purposes only and in no way constitutes endorsement by the U.S. Geological Survey.

program that computed a flight path by linear interpolation between adjacent pairs of documentation points. The flight path was then collated with the magnetic tape data.

The radioactivity maps (Plates II, III, IV, and V) were processed by computer except for the final step of contouring. Processing prior to contouring included subtraction of a background component and normalization of all data to the flight altitude of 122 m. Compton corrections were applied only to the K and eU data. Contour value bases were made for all data channels and contoured manually.

Geology

Plate I shows the generalized geology of that part of the Cripple Creek district covered by the aerial gamma-ray survey. Precambrian rocks, mostly granite with subordinate gneiss and schist, are dominant in the district. A volcanic subsidence basin of Tertiary age, located within the Precambrian sequence, is filled with brecciated volcanic and non-volcanic rocks. The volcanic detritus predominates at the surface and is chiefly phonolite and latite-phonolite. A variety of plutons of Tertiary age have intruded the basin and the Precambrian rocks. Only those plutons mapped as phonolites are mapped separately from other Tertiary rocks on Plate I. Gold occurs in linear fissures mostly within the basin. Geologic data used in this report are from Lindgren and Ransome (1906), Koschman (1949), and Kleinkopf and others (1970).

Geochemical and geophysical investigations

The last producing gold mine in the Cripple Creek district ceased operations in 1962. Later in the 1960's, the U.S. Geological Survey made geochemical and geophysical investigations in the district in an attempt to develop exploration guides, direct and indirect, that would encourage resumption of gold mining.

The geochemical study was by Gott and others (1969) and resulted in the mapping of the surface distribution of a number of elements. This investigation was hampered by difficulties in systematically sampling bedrock because the surface was badly scarred by more than 80 years of mining activity. The geochemical data show K enrichment of as much as 12 percent, and good correlation of high K values with the highest concentrations of gold, tellurium, and silver (Gott and others, 1969, p. A4).

Kleinkopf and others (1970) interpreted aeromagnetic and gravity data in conjunction with the surface distribution of gold, tellurium, and silver, and made significant conclusions about the structure of the district.

Interpretation of gamma-ray data

The gamma-ray data show higher values for all three elements for the basin comparative to most of the area surveyed outside of the basin. Also higher in radioactivity are some phonolite intrusives which occur outside of the basin.

K map (Plate II). The 80 counts per second (cps) contour labeled A approximately coincides with the border of the basin. Within this contour is an area of 100 to 140 cps which coincides with geochemical highs of gold, tellurium, silver, and potassium*. The northwest-trending nose of contour A well defines an area of anomalous gold and silver concentration just outside of the basin. Two K highs coincide with mapped phonolites: (1) the 120 cps area south of Rhyolite Mountain, and (2) the 100 cps area west of Cripple Creek. The other two phonolite bodies shown on Plate I are not defined by the K data.

eU map (Plate III). Most of the basin registers values of 20 to 30 cps. Contour closures of 25 and 30 cps correlate with the K high of 140 cps, and they both coincide with anomalous geochemical concentrations of gold, tellurium, silver, and potassium. The phonolite south of Rhyolite Mountain is defined by a high of 25 cps, while the other three phonolite bodies, although not well defined, do register values of 20 cps.

eTh map (Plate IV). The volcanic subsidence basin is characterized by values of 25 to 40 cps; the highest area is located about 1 km northeast of the previously described K and eU closures. The 40 cps area coincides with anomalous concentrations of potassium and silver. Highs of 45 and 50 cps coincide with the phonolite bodies

---

* From this point on in the report, the chemical symbol K refers to potassium concentrations determined from aerial radioactivity data, and the word potassium refers to geochemically determined concentrations.

west of Cripple Creek and south of Rhyolite Mountain. A 35 cps closure south of Cripple Creek is partially coincident with two phonolite occurrences.

Gross count map (Plate V). The basin is approximately outlined by a 1400 cps contour which includes a 2000 cps closure coincident with the K and eU highs northwest of the larger Precambrian island. A strong 2000 cps closure 2 km southeast of Cripple Creek, mostly outside of the basin, is not apparent in any of the elemental data. The phonolite bodies south of Rhyolite Mountain and west of Cripple Creek coincide with strong highs of 2000 and 1800 cps, respectively.

Summary. Correlation of the K data with the geochemical data was not unexpected because potassium is known to occur in anomalous quantities sympathetically with gold, tellurium, and silver in the Cripple Creek district. However, exact correspondence is lacking because (1) the geochemical data represent bedrock sampling, and (2) the aerial data represent whatever is at the ground surface, bedrock or soil.

Explanation of the eU and eTh distribution is more difficult. Phonolite and latite-phonolite detritus comprise most of the breccia at the surface of the basin. These silicic rocks generally contain more uranium and thorium than do less silicic rocks, and their occurrence could explain the higher eU and eTh values of the basin. However, the basin is in Precambrian rocks, mostly Pikes Peak granite, and the granite contains an average of 5 ppm uranium and 26 ppm thorium (Phair and Gottfried, 1964, p. 23). These concentrations are higher than those found for the most radioactive silicic granites, which average 4 ppm uranium and 18 ppm thorium (Rogers and Adams, 1969, p. 92-B-2). Therefore, the Cripple Creek basin should have lower amounts of uranium and thorium than the adjacent granite. The aerial gamma-ray data show the reverse, that the basin contains more uranium and thorium than the adjacent rocks.

