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Geological Survey

INTERPRETATION OF AERIAL GAMMA-RAY DATA FOR NEVADA

by

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INTRODUCTION

The aerial gamma-ray data for Nevada were compiled to produce maps for the state. These maps provide a regional presentation of the surface distribution of the radioactive elements potassium, uranium, and thorium. This report presents a preliminary interpretation of the gamma-ray maps with a particular attempt to look at correlations with known gold mineralization. This effort was part of an overall project to look at various geophysical data sets as a means of determining a regional assessment of gold mineralization in Nevada. The following discussion of the geologic setting of Nevada was adapted from Stewart (1980) and is presented here as a convenience to the reader.

GEOLOGIC SETTING OF NEVADA

The geologic history of Nevada includes major periods of sedimentation, igneous activity, orogenic deformation, and continental rifting. The oldest rocks in Nevada crop out in the southern part of the state and consist of metamorphic and intrusive rocks of Precambrian age. Next youngest are uppermost Precambrian to upper Devonian sediments and carbonate strata deposited on a broad shallow-water shelf.

During the late Devonian and early Mississippian widespread orogenic activity of the Antler orogeny resulted in the emplacement of the Robert Mountains allochthon, a sheet of oceanic siliceous and volcanic rocks thrust eastward as much as 90 miles (145 km) over coeval shelf carbonate rocks. This orogeny produced the Antler highland, an upland belt trending north-northeast in central Nevada.

During the late Paleozoic, the sedimentary and tectonic provinces of Nevada varied from east to west and were (1) a shallow-water carbonate shelf; (2) a foreland basin containing detrital material derived from the west in addition to more widespread shallow-water carbonate sediments; (3) the Antler highland, overlapped in Pennsylvanian and Permian time by marine sediments; (4) a western deep-water basin containing detrital rocks, chert, limestone, and lava; and (5) a Permian magmatic arc terrane.

During the Late Permian and Early Triassic, the Sonoma orogeny thrust ocean-floor sediments eastward as part of the Golconda allochthon for as much as 60 miles (100 km) over shallow-water deposits on the Antler highland.

Mesozoic sedimentary rocks in Nevada are largely of Triassic and Early Jurassic age and occur in an eastern and a western region. In the eastern region, the strata are shallow-water marine and continental deposits that are widely exposed in the Colorado Plateau region of Utah and Arizona. In the western region, marine sediments give way westward into volcanic sediments and rocks. Sedimentary rocks of Cretaceous age occur at scattered locations in Nevada and are continental sediments deposited in local basins.

Jurasic and Cretaceous igneous rocks occur widely in western Nevada and at scattered localities elsewhere. Those in western Nevada are along the eastern margin of the Sierra Nevada batholith.

Tectonic activity was widespread in Nevada during the Mesozoic and folding and thrusting may have started again as early as the Late Triassic or Early Jurassic and was extensive in western Nevada by the mid-Jurassic. Tectonic activity continued during the remainder of the Mesozoic over much of the state and culminated in the Late Mesozoic Sevier orogeny in eastern Nevada and western Utah.

During the early Cenozoic the state was probably high and undergoing erosion. Volcanic activity was widespread in Nevada during middle Cenozoic time and resulted in voluminous ash-flow tuffs in the central part of the state.

About 17 m.y. ago, the tectonic setting of Nevada changed with the onset of extensional faulting and the eruption of basalt or bimodal assemblages of basalt and rhyolite. The major basins and ranges seen today were formed and continental sediments were deposited in the basins.

DATA PRESENTATION

The aerial gamma-ray data used to produce the maps presented here were obtained from the U.S. Department of Energy (DOE) and are part of the data base obtained during the DOE National Uranium Resource Evaluation (NURE) Program (1975-1983). The index map in figure 1 shows the 2-degree quadrangles used. These data were processed and compiled to produce contour and composite-color maps as described below.

The aerial surveys were flown by several different contractors using high-sensitivity gamma-ray spectrometers with 2,000-3,000 cubic inches of sodium-iodide detector crystals. The nominal survey altitudes were 400 feet above the ground surface. The flight lines were flown east-west at line spacings ranging from 1 to 3 miles with north-south tie lines spaced 12-15 miles apart. The data were fully corrected by the contractors for background radiation, altitude variations, and airborne Bi-214 radiation. Using the DOE calibration pads at Grand Junction, Colorado (Ward, 1978), and the DOE dynamic test strip at Lake Mead, Arizona (Geodata International, Inc., 1977), the gamma-ray systems were calibrated so that the measurements could be expressed as the apparent surface concentrations of equivalent uranium (ppm eU), potassium (percent K), and equivalent thorium (ppm eTh).

