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RADIOACTIVITY OF NEVADA HOT-SPRING SYSTEMS

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Abstract. Field gamma radiometry and laboratory gamma-ray spectrometry of waters and spring deposits were accomplished for some hot-spring systems in northern Nevada. Gamma-ray exposure rates measured on-site range from 2 to 500 μR/hr, and depend mainly on the amounts of the natural radioelements in the spring deposits. High radioactivities, primarily from ^{226}Ra, are associated with hot-spring systems dominated by $CaCO_3$, while silica-dominated systems are relatively low in radioactivity. Gamma spectrometry disclosed the enrichment of ^{226}Ra with respect to its parent U in $CaCO_3$ dominated systems. ^{226}Ra preferentially associates with Ca; therefore, where tufa and siliceous sinter are present in a deposit, the calcareous material is highest in radioactivity. Spring deposits at fast-flowing $CaCO_3$ dominated systems are generally less radioactive than calcareous deposits at slower flowing springs.

Introduction

Radioactive anomalies associated with mineral and hot-spring systems have been recognized and documented by many scientists. For example, Pohl-Rüling and Scheminzky (1972) described the radium and radon-rich environment of Badgastein, an Austrian spa celebrated for decades for its healing hot radioactive air, waters, and muds. Earlier, Belin (1959) described the occurrence of radon in New Zealand geothermal regions, and Mazor (1962) related radium and radon in Israeli water sources with oil, gas, and brine reservoirs of the Rift Valley. Since the late 1940's several Japanese scientists, among them Kikkawa (1954), Kimura (1949), and Hataye (1962), have reported on the association of radioelements and hot- and mineral-spring systems. Scott and Barker (1962) made a comprehensive tabulation of uranium and radium contents of ground waters of the United States.

Recently, we have visited hot-spring areas in northern Nevada to evaluate sites for a geothermal energy program [Hollander et al., 1973]. A study of the radioactivity of the spring systems has begun, with the expectation that knowledge of the distribution and abundance of their radioelements will shed some light on the plumbing systems operating beneath the springs; equally important, an assessment of the environmental impact of a geothermal development project requires an understanding of its radioactive setting.

Location and Measurements

The hot-spring areas examined to date are shown on the location map (Fig. 1) and are listed by name on Tables I and II. At the sites field gamma radioactivity was measured with a portable 3" × 3" NaI(Tℓ) scintillation detector coupled to a count-rate meter. Field radioactivities were measured over hot pools, sinter (SiO_2-rich), and tufa ($CaCO_3$-rich) deposits, and also away from the spring areas to obtain background values. Samples of spring-deposit tufa, sinter, spring wall muck, and water are collected at all sites, and on return to the laboratory, were analyzed for uranium-238, thorium-232, their daughter products, and potassium-40 by gamma-ray spectrometry (field and laboratory instrumentation and procedures have been described by Wollenberg and Smith, 1972).

Field Measurement Results

Results of field measurements and laboratory gamma-ray spectrometric analyses are shown on Tables I and II. Table I summarizes the field radiometric data; radioactivities (exposure rates) are expressed in microroentgens per hour (μR/hr), based on calibration of the field instrument (counts/sec to μR/hr) with a radium source of known strength. Immediately apparent is the association of high radioactivities, "anomalies," with $CaCO_3$-rich spring deposits; with one exception, Lees Hot Springs, silica-rich deposits have no anomalies. The greatest radioactivities, 250 - 500

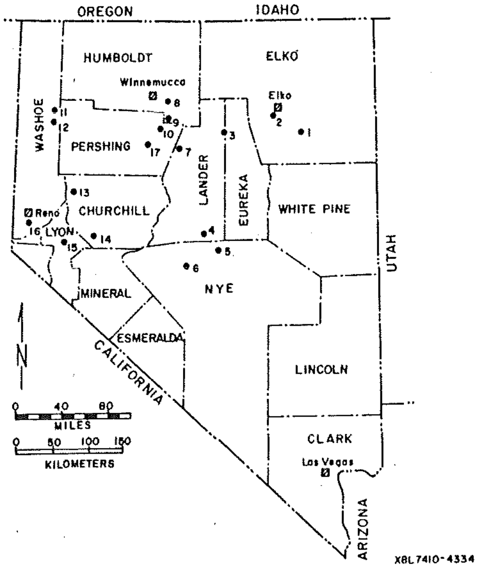

Fig. 1. Location map of hot springs visited in Nevada. Numbered springs: 1) Big Sulfur, 2) Elko, 3) Beowawe, 4) Spencer, 5) Diana's Punchbowl, 6) Darrough, 7) Buffalo Valley, 8) Golconda, 9) Pumpernickel, 10) Leach, 11) Fly Ranch, 12) Gerlach, 13) Brady, 14) Lee, 15) Wabuska, 16) Steamboat, 17) Kyle.

Table I. Field gamma radiometry of spring areas.

