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Permalink https://escholarship.org/uc/item/7pr2c6jq

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Publication Date 1974-03-01 Submitted to Nature

LBL-2482 Rev. Preprint

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Prepared for the U. S. Atomic Energy Commission under Contract W-7405-ENG-48

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Radioactivity of Nevada Hot-Spring Systems

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March 1974

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 dose rates measured on-site range from 2 to 500 μ r/hr, and depend mainly on the amounts of the natural radioelements in the spring deposits. At several locations ²²²Rn, emanating from the water causes recognizable gamma-ray anomalies. High radioactivities, primarily from ²²⁶Ra, are associated with hot-spring systems dominated by CaCO₃, while silica-dominated systems are relatively low in radioactivity. Gamma spectrometry disclosed the enrichment of ²²⁶Ra with respect to its parent U in CaCO₃-dominated systems. ²²⁶Ra 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 CaCO₃-dominated systems are generally less radioactive than calcareous deposits at slower flowing springs.

*Work done under the auspices of the U.S. Atomic Energy Commission.

I. INTRODUCTION

Radioactive anomalies associated with mineral - and hot - spring systems have been recognized and documented by many scientists. For example, Pöhl-Rüling and Scheminzky¹ described the 'radium- and radon-rich environment of Bad Gastein, an Austrian spa celebrated for decades for its healing hot radioactive air, waters, and muds. Earlier, Belin² described the occurrence of radon in New Zealand geothermal regions, and Mazor³ related redium and radon in Israeli water sources with oil, gas, and brine reservoirs of the Rift Valley. Since the late 1040's several Japanese scientists, among them Kikkawa⁴, Kimura⁵, and Hitaye⁶ have reported on the association of radioelements and hot- and mineral-spring systems. Scott and Barker⁷ 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.⁸). 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 importtant, an assessment of the environmental impact of a geothermal development project requires an understanding of its radioactive setting.

II. 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-in. by 3-in. NaI(Tl) scintillation detector coupled to a count-rate meter. Field radioactivites were measured over hot pools, sinter (SiO₂-rich), and tufa (CaCO₃-rich) deposits, and also away from the spring areas to obtain background values. Figure 2 illustrates the field gamma counter, and Fig. 3 shows typical measurement conditions at a hot spring in Ruby Valley. Samples of spring-deposit tufa, sinter, spring-wall muck, and water were 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 Smith⁹.

III. 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 are expressed in microroentgens per hour $(\mu r/hr)$, based on calibration of the field instrument (counts/sec to $\mu r/hr$) with a radium source of known strength. Immediately apparent is the association of high radioactivities, "anomalies," with CaCO3-rich spring depositis; with one exception, Lee Hot Springs, silica-rich deposits have no anomalies. The greatest radioactivities, 250-500 μ r/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 hot and boiling pools and sinter at Beowawe Hot Springs. In no case was there any apparent connection between surface spring temperature and radioactivity. Among the spring systems where CaCO₂ predominates there were no anomalies associated with blowing wells, nor with the fast-flowing spring at Fly Ranch. A strong radioactivity contrast exists at Darroughs Hot Springs where there is no apparent anomaly in the vicinity of a moderately blowing well, while approximately 200 meters away 75 μ r/hr was observed over a still pool. Thus, radioactive anomalies in the hot-spring areas appear to be associated with low-flowing CaCO₃-rich systems. An inverse correlation of radioactivity with flow rate was observed by Vincenz¹⁰ 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 Lee 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 fieldradiometric anomalies were detected down-wind from pools, indicating the emanation of ²²²Rn from the waters and spring walls.

IV. LABORATORY MEASUREMENT RESULTS

A. Spring Deposits

Table II summarizes laboratory gamma-spectrometric analyses of springdeposit materials. As with the field data, the high radioactivities, attributable primarily to "apparent 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 Lee Hot Springs, where the tufa introduces relatively high apparent U, and the low-radioactivity sinter terrace at Steamboat Hot Springs.

For guidance in the following discussion the uranium decay series is shown in Fig. 4. The uranium values in Table II are listed as apparent because they are based on the gamma-ray peaks of ²¹⁴Bi, one of the radioactive decay products of ²²⁶Ra. Radium-226, in some chemical environments, may be completely separated from its parent ²³⁸U, transported in bicarbonate-rich waters, and deposited with $CaCO_3$ on spring walls in the upper portions of a spring system (Tanner¹¹). Therefore, the high apparent U in samples of calcareous deposits actually indicates $\frac{226}{Ra}$ anomalies. Uranium-238 or its decay products higher in atomic mass number than ²²⁶Ra are missing. This was disclosed by examining high-resolution gamma-ray spectra of the calcareous samples, counted on a Ge(Li) detector system. Figure 5 displays superimposed gamma-ray spectra, in the x-ray energy region, of a ²²⁶Ra 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. Corroborative evidence for radon anomalies in the calcareous material is furnished by comparison of the intensities of peaks at 186 and 352 keV (not shown on Fig. 5) in the equilibrium and Ra spectra. In the U spectrum 62% of the 186-keV peak is from 226 Ra, 38% from 235 U, while all of the 352-keV peak is from ²¹⁴Po, a Ra daughter; the ratio of counts in the 352-keV peak to counts in the 186-keV peak is approximately 2. In samples of Ra-rich spring deposits the corresponding peak ratios are approximately 3, indicating the absence of the ²³⁵U component in the 186-keV peak.

