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A DETAILED CHEMICAL AND RADIO-METRIC STUDY OF
GEO-THERMAL WATERS AND ASSOCIATED ROCK
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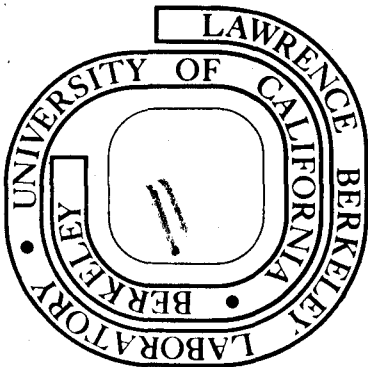
H. Bowman, A. Hebert, H. Wollenberg, and F. Asaro

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A DETAILED CHEMICAL AND RADIOMETRIC STUDY OF GEOTHERMAL WATERS AND ASSOCIATED ROCK FORMATIONS, WITH ENVIRONMENTAL IMPLICATIONS

H. Bowman, A. Hebert, H. Wollenberg, and F. Asaro

Major trace, and radioactive element abundances including non-condensable gas contents, of hot and cold spring waters from geothermal resource areas in north-central Nevada are being studied. These studies will serve as a baseline for the evaluation of the environmental impact of geothermal resource development.

Over 50 elements were looked for by x-ray fluorescence and high precision neutron activation analysis techniques. About 15 elements were usually detected in basic hot waters and substantially more in a single acid pool. Tungsten was unusually high in abundance in the hot waters but not in cold.

In two areas, uranium was detected at the level of ~2-5 ppb in cold water and not detected in the hot spring waters. Attempts are being made to correlate the uranium hot-cold spring data with measurements of radon and radium in the springs in terms of the minimum age of the hot aquifer and the hot water flow rate.

INTRODUCTION

Nuclear analytical techniques presently employed at Lawrence Berkeley Laboratory allow precise quantitative measurements of elemental abundances in water, rock, and soil samples from geothermal areas. Many potentially diagnostic elements have been determined which heretofore have not been utilized in geothermal applications.

The techniques include neutron activation, soft x-ray, and gamma ray spectrometric analysis. This work is part of a general program to evaluate the geothermal potential of north-central Nevada.

Preliminary results from initial chemical analyses of hot and cold water systems, associated rock, gases, and emanations from four geothermal areas in Nevada suggest that this type of data may lead to indicators of:

1. The temperatures and rock types within the geothermal system.
2. The size and depth of the convecting system.
3. The extent of which hot and cold waters mix.
4. The amounts of valuable elements and compounds in these waters.
5. The causes of hot spring and high-heat-flow activities.
6. The extent to which noxious and hazardous materials are released into the environment.

RADIOMETRIC MEASUREMENTS

Table I lists environmental gamma radioactivities measured at 17 hot spring locations in northern Nevada. These areas are broken down into two categories depending on whether the predominant spring deposit materials were CaCO_3 or SiO_2 (Wollenberg, 1974). These data were evaluated along with laboratory gamma-ray spectrometric measurements of the natural radioactive elements in samples of water and spring deposit material. The highest radioactivities are associated with radium and radon in low-to-moderate flowing springs where CaCO_2 is the predominant spring deposit material.

The tentative conclusion of this early study was that some of the low-flowing CaCO_3 springs deposit ^{226}Ra near the surface and that most of the ^{222}Rn is probably derived from the decay of ^{226}Ra deposited on the spring walls.

Four of the hot spring sites listed in Table I: Kyle, Leach, Buffalo Valley, and Beowawe were chosen for a more detailed geochemical study.

Water Sample Collection and Preparation

Water samples were collected from both hot and cold springs by drawing water through a 0.45 μg cellulose acetate filter using a hand operated vacuum-pump. Whenever possible, the waters were syphoned through a tygon-tube directly from the springs.

A drop of water from each spring was evaporated onto a lexan disc, using a fixing solution at each site, for later analyses using soft x-ray fluorescence. A silver disc was placed in a separate sample from each spring for later H_2S determination.

The $\frac{1}{2}$ liter water samples were evaporated in the laboratory (at 80°C) in the original plastic collecting bottles.

Neutron Activation Analysis

A high precision neutron activation technique developed for analysis of pottery (Perlman and Asaro, 1969) was used in these measurements. Evaporates from water samples and powders from crushed rock and soil samples were made into pellets and irradiated along with a composite standard pellet in the Triga Research Reactor at the University of Calif., Berkeley. Nearly all elements in the samples have their counter parts in the standard and the abundances are determined by comparing the gamma rays emitted from the unknowns and standards. This method is capable of quantitatively analyzing for in excess of 50 elements in a sample. In rock samples, more than 2 dozen elements can be determined with precisions of less than 5%, and a number of these are determined to better than 1% (Bowman, Asaro, and Perlman, 1973).