Location	*Gamma exposure rates* (μR/hr) General background	Anomalously high radioactivity	Remarks
Spring systems where $CaCO_3$ is the predominant deposit			
Gerlach	6.25 - 7.5	60 - 65	Tufa, high rad. zone
Gerlach	--	20 - 25	Mixed sinter and tufa
Fly Ranch	6.25 - 8.75	None apparent	Travertine
Kyle	12.5 - 25	250 - 500	Over radioactive pools
Elko	7.5 - 10	19	Tufa at edge of pool
Buffalo Valley	6.25 - 7.5	30 - 38	Tufa mounds
Spencers	5 - 10	19	Tufa at edge of pools
Diana's Punchbowl	5 - 10	16	Springs at base of tufa mound
Wabuska	3.75 - 6.25	None apparent	Blowing wells
Darroughs	15 - 20	75	Edge of fenced pool
Darroughs	10 - 12.5	None apparent	Moderately blowing well
Golconda	12.5 - 17.5	37.5 - 175	Pools and interconnecting streams
Pumpernickel	7.5 - 10	17.5 - 22.5	Small pool
Pumpernickel	15	17.5	Outflow stream
Spring systems where SiO_2 is the predominant deposit			
Brady's	5 - 7.5	--	Sinter soil
Beowawe	2 - 2.5	--	Sinter apron
Beowawe	13.8 - 17.5	--	Andesite, escarpment above blowing wells
Big Sulfur (Ruby V)	2.5 - 5	--	Sinter
Leach	5 - 7.5	--	Sinter
Lee	5 - 7.5	20 - 25	Tufa and sinter
Lee	--	10	Edge of pool
Steamboat	2.5 - 4	--	Main terrace sinter
Steamboat	6.9	--	Altered granitics, west area, blowing well

Table II. Laboratory gamma spectrometry of spring deposits.

Location	Description	Th (ppm)	Equivalent U (ppm)	K (%)	^{226}Ra* (pCi/g)	Th/U
Spring systems where $CaCO_3$ is the predominant deposit						
Gerlach	Tufa, high radioactivity zone	13.41	109.25	1.02	39	0.12
	Predominantly Si sinter, some tufa	2.38	33.3	0.41	12	0.07
Fly Ranch	Travertine	2.14	10.99	0.02	4	0.19
Kyle	Calcareous muck from spring walls	11.62	76.32	0.16	27	0.15
	Travertine away from active springs	0.19	4.06	0.09	1.5	0.05
Elko	Tufa	3.12	7.60	0.07	2.7	0.41
Buffalo Valley	Calcareous muck from a small mound	45.89	25.49	0.21	9.2	1.80
	Predominantly tufa, some Si sinter	6.20	65.67	0.35	23.7	0.09
Spencers	Predominantly calcareous mud	10.92	11.54	1.51	4.1	0.95
Golconda	Spring wall tufa	31.20	469.6	--	169	0.07
Pumpernickel	Calcareous muck from small pool	6.33	8.19	0.46	2.9	0.77
Spring systems where SiO_2 is the predominant deposit						
Brady	Mud from hot vent	6.32	2.93	0.41		2.15
Beowawe	Andesite, escarpment above blowing wells	15.99	3.28	3.74		4.88
	Sinter soil, vicinity of hot pools	0.91	0.37	0.40		2.43
Big Sulfur (Ruby Valley)	Sinter	0.18	0.11	0.16		1.60
Leach	Sinter	1.08	0.72	0.35		1.50
Lee	Sinter	4.76	2.49	1.11		1.91
	Tufa and sinter	3.71	11.67	0.51		0.31
Steamboat	Sinter, main terrace	0.30	1.42	0.13		0.21
	Sinter and altered granitics, west area	8.10	4.90	1.13		1.65

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*Calculated from activities ratio, $^{226}Ra/^{238}U = 2.78 \times 10^6$.

μR/hr, were observed over hot pools (75 - 90°C) at Kyle Hot Springs, while the lowest values, two orders of magnitude lower than at Kyle, were measured over the hot and boiling pools and sinter at Beowawe Hot Springs. In no case was there any apparent connection between the surface spring temperature and radioactivity. Among the spring systems where $CaCO_3$ predominates there were no anomalies associated with blowing wells nor with fast flowing springs. Thus, radioactive anomalies in the hot-spring areas appear to be associated with low flowing $CaCO_3$-rich systems. An inverse correlation of radioactivity with flow rate was observed by Vincenz (1959) at a mineral spring in Jamaica.

Where tufa and sinter are both present in a deposit, the calcareous material is highest in radioactivity. This is exemplified at Lees Hot Springs where sinter is the predominant spring deposit material; spotty zones of high radioactivity were observed over intermixed patches of tufa, while neighboring sinter was comparatively low. Similar conditions exist at Gerlach Hot Springs where siliceous and calcareous zones intermingle.

At Buffalo Valley and Kyle Hot Springs, $CaCO_3$-rich sites, sharp field radiometric anomalies were detected downwind from pools, indicating the emanation of ^{222}Rn from the waters and spring walls.