To prepare these maps, the data were further processed as follows. (1) The flight-line data were filtered using a 5-point median filter as a de-spiking technique. This procedure eliminates noise spikes that are two points wide but does not eliminate any valid signals because the response function of the measurement system is such that valid anomalies always have more than two points. (2) The flight-line data were filtered using a Gaussian filter (with the standard deviation equal to 3 data points along the flight line) to reduce noise and other high-frequency variations. (4) Where necessary, detector sensitivity corrections were made by multiplying all or part of a data set by a constant factor. Problems with data levels usually occurred within a single data set and may have been caused by small gain shifts in the spectra, the use of different background corrections, differences in water content of soil as the result of rain, or errors in data processing by the contractors. (5) All possible ratios of K, eU, and eTh were calculated, and the data were gridded using a minimum curvature algorithm (Briggs, 1974; Webring, 1981). (6) The gridded data were additionally filtered using a fast Fourier technique to remove short-wavelength trends (less than 15 miles) parallel and perpendicular (east-west and north-south) to the flight-line directions. This filtering process does result in the reduction of amplitude in features with wavelengths 0-15 miles. Because the composite-color technique (see below) brings out differences as small as 10 percent, the composite-color maps show some east-west lineations caused by flight-line differences that could not be removed without making arbitrary changes to selected parts of the flight lines. Additionally the trend filters enhance trends that run northwest and northeast and any observed trends in these directions must be interpreted with care.

Because of the wide flight-line spacing, the 2-mile grid interval, and the filters applied, the resulting maps are regional maps and should only be used in a regional context. The accuracies of the concentration values are estimated to be better than 20 percent in a relative sense and from 50 to 100 percent in an absolute sense. "Relative sense" means the comparison of data from different parts of the map area. "Absolute sense" means the comparison of these concentration values to values obtained from other sources such as ground or laboratory measurements.

After the final gridded data sets were obtained for each of the three elements--uranium, potassium, thorium, and for the ratios eU/K, eU/eTh, K/eU, K/eTh, eTh/eU, and eTh/K -- these data sets were used to make color contour maps (maps A-C) and composite-color maps (CCM's, maps D-G). The contour maps are regional maps of the surface concentrations of potassium (percent K), equivalent uranium (parts per million eU), and equivalent thorium (parts per million eTh). The CCM's are regional maps that combine K, eU, eTh and their various ratios as varying shades of red, green, and blue . The CCM's were made using the techniques described by Duval (1983). Three selected data sets were printed as varying shades of the primary colors red, green, and blue with the density of each color proportional to the magnitude of the data. The maps presented here are denoted as the element, uranium, potassium, and thorium CCM's. The element CCM (map D) combines uranium (eU) as shades of red, potassium (K) as shades of green, and thorium (eTh) as shades of blue. The uranium CCM (map E) combines uranium as shades of red, eU/K as shades of green, and eU/eTh as shades of blue. The potassium CCM (map F) combines potassium as shades of red, K/eU as shades of green, and K/eTh as shades of blue. The thorium CCM (map G) combines thorium as shades of red, eTh/eU as shades of green, and eTh/K as shades of blue. Areas on the CCM's that have relatively low values for all three parameters are dark and areas that have relatively high values for all three parameters are white. Because of the complexities of color combinations and reproduction, the reader should not attempt to interpret the relative amounts of the elements or ratios from the observed colors except in a qualitative way. The value of these maps is to provide a synthesis of the radiometric data that shows at a glance a partial geochemical signature of the surface materials. These maps should be interpreted in terms of color patterns and any determination of concentration levels or relative amounts of any two parameters should refer to the contour maps presented as maps A-C.