RESULTS

Figure 1 shows the uranium content of hot and cold springs in the areas surrounding Kyle, Leach, Buffalo Valley, and Beowawe hot springs. The cold springs at Kyle and Leach have appreciable uranium, but uranium is not detected in the hot springs. In a carbonate-dominant hydrothermal system, this might be expected since uranium has a retrograde solubility in the carbonate form. Uranium can also be reduced from the + 6 state to the + 4 and precipitated in the presence of H_2S .

From these uranium data along with assumptions based on the radium and radon measurements, one may be able to estimate the hot water subsurface-flow rates or, conversely, the amounts of uranium accumulated at depths.

Buffalo Valley Hot Springs

Figure 2 shows the abundance for a number of the more prominent elements found in four separate hot sources at Buffalo Valley hot springs. Sodium and chloride abundances obtain by the U. S. Geological Survey on a separate source (Mariner, et al., 1974) using conventional methods, are shown at the top of Figure 2 for comparison. The slight chemical variation with surface water temperature is thought to be accidental. An example of the neutron activation analytical precision on hot water samples is shown in Table II. The Cs, Rb, and Na abundances are tabulated and averaged for the four separate springs at Buffalo Valley. The root-mean-square deviations found here are about what one would expect from multiplet samples of a single reservoir. Rather precise determinations such as these may be useful in determining rock types and temperatures at depths since the behavior of these elements in feldspars has been

studied under hydrothermal conditions (J. I. Iiyama, 1974). These data suggest that the four springs studied at Buffalo Valley hot springs are fed from a single source.

Leach Hot Springs

Three springs were sampled at Leach hot springs; their analyses are shown in Figure 3. Considerable variation was found in these. The hottest spring was found to have the lowest abundances of Na, Cl, W, Br, Cs, and Rb. The variations observed here do not appear to be related to ground water mixing with the hot water system. Typical cold-spring elemental abundances in this area are: Na (29±1 ppm), Cl (56±2 ppm), W (< 3 ppb), Br (118±2 ppb), Cs (.23±02 ppb), Rb (3.7±6 ppb), Ba (75±10), Mo (< 2), and Sb (< 0.2 ppb).

Beowawe Hot Springs

Figure 4 shows the chemical abundances in water of three separate hot springs in the Beowawe area. The bar labelled "ST." represents data from a blowing-steam-well. The low temperature spring (78°C) was found to have a pH of about 3, quite different from all of the other hot springs tested.

Disregarding the low temperature, unusually acid spring, one can consider the differences found in the other two sources in terms of ground-water mixing. Elemental abundances for W, Sb, As, and Mo from a nearby well were < 1, < .3, 4 ± 1 and < 2 ppb, respectively. The waters from at least this level are probably not responsible for the elemental abundance variations found in the two hotter sources.

Kyle and Brady

Only a single sample was taken from Kyle hot springs and the blowing well at Brady. No cold spring samples were taken from the Brady area. The hot water results are shown in Fig. 5. In general, the elemental abundance at Kyle and Brady are much higher than for the other hot springs tests. Spring deposits at Brady are SiO₂ dominated while Kyle is dominated by CaCO₃. The greater Ba, Cs, and Rb abundances at Kyle probably reflect the high concentration of CaCO₃ in the water.

Rock Analysis

Rock samples from the probable source terranes for the geothermal waters were also collected. This data is quite extensive and will be published elsewhere. Only a brief description of some of the findings are given here.

The very high uranium and thorium abundances in the Fish-Creek-mountain-tuff near Buffalo Valley reflects its rhyolitic character. Typical uranium values are 20 ppm while thorium abundances are as high as 85 ppm. The high uranium content of this volcanic ash may be principally responsible for the high uranium found in the associated cold spring waters. Many other heavy cations were found to be very abundant in the tuff. With respect to other rare earth elements, europium is depleted considerably. This is usually called a negative europium anomaly and is quite evident when rare-earth abundances are normalized to chondrite abundance. In general, Eu anomalies in magmas are indicative of extensive differentiation under the (low pressure) conditions where feldspar is stable (Philpotts, *et al.*, 1971).

Europium anomalies may turn out to be indicators of shallow magma chambers, and hence possible geothermal heat sources.