The area of the aerial survey northeast of the basin, also northeast of the Rhyolite Mountain anomalies, is underlain primarily by Pikes Peak granite. Here eTh is 10 to 15 cps versus 25 to 40 cps for the basin, while eU is 10 to 15 cps versus 20 to 30 cps for the basin. Similar count-rate contrasts also occur in an area of Pikes Peak granite north of Cripple Creek, between the two very radioactive phonolite bodies. It is evident that the part of the basin covered by the aerial survey has higher values of eU and eTh than the adjacent Pikes Peak granite, perhaps twice as much. A mineralogic explanation of this occurrence is not yet available.

Some mineralogic data are available for the phonolite bodies, whose essential minerals are alkali feldspar, nepheline, and alkali pyroxene (Lindgren and Ransome, 1906, p. 57). This composition explains the high K of the phonolites, but not the higher eU and eTh. Accessory minerals of the phonolites include apatite, biotite, and zircon (Lindgren and Ransome, 1906, p. 59) which can contain uranium and thorium. Available data do not explain why the phonolite south of Rhyolite Mountain is higher in eU and K than the phonolite west of Cripple Creek.

The comparative two-fold increase within the basin of eU and eTh could be explained by the occurrence of phonolite plutons within that part of the basin covered by the aerial survey. However, such rocks have been mapped in the southeast part of the basin, but not in the northwest part.

<u>Quantifying of the gamma-ray data</u>

Recent research (Pitkin and Duval, 1977) permits quantifying of aerial gamma-ray data obtained with thallium-activated sodium iodide crystals, comparable to that obtained at Cripple Creek. Table 1 shows sensitivity constants calculated for a crystal volume of 7.4 liters at 122 m above ground. These constants were used to convert the aerial cps to concentrations of percent and ppm (parts per million). Average values of cps were arbitrarily chosen for the basin and several areas outside of the basin, excluding the phonolite plutons. The concentrations outside of the basin are in good agreement for the more radioactive granites.

It should be noted that the absolute precision of the aerial gamma-ray data presented here could approach $\pm$100 percent, because of the small detector volume, and the quantified data would be similarly affected. In comparison, the relative precision is realistically estimated at $\pm$30 percent, which means that the eU and eTh values of the basin are actually about twice those of the granite outside of the basin.

Table 1.--Calculated radioelement concentrations for part of the Cripple Creek district, Colorado. Sensitivity constants are for 7.4 liters of NaI(Tl) at 122 m above ground.

Radioelement	Sensitivity constant	Average count rates, in cps, for specified areas, excluding phonolites		Calculated concentrations	
		Basin	Exterior to basin	Basin	Exterior to basin
K	13.3 cps per %K	100	70	7.5%	5.3%
eU	2.4 cps per ppm eU	25	12.5	10 ppm	5 ppm
eTh	.74 cps per ppm eTh	30	15	40 ppm	20 ppm

Conclusions

The aerial gamma-ray data define the northwest part of the Cripple Creek volcanic subsidence basin. The K data are correlative with geochemical concentrations of potassium and gold, tellurium, and silver. The eU and eTh values of the basin are approximately two times those of nearby occurrences of Pikes Peak granite. A mineralogic explanation of this increase in radioactive mineralization is not yet available. Quantifying of the aerial gamma-ray data shows the postulated increase in radioactive mineralization to be within reasonable limits for the rock types discussed.

References

Gott, G. B., McCarthy, J. H., Jr., Van Sickle, G. H., and McHugh, J. B., 1969, Distribution of gold and other metals in the Cripple Creek district, Colorado: U.S. Geol. Survey Prof. Paper 625-A, p. A1-A17.

Kleinkopf, M. D., Peterson, D. L., and Gott, G. B., 1970, Geophysical studies of the Cripple Creek mining district, Colorado: Geophysics, v. 35, no. 3, p. 490-500.

Koschman, A. H., 1949, Structural control of the gold deposits of the Cripple Creek district, Teller County, Colorado: U.S. Geol. Survey Bull. 955-B, p. 19-58.

Lindgren, Waldemar, and Ransome, F. L., 1906, Geology and gold deposits of the Cripple Creek district, Colorado: U.S. Geol. Survey Prof. Paper 54, 516 p.

Phair, George, and Gottfried, David, 1964, The Colorado Front Range, Colorado, U.S.A., as a uranium and thorium province, p. 7-38 in Adams, J. A. S., and Lowder, W. M., eds., The natural radiation environment: Chicago Univ. Press, Rice Univ. Semicentennial Pubs., 1069 p.

Pitkin, J. A., and Duval, J. S., 1977, How to plan an aerial gamma-ray survey, p. 19-20, in Campbell, J. A., ed., Short papers of the U.S. Geological Survey uranium-thorium symposium, 1977: U.S. Geol. Survey Circular 753, 75 p.

Rogers, J. J. W., and Adams, J. A. S., 1969, Uranium, in Wedepohl, K. H., ed., Handbook of Geochemistry, vol. II/3: Springer-Verlag, New York.