B. 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 ²²⁶Ra in these waters. Otherwise, Ra would have resupplied Rn, eventually achieving radioactive equilibrium between these isotopes. The ²¹⁴Bi 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 hotspring deposits. 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 shall 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.

V. FIELD RADON DETECTION

Alpha-track detectors for ²²²Rn, furnished by the General Electric Company's Vallecitos Nuclear Center, were placed in the ground near and away from radioactive pools at Buffalo Valley Hot Springs. (This application of track etching has been briefly described by Fleischer et al. ¹²) Subsequent etching of the alpha tracks showed high track densities in detectors near the pools and a tenfold decrease in track densities in detectors away from the pools. We plan a systematic study of the Rn field in the vicinity of the springs, employing a large array of track detectors, to better define the randon emanation field and to compare it with other geophysical parameters.

VI. CONCLUSIONS

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

1) Radium preferentially associates with CaCO₃ 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 CaCO₃-dominated spring systems are the most radioactive.

Tentatively, it may be concluded that waters in some of the CaCO₃dominated hot-spring systems deposit ²²⁶Ra near the surface of low-flowing springs. Most of the ²²²Rn observed in these waters is probably derived from decay of ²²⁶Ra deposited on the spring walls.

Acknowledgement

I thank Richard Hose of the U. S. Geological Survey for guidance in the field, and Alan Smith of Lawrence Berkeley Laboratory for consultation and aid in laboratory gamma spectrometry. The help of members of the LBL geothermal studies group in field operations is greatly appreciated.

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	G	amma dose rates (µr/h	r)		
Location	General background	Anomalously high radioactivity	Remarks		
Sp	ring systems v	where CaCO ₃ is the pre	dominant deposit		
Gerlach Gerlach	6.25 - 7.5	60 - 65 20 - 25	Tufa, high rad. zone		
Fly Ranch	6.25 - 8.75	None apparent	Travertine		
Kyle	12.5 - 25	250 - 500	Over radioactive pacta		
Elko	7.5 - 10	19	Tufa at edge of pool		
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		
Pumpernicke	1 7.5 -10	17.5 - 22.5	Small pool		
Pumpernicke	1 15	17.5	Outflow stream		
Sp	oring systems	where SiO ₂ is the predo	ominant deposit		
Brady's	5 - 7.5		Sinter soil		
Beowawe	2 - 2.5		Sinter apron		
Beowawe	13.8 - 17.5		Andesite		
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 I. Field gamma radiometry of spring areas.

Location	Description	Th (ppm)	Apparent U (ppm)	K (%)	226 Ra ^a 10 ⁻¹² Ci/g	Th/U			
	Spring systems where CaCO ₃ is the predominant deposit								
Gerlach Gerlach	Tufa, high radioactivity zone Pred. Si sinter, some tufa	13.41 2.38	109.25 33.3	1.02 0.41	39 12	0.12 0.07			
Fly Ranch '	Travertine	2.14	10.99	0.02	4	0.19			
Kyle Kyle	Calcareous muck from spring walls Travertine away from active springs	11.62 0.19	76.32 4.06	0.16 0.09	27 1.5	0.15 0.05			
Elko	Tufa	3.12	7.60	0.07	2.7	0.41			
Buffalo Valley	Calcareous muck from a small mound Pred. tufa, some Si sinter	45.89 6.20	25.49 65.67	0.21 0.35	9.2 23.7	1.80 0.09			
Spencers	Pred. 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 Sinter soil, vicinity of hot pools	15.99 0.91	3.28 0.37	3.74 0.40		4.88 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 Lee	Sinter Tufa and sinter	4.76 3.71	2.49 11.67	1.11 0.51	<u></u> .	0.91 0.31			
Steamboat Steamboat	Sinter, main terrace Sinter and altered granitics, west area	0.30 8.10	1.42 4.90	0.13 1.13	······································	0.21 1.65			

Table II. Laboratory gamma spectrometry of spring deposits.

^aCalculated from activities ratio, 226 Ra/ 238 U = 2.78×10⁶.

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Location	Net radioactivity in 1.76-MeV peak of ²¹⁴ Bi [(counts/min-g)×10 ⁻²] ^a
Gerlach	1.17
Kyle	1.79
Buffalo Valley	0.34
Golconda	0.70
Pumpernickel: Small pool Outflow	3.62 1.62
Lee	1.66
^a Corrected for 3.8-day half-life de	ecay of ²²² Rn.

Table III. Radioactivity of hot-spring waters.



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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.

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Fig. 2. Field gamma counter. The 3-in. by 3-in. NaI(T1) scintillation crystal and photomultiplier tube are encased by the steel cylinder, and are connected to the accompanying count-rate meter.



Fig. 3. Field gamma radioactivity and water-temperature measurements at Big Sulfur Hot Springs, Ruby Valley.



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