X-Ray Fluorescence

This method provides rapid and precise analysis of major elements in rock and water samples. Single drops of spring water samples were evaporated onto lexan discs in the field and analysed later in the laboratory, using a non-dispersive vacuum x-ray fluorescence spectrometer (Hebert and Street, 1973). This collection method was devised to retain all solid material including those

which would normally precipitate on cooling. Semi-quantitative results were obtained on the amount of H_2S in the water samples by precipitating the S^{2-} as Ag_2S on the surface of a silver disc in each sample bottle at the site. The sulfur abundances were determined using the x-ray fluorescence technique later in the laboratory. A tentative calibration curve for this work is shown in Fig. 6. Powdered rock and soil samples were analysed with the x-ray spectrometer mentioned above. The powders were fused with lithium borate to form a glass pellet for the analysis. This method gives precisions in the range of 1 to 3% on major elements ranging, in atomic mass, between Na and Fe.

CONCLUSION

Preliminary results from a detailed chemical study of four hot spring areas in north central Nevada indicate that high radioactivities are associated with low-flowing $CaCO_3$ hot spring systems and that a number of the trace elements found in these hot waters may be useful in evaluating the pathways of waters from its source area into these geothermal systems. This type of data may also lead to indicators of:

1. The rock types and temperatures within the geothermal system.
2. The sizes, ages, and depths of convecting systems.
3. The extent of cold and hot waters mixing.
4. The causes of hot spring activities.
5. The extent to which noxious and hazardous materials are released into the environment.

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FIGURES CAPTIONS

- Fig. 1. Uranium abundances (ppb) in hot and cold springs from 4 geothermal areas in north central Nevada. C-cold springs, H-hot springs, vertical arrows indicate detection limits.
- Fig. 2. The abundances of the most prominent elements found in 4 separate hot water sources at the Buffalo hot spring area. Surface water temperature is indicated on each bar graph.
- Fig. 3. The elemental abundances measured in 3 separate hot springs at the Leach hot spring area.
- Fig. 4. The abundances of elements found in 3 hot water sources in the Beowawe hot spring area. The pH of the low temperature hot water source (78°C) was quite different from all other hot springs tested (ST.-Blowing steam well).

Fig. 5. Elemental abundances determined in hot spring water from Kyle hot spring and the blowing well at Brady hot springs.

Fig. 6. A tentative calibration curve for determining equivalent H_2S in hot and cold spring water using vacuum x-ray fluorescence methods.

TABLE CAPTIONS

Table I. Field gamma-ray measurements of hot spring areas in central Nevada.

Table II. The cesium, rubidium, and sodium abundances for four separate hot water sources at Buffalo hot springs in north central Nevada.

Gamma dose rates ($\mu\text{r/hr}$)

Location	General background	Anomalously high radioactivity	Remarks
<u>Spring systems where CaCO₃ predominates</u>			
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
<u>Kyle</u>	12.5 - 25	250 - 500	Over radioactive pools
Elko	7.5 - 10	19	Tufa at edge of pool
<u>Buffalo Valley</u>	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
Pumpnickel	7.5 - 10	17.5 - 22.5	Small pool
Pumpnickel	15	17.5	Outflow stream

Gamma dose rates ($\mu\text{r/hr}$)

Location	General background	Anomalously high radioactivity	Remarks
<u>Spring systems where SiO₂ predominates</u>			
<u>Brady's</u>	5 - 7.5	---	Sinter soil
<u>Beowawe</u>	2 - 2.5	---	Sinter apron
<u>Beowawe</u>	13.8 - 17.5	---	Andesite
Big Sulfur (Ruby V.)	2.5 - 5	---	Sinter
<u>Leach</u>	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

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Table II

Buffalo Hot Springs

Spring	Temp.	Cesium (PPB)	Rubidium (PPB)	Sodium (PPM)
1	72°	153±3	130±6	264±4
2	65°	155±3	126±5	272±4
3	68°	155±3	134±5	275±4
4	72°	147±3	125±5	263±4
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Ave.		153±4	129±5	269±6

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URANIUM (PPB) Hot and Cold Springs