Laboratory Measurement Results

Spring Deposits. Table II summarizes laboratory gamma-spectrometric analyses of spring deposit materials. As with the field data, the high radioactivities, attributable primarily to equivalent U, are associated with the calcareous hot-spring deposits. Siliceous deposits are comparatively low in U and Th, and most have Th/U ratios similar to those of ordinary siliceous rocks. Exceptions are the mixed tufa and sinter soil at Lees and Gerlach Hot Springs, where the tufa introduces relatively high equivalent U, and the low radioactivity sinter terrace at Steamboat Hot Springs.

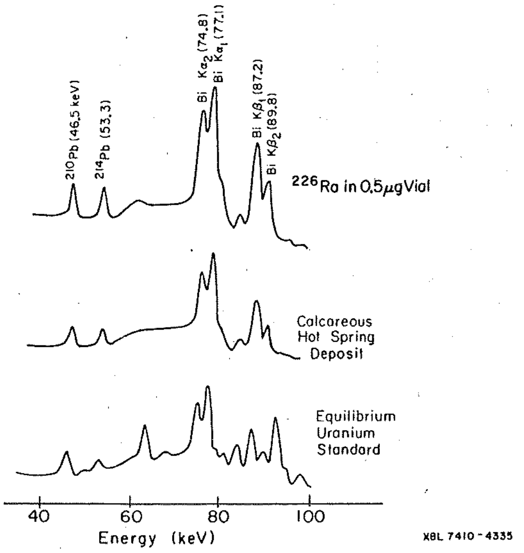

Fig. 2. Gamma-ray spectra in the energy region 40 to 100 keV. The spectra were taken on a high-resolution system, utilizing a 10 cm^3 Ge(Li) detector.

The uranium values in Table II are listed as equivalent because they are based on the gamma-ray peaks of ^{214}Bi, one of the radioactive decay products of ^{226}Ra. Radium-226, in some chemical environments, may be completely separated from its parent ^{238}U, transported in bicarbonate-rich waters, and deposited with $CaCO_3$ on spring walls in the upper portions of a spring system [Tanner, 1964]. Therefore, the high equivalent U in samples of calcareous deposits actually indicates ^{226}Ra anomalies. Uranium-238 or its decay products higher in atomic mass number than ^{226}Ra are missing. This was disclosed by examining high resolution gamma-ray spectra of the calcareous samples, counted on a Ge(Li) detector system. Figure 2 displays superimposed gamma-ray spectra, in the X-ray energy region, of a ^{226}Ra source, calcareous muck from Kyle Hot Springs, and an equilibrium ^{238}U standard. The muck and ^{226}Ra source spectra match peak for peak. The U-standard spectrum shows the characteristic Bi and Pb X-ray peaks, as well as peaks from precursors to Ra in the U decay series.

Waters. Samples of water, approximately 550 ml, were collected from all of the springs for subsequent laboratory gamma-ray spectrometry. Radon-222 was indicated by the presence of the 1.76 MeV peak of ^{214}Bi in the gamma spectra of seven of the water samples. Several days elapsed between collection and laboratory analyses of the samples. Therefore, it is expected that in some of the samples ^{222}Rn activity (a 3.8 day half-life) had decayed below detectability. Repeated gamma counting of the samples from Buffalo Valley, Kyle and Gerlach Hot Springs showed that the ^{214}Bi activity decayed with the Rn half-life, indicating that there was little or no ^{226}Ra in these waters. Otherwise, Ra would have resupplied Rn, eventually achieving radioactive equilibrium between these isotopes. The ^{214}Bi activities of the measureable water samples are listed in Table III; they should be considered in the relative sense, pending calibration experiments. There is no apparent correlation between the radioactivities of the waters and those of the calcareous hot-spring deposits.

Table III. Radioactivity of hot-spring waters.

Location	Net radioactivity in 1.76-MeV peak of ^{214}Bi* (counts/min-g)
Gerlach	0.0117
Kyle	0.0179
Buffalo Valley	0.0034
Golconda	0.0070
Pumpernickel:	
Small pool	0.0362
Outflow	0.0162
Lee	0.0166

*Corrected for 3.8-day half-life decay of ^{222}Rn.

The comparatively high radioactivities of the waters from Pumpernickel and Lees Hot Springs, compared with the relatively low activities of corresponding spring deposit material, suggests that these waters may contain radon from sources other than the radium on near surface spring walls. Future sampling of hot-spring waters will include on-site radon analyses and chemical separation of radium, which, coupled with subsequent laboratory analyses, should determine the component of radon from radium in the waters and the component emanating from radium deposited near the surface.

Conclusions

At this stage of the study there are some definite conclusions:

1. Radium preferentially associates with $CaCO_3$ in the Nevada hot-spring deposits.
2. Where sinter and tufa are mixed in a hot-spring deposit, the calcareous material has the highest radioactivity.
3. Low flowing $CaCO_3$-dominated spring systems are the most radioactive.

Tentatively, it may be concluded that waters in some of the $CaCO_3$-dominated hot-spring systems deposit ^{226}Ra near the surface of low flowing springs. If flow is too rapid, little or no radium may deposit, because reactions involving Ca, HCO_3^-, and water are slow in precipitating $CaCO_3$ and coprecipitating Ra. Most of the ^{222}Rn observed in these waters is probably derived from decay of ^{226}Ra deposited on the spring walls.

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