EFFECTS OF RADON IN DRILL HOLES ON GAMMA-RAY LOGS

By L. S. Hilpert and C. M. Bunker

Trace Elements Investigations Report 553

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

March 26, 1957

AEC - 421/7

Mr. Robert D. Nininger
Assistant Director for Exploration
Division of Raw Materials
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Bob:

Transmitted herewith are three copies of TEI-553, "Effects of radon in drill holes on gamma-ray logs," by L. S. Hilpert and C. M. Bunker, February 1957.

We plan to submit this report for publication in Economic Geology.

Sincerely yours,

John H. Eric
for W. H. Bradley
Chief Geologist

Geology and Mineralogy

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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By

L. S. Hilpert and C. M. Bunker

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This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

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EFFECTS OF RADON IN DRILL HOLES ON GAMMA-RAY LOGS

By L. S. Hilpert and C. M. Bunker

ABSTRACT

Drill holes in uranium deposits in the Todilto limestone of Late Jurassic age near Grants, N. Mex., do not yield duplicate gamma-ray logs when probed at different times; some logs show equivalent uranium greatly in excess, in thickness and grade, of the chemical and laboratory radiometric analyses. Radon and its daughter products principally cause the discrepancies. Experimental work was undertaken by the writers to learn the relations of the radon to the uranium deposits and its behavior under different physical conditions. The work is based on the interpretation of about 600 gamma-ray logs, taken from 480 drill holes.

Abnormally high amounts of radon, referred to here as contamination, ranged from barely detectable amounts to amounts that emitted as much radiation as ore-grade material. Most contaminated holes were in the higher-grade ore, and the contamination increased with elapsed time after drilling.

Geologic conditions favorable for contamination by radon and its daughter products in drill holes are: proximity to uranium deposits, and fractured or highly permeable rocks above the water table. Most drill holes can be decontaminated by blowing them out with compressed air or filling them with water. Water, however, tends to reduce the thickness-times-grade figures below the amounts determined in air.

INTRODUCTION

During the fall of 1954, it was necessary for the U. S. Geological Survey to obtain gamma-ray logs of the drill holes on properties being explored under Defense Minerals Exploration Administration assistance near Grants, N. Mex. Early in the work it was found that some of the drill holes did not yield duplicate logs when probed at different times, and some showed amounts of equivalent uranium greatly in excess, both in thickness and grade, of the amounts determined chemically or by laboratory radiometric analysis. In fact, the disparity between logs of some holes was so great that the gamma-ray data were very misleading when used alone for determining uranium reserves. This had also been the experience of private companies and individuals in the area, and as a result, such logs were considered unreliable for uranium determinations. It was apparent that if gamma-ray logs were to be used effectively, either by the Government or private industry to help appraise uranium reserves, the causes for the discrepancies would have to be determined, and the means found to eliminate or control them.

Company personnel, suspecting that the cause might be radon gas and its gamma-emitting daughter products, had used compressed air to blow out the affected holes. Although this practice met with some success, to our knowledge no one had actually identified radon and its gamma-emitting daughters as the cause of the anomalously high and variable gamma-ray intensities, and data were sparse on the specific nature, distribution, and spatial relationships of the radioactive materials causing the radioactivity.

Late in 1954, A. B. Tanner of the U. S. Geological Survey became interested in reports of the relatively high radon content of some of the drill holes in the Grants area. He took air samples from selected holes and specifically identified by alpha-particle measurement the presence of radon in high concentrations. He then did some experimental work to determine the relations of the radon to atmospheric pressure, temperature, and wind conditions. His work showed that the radon concentration increased at times of decreasing atmospheric pressure and was affected by wind conditions._/

_/ Tanner, A. B., in preparation, Radon in drill holes.

For some of the same holes in which Tanner identified radon in abnormally high concentration, gamma-ray logs--obtained almost simultaneously--showed curves with peaks that agreed in position and intensity with what would be expected from the radon cencentrations measured by Tanner. Where gamma-ray logs showed a radiation intensity more than twice background for the rocks above and below the ore zone, the drill hole was inferred to be contaminated by the daughter products of radon.

About 600 gamma-ray logs, taken from 480 drill holes, were evaluated by the writers to learn the relation of the radon to the uranium deposits, its behavior under different conditions of possible removal by use of compressed air or water, and the degree of contamination. The depth of the drill holes ranged from 30 feet to about 400 feet and averaged about 200 feet. The results are presented here to assist mining men and geologists to obtain more reliable gamma-ray data and better evaluations of such data.

The properties on which the work was done are all in sec. 30, T. 13 N., R. 9 W., McKinley County, N. Mex. (fig. 1). Section 30 is accessible by about 1 mile of graded dirt road that leads westward from State Highway 53 about 12 miles north of Grants. The work was done between November 1954 and April 1955 by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

RADON--ITS PROPERTIES AND CHARACTERISTICS

Radon is a gaseous radioelement, a daughter product formed during the natural disintegration of uranium. It emits no significant gamma radiation, so that it is not directly or specifically determined by gamma-ray measurement. It disintegrates, however, to short-lived daughter products that do emit gamma radiation. One of these is bismuth 214, which has a half-life of about 20 minutes. The gamma rays from bismuth 214 are more energetic and more easily detected than the gamma rays from the other uranium daughter products and largely constitute what is registered by hand counters and logging equipment when the radioactivity of uranium ore is measured.