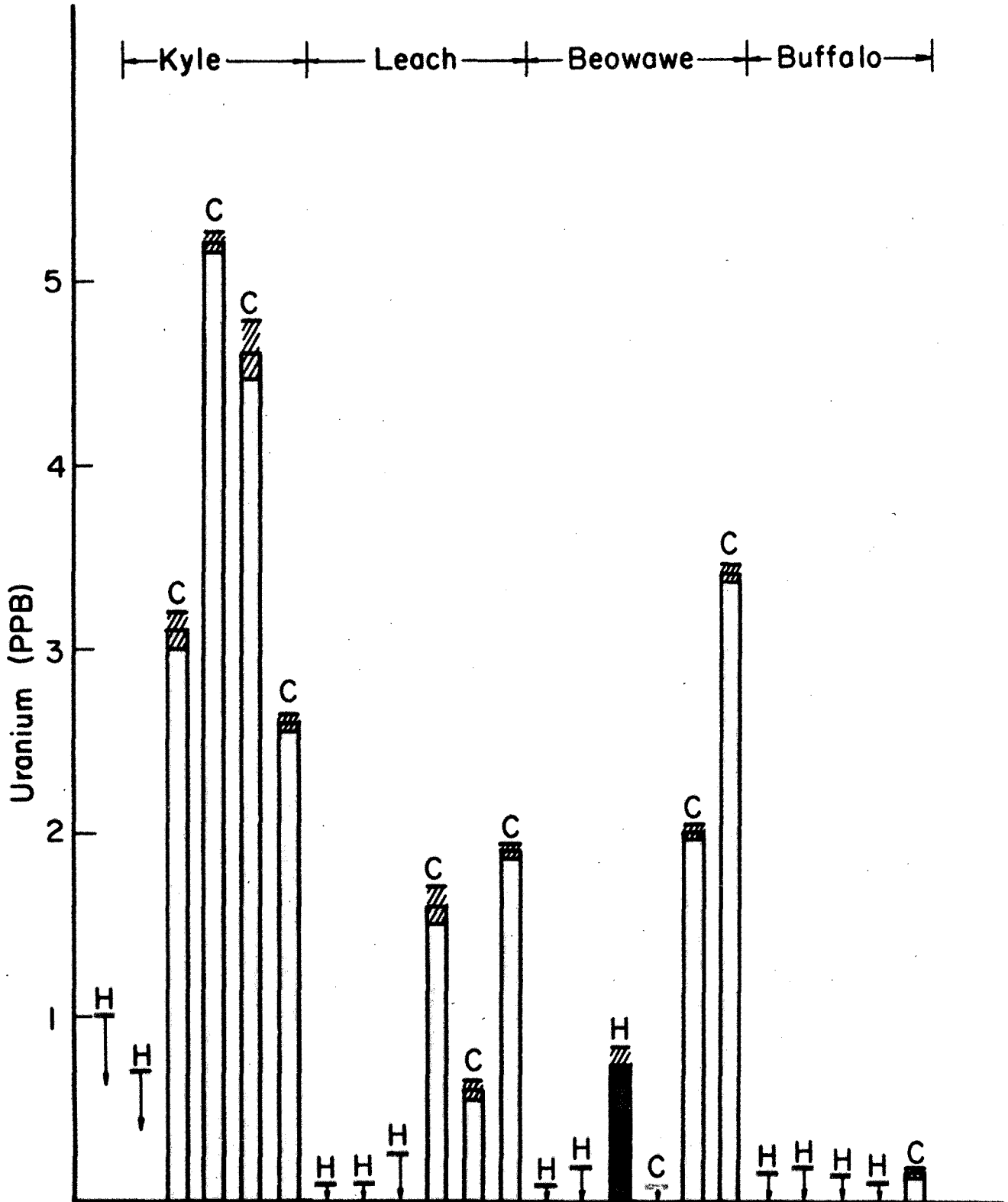


Fig. 1

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BUFFALO HOT SPRINGS