The color scales shown on the CCM's are intended to illustrate the resultant colors formed by combining various levels of the primary colors. Each of the primary colors varies in three steps, low, medium, and high, and the multicolor scale at the top shows all possible combinations of these color levels. When all three radiometric parameters are low, the result is black. When all three parameters are high, the result is white. When two parameters are low and the third is high, the result is the corresponding primary color, red, green, or blue. The red, green and blue separates shown below the resultant colors indicate the color levels that were combined. For the color separates black is used to indicate an absence of the color and the three color levels (low, medium, and high) are shown with the lowest being near zero followed by a value near the middle of the range followed by the highest value. Because the actual inks used to print these maps are magenta, cyan, and yellow, the colors produced by the additive color scheme chosen are not intuitive and the primary colors are not perfectly reproduced.

These maps can be used to aid both geologic mapping and mineral exploration. Bates (1962), Gregory (1960), Moxham (1960), and Pitkin (1968) discussed the use of aerial gamma-ray data to aid geologic mapping. Force and others (1982) and Yeates and others (1982) presented examples of applications in mineral exploration. Clark and others (1972), Darnley (1970), Duval and others (1971), and Grasty and others (1978;1979) described various aspects of aerial gamma-ray spectroscopy and its limitations.

DISCUSSION

The element CCM (map D) shows distinctive color patterns and the following discussion is an attempt to point out some of the more obvious features. Areas of relatively higher radioactivity are seen as lighter colors on the element CCM. The largest region of elevated radioactivity with a unique color signature occurs from 116 W to 118 W longitude and from 37 N to 40 N latitude. The dominant color pattern is a mottled green. This area contains most of the highest potassium values ranging from 2.0 to greater than 2.8 percent K. Uranium values are generally 3-5 ppm eU with localized areas greater than 5 ppm eU. Thorium values are generally 8-16 ppm eTh with localized areas greater than 16 ppm eTh. The dominant lithologies in the area are silicic ash-flow tuffs, rhyolitic flows, and andesite, and the area contains most of the 34-17 Myr old calderas in the state (Stewart and Carlson, 1976). The gravity data show an approximately coincident area characterized by relatively low values (-300 to -200 mgal) on the complete Bouguer gravity map (Saltus, in press). A similar radiometric pattern extends eastward to the Utah border with a rough crescent shape centered on the town of Caliente. The concentration values are similar and Stewart and Carlson (1976) show that 34-17 Myr old sedimentary and igneous rocks are common within the area of the radiometric crescent.

The southern tip of the state has overall higher radioactivity with concentrations of 3-5 ppm eU, 1.8-2.8 percent K, and 12-22 ppm eTh. This region has localized areas with greater than 5 ppm eU, large areas greater than 2.8 percent K, and about half of the area exceeds 22 ppm eTh. The area has Precambrian metamorphic rocks intruded and overlain by 17-6 Myr old volcanic rocks (Stewart, 1980; Stewart and Carlson, 1976). The volcanic rocks are generally less radioactive than the Precambrian rocks and the highest thorium values are mostly associated with the Precambrian rocks.

Another zone of distinctive high radioactivity occurs north of the town of Ely from 39.4 N to 40.4 N latitude, with concentrations of 3.5-6.0 ppm eU, greater than 2.8 percent K, and from 14 to greater than 22 ppm eTh. These rocks are 43-34 Myr old rhyolitic intrusives (Stewart and Carlson, 1976).

Elevated radioactivity along the Idaho border in the northeast corner of the state is associated with 17-6 Myr old ash-flow tuffs (Stewart and Carlson, 1976). These rocks have concentrations of 3.5-6.0 ppm eU, 2.0 to greater than 2.8 percent K, and 14-22 ppm eTh. A localized outcrop of 17-6 Myr old rhyolitic intrusive rocks near 114.2 W and 41 N has perhaps the highest radioactivity in the state with greater than 6 ppm eU, greater than 2.6 percent K, and greater than 22 ppm eTh.

Rocks with elevated radioactivity occur in an area mostly contained between 116 W to 117 W and 36.6 N to 37.3 N. The colors seen on the element CCM are light pinks, oranges, and white. Concentration values are greater than 4.5 ppm eU, greater than 2.4 percent K, and greater than 16 ppm eTh. Rocks with similar radiometric signatures and concentration values occur in the northwest corner of the state about midway between the town of Winnemucca and Pyramid Lake. Most of these rocks are 17-6 Myr old rhyolitic flows and shallow intrusives (Stewart and Carlson, 1976).