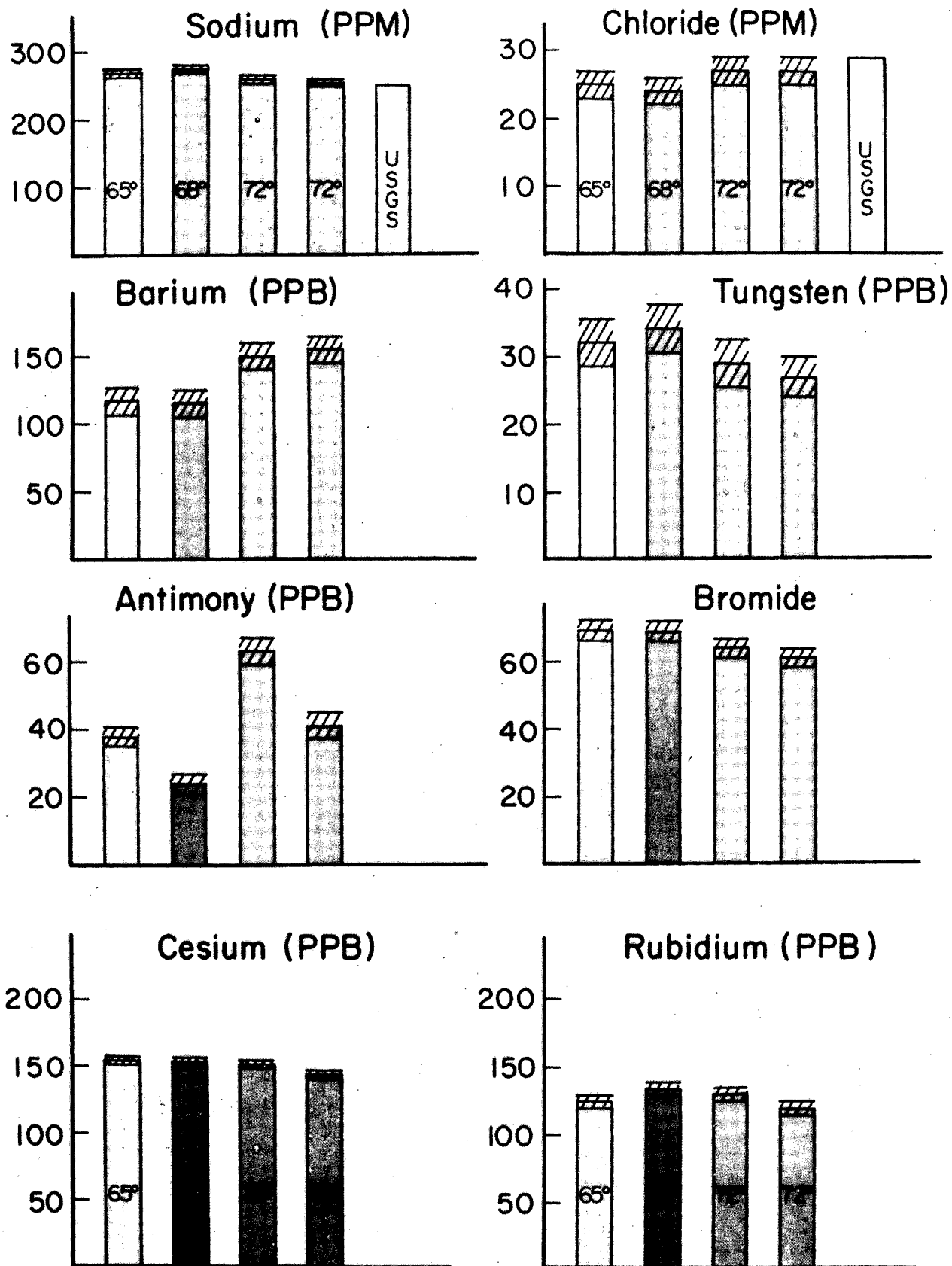


Fig. 2

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LEACH HOT SPRINGS

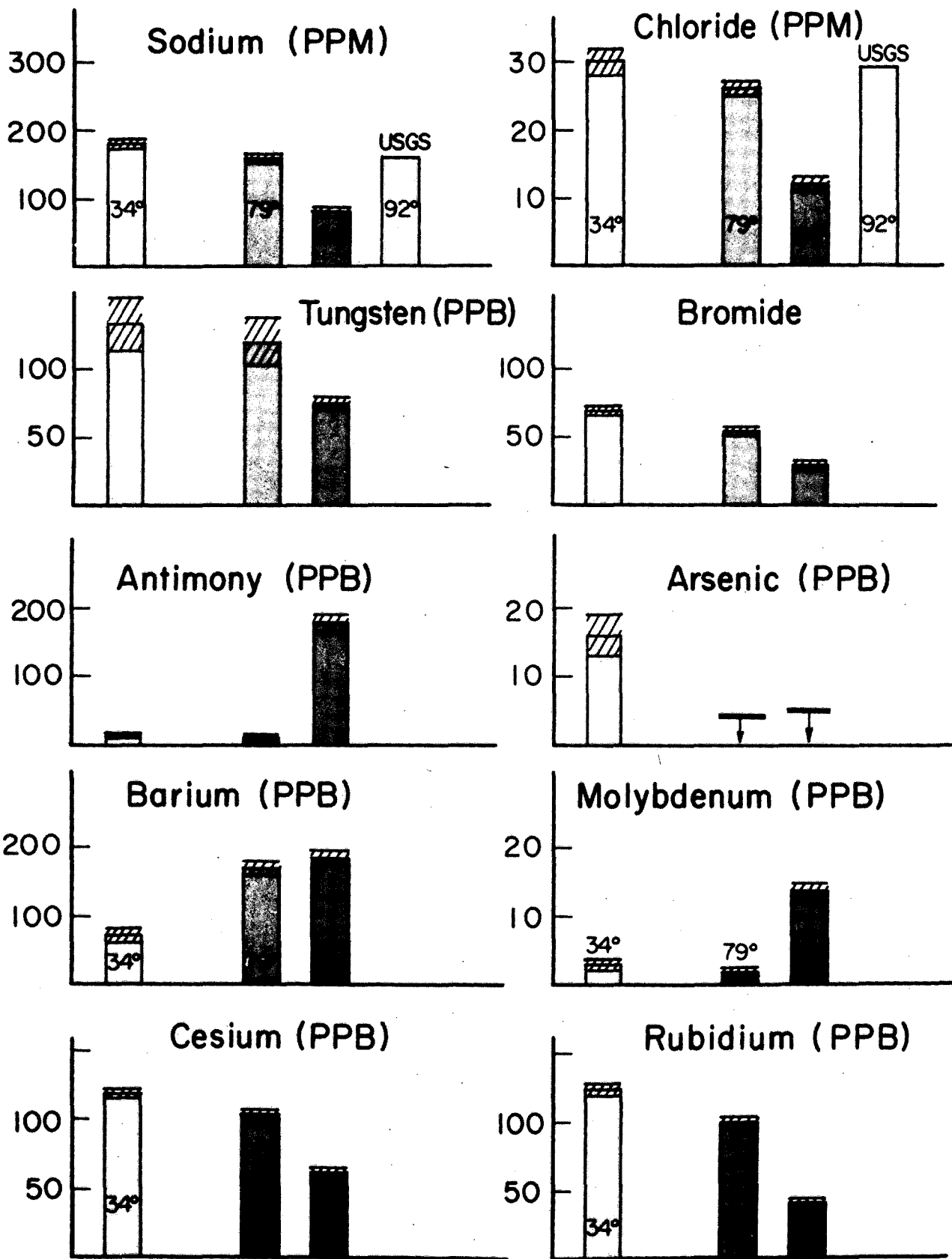


Fig. 3

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BEOVAWE HOT SPRINGS

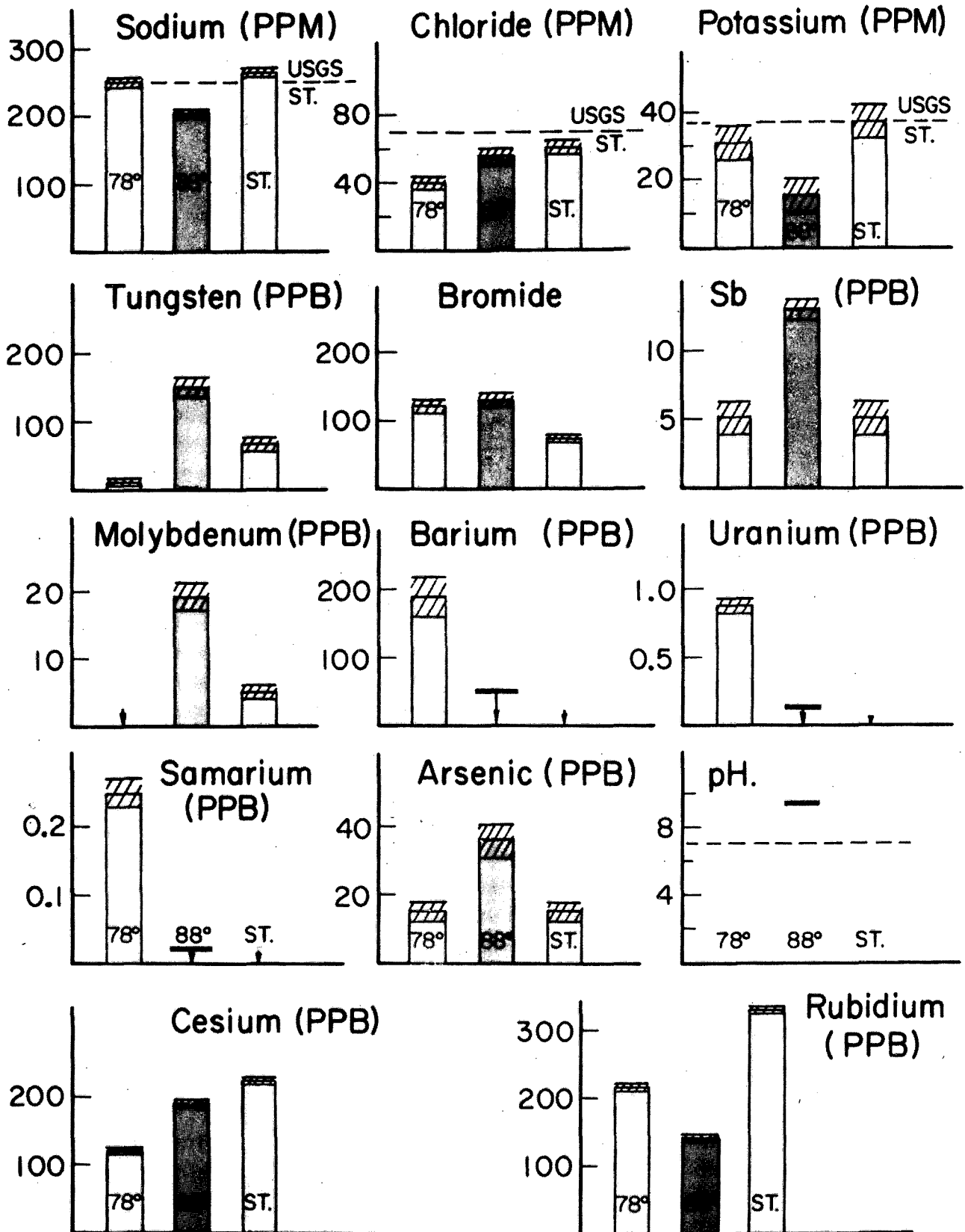