Areas with low radioactivity are seen as dark colors on the element CCM. East of 117 W longitude the lows are mostly associated with carbonate rocks and have concentrations less than 2 ppm eU, less than 1.2 percent K, and less than 6 ppm eTh. West of 117 W the areas of lowest radioactivity are mostly associated with basalts with concentrations less than 2.5 ppm eU, less than 1.4 percent K, and less than 6.0 ppm eTh.

LINEAR FEATURES

Several large linear features seen in the contour maps and CCM's are presented in Map H with an overlay of the known gold prospects (Sherlock, 1987). Feature L1 is subtle and is best seen in the element CCM. The gravity data (Saltus, in press) provide very subtle support and the geologic map (Stewart and Carlson, 1978) shows that some distinctive geologic units (e.g. Devonian age Slaven chert, Silurian dolomite, Havallah sequence if Silberling and Roberts (1962), and Ordovician and Tertiary volcanic rocks) occur in the zone between L1 and L2. Feature L2 is best seen on the element CCM and is characterized by a lineation of different lithologies on either side of the line. The northern part of this feature (above 40 N) coincides with the Nevada rift and linear features in both magnetic (Hildenbrand and Kucks, in press) and gravity data. Below 40 N the radiometric linear feature coincides with a linear feature in the gravity data characterized by low gravity to the west of the line. Feature L3 is seen in the potassium and element CCM's and is characterized by low potassium. Linear Zone 1 was drawn to highlight the fact that a number of localized areas with relatively high radioactivity fall within the zone which is approximately parallel to the Nevada rift. The significance of linear Zone 1 and of feature L1 are unclear and open to question. Feature L2 clearly is associated with the Nevada rift and together with the gravity data supports the conclusion of Blakely (1987) that the rift extends to the southern part of the state. Feature L3 is supported to some extent by the presence of mapped faults and its southern part (below 40 N) shows a positive correlation with known gold prospects.

CCM CHARACTERISTICS AND GOLD MINERALIZATION

The gamma-ray data for Nevada show a number of interesting correlations with known gold mineralization. Dark areas on the potassium CCM are an indication of potassium depletion relative to uranium and thorium. This condition may be a characteristic of the lithology and does not necessarily indicate that the potassium has been mobilized and removed by geochemical processes. Regardless of the exact significance of each dark area on the potassium CCM, such areas show a positive correlation with known sediment-hosted gold deposits. Map I shows the dark areas with an overlay of the sediment-hosted gold deposits. Of particular interest is the fact that the Carlin trend shows up on this map and a similar northewest trend forms a junction with an extension of the Carlin trend at about 116 W and 40.7 N. The significance of this northwest trend is not known. The Getchall trend of sediment-hosted gold deposits shows up on the uranium CCM as a subtle positive anomaly with an indication of some uranium enrichment. This uranium anomaly extends beyond the Getchall trend to the north and northeast.

The uranium and potassiuum CCM's have numerous light or white colored areas. Such colors on the uranium CCM are indications of possible uranium concentrations and on the potassium CCM indicate possible potassium concentrations. Such areas represent an initial set of targets for alteration zones where gold mineralization might occur.

CONCLUSIONS

The gamma-ray regional data presented here exhibit various interesting correlations with both magnetic and gravity data. Some of these, such as the Nevada rift, are understood whereas the significance of others is in doubt. It is nevertheless clear that these regional maps contain information not obvious in the separate data sets and that regional compilations of the gamma-ray data should be done for other areas. It is also clear that the interpretation of the data as presented here is incomplete and that much remains to be done.

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INDEX MAP

120° – 118°	118° – 116°	116° – 114°	Latitude
VYA DOE,(1979e)	McDERMITT DOE,(1979j)	WELLS DOE (1979f)	42° – 41°
LOVELOCK DOE (1978b)	WINNEMUCCA DOE (1979a)	ELKO DOE (1979h)	41° – 40°
RENO DOE (1978a)	MILLETT DOE (1979g)	ELY DOE (1982)	40° – 39°
WALKER LAKE DOE (1978c)	TONOPAH DOE (1979d)	LUND DOE (1980c)	39° – 38°
MARIPOSA DOE (1980b)	GOLDFIELD DOE (1979c)	CALIENTE DOE (1980a)	38° – 37°
	DEATH VALLEY DOE (1979i)	LAS VEGAS DOE (1979b)	37° – 36°
		KINGMAN DOE (1979b)	36° – 35°

120° 118° 116° 114°