Fig. 4

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BRADY and KYLE

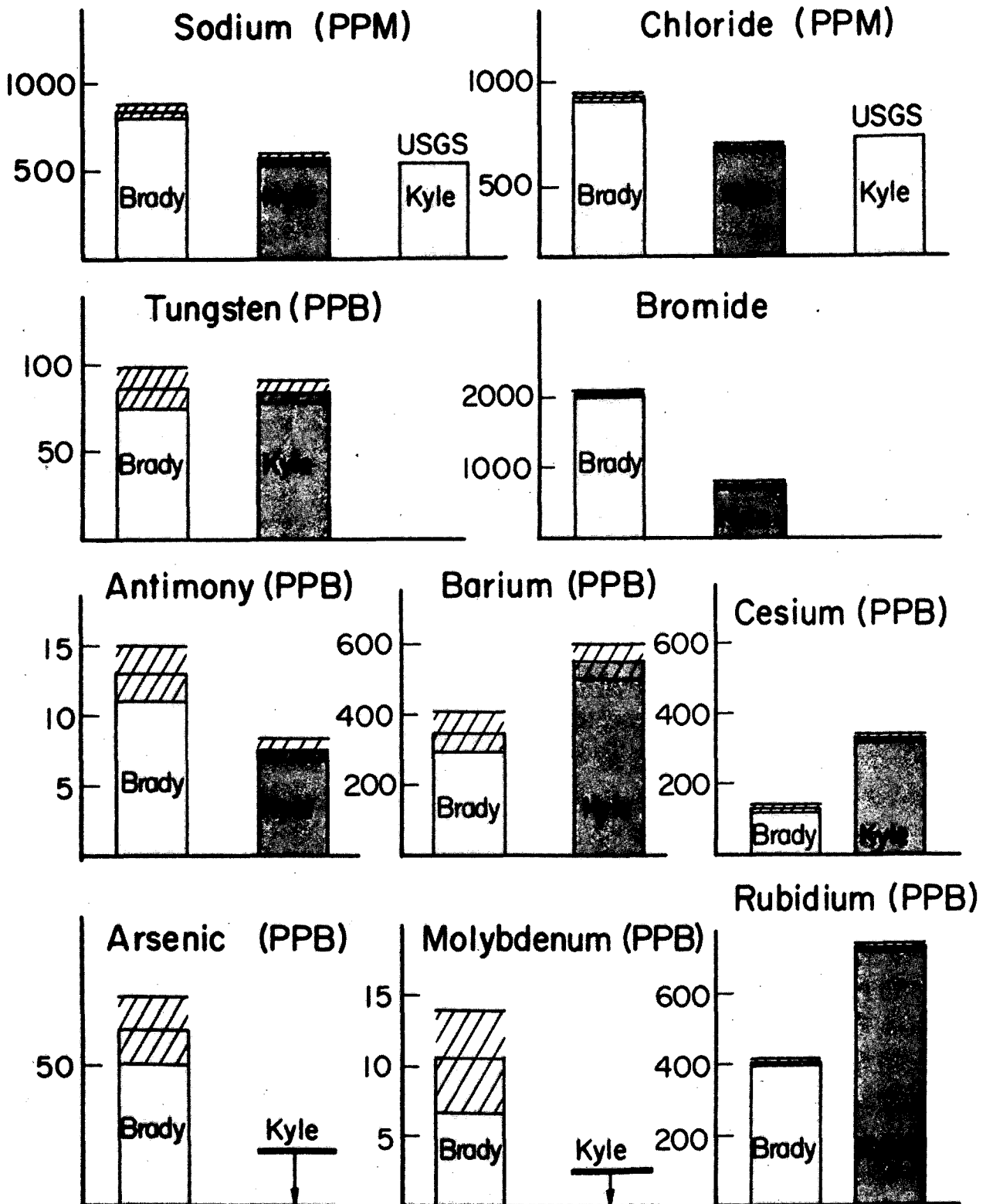
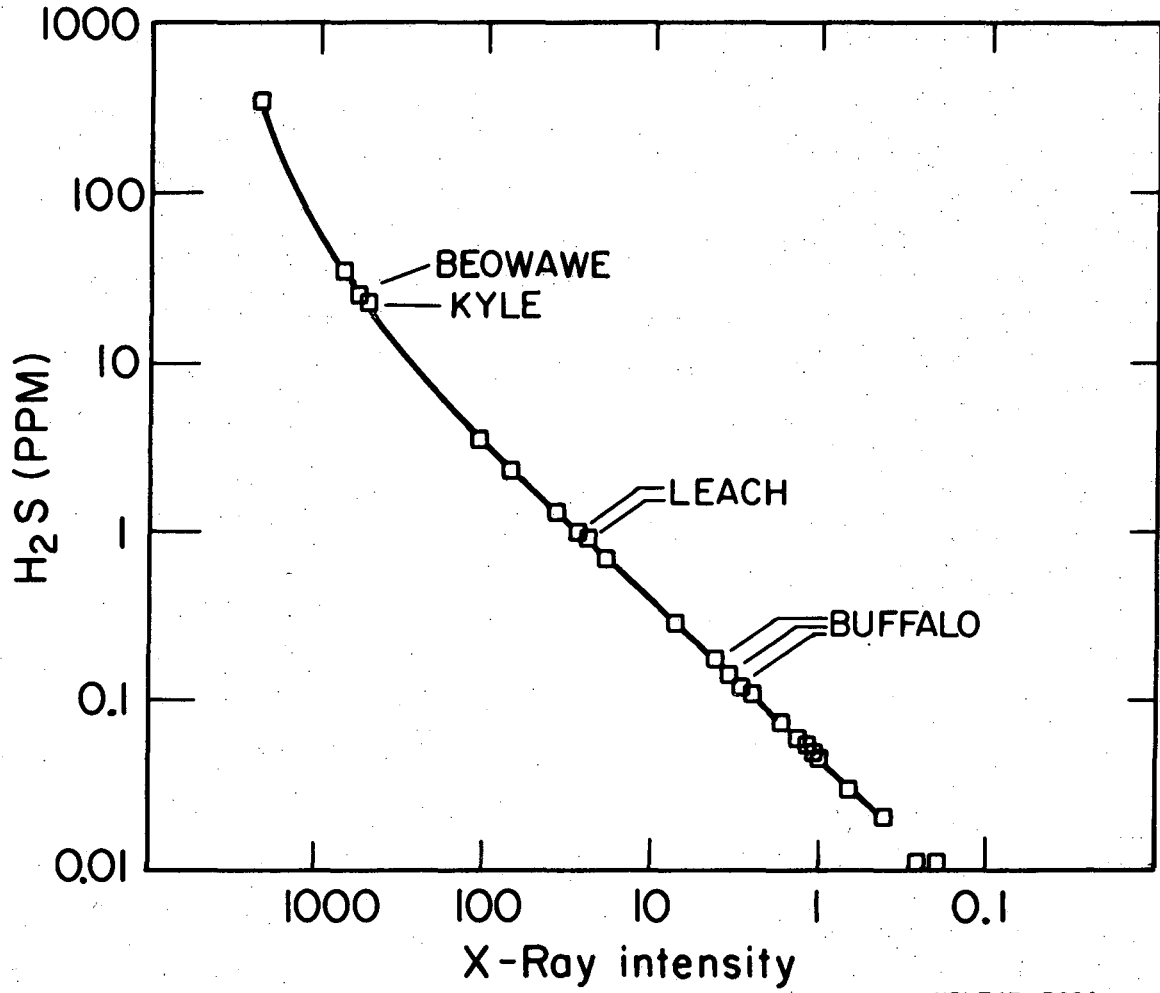


Fig. 5

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Fig. 6

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