All uraniferous minerals emit some of the radon that is generated within them. Radon is unique among the radioactive daughters of uranium,

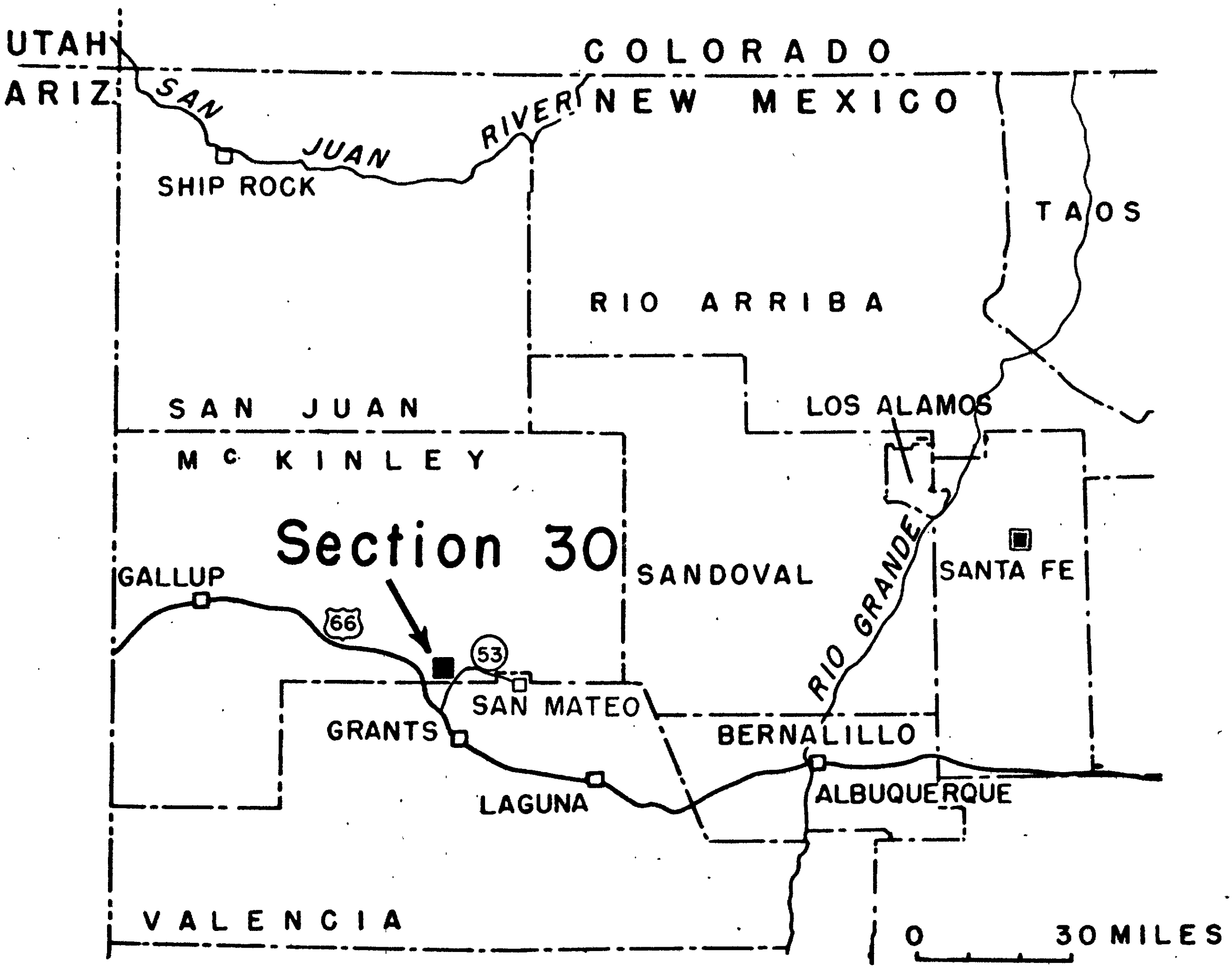


Figure 1.--INDEX MAP OF NORTHWESTERN NEW MEXICO SHOWING LOCATION OF SEC. 30, T.13 N., R.9 W., N.M.P.M.

in that as a gas it can migrate from the parent mineral into air as well as into solution. The more open the lattice of the mineral, the greater will be the loss of radon (Faul, Henry, 1954, p. 139).

Radon is many times heavier than any of the major components of air, but because of its very small percentage per unit volume in the atmosphere of a drill hole it shows no tendency to stratify. Its location within the drill hole is affected by the same factors that cause movement of the air, such as atmospheric pressure and wind.

It is soluble in water and other hydrogenous fluids. The solubility is affected by the amount of surface area exposed to the radon; hence, a flat surface of water absorbs less radon than does a froth. For this reason care was taken in filling the holes with water, as described subsequently, for this study.

GENERAL GEOLOGY

Stratigraphy and structure

The rocks exposed in sec. 30, T. 13 N., R. 9 W. are a conformable sedimentary sequence that includes, from bottom to top, the Entrada sandstone, Todilto limestone, Summerville formation, and what is tentatively called the Bluff sandstone, all of Jurassic age. These rocks dip northward at a low angle, are gently folded, and locally are broken by faults that generally have not more than a few feet of displacement. Most of the surface is covered by a mantle of windblown sand that ranges from a few feet to as much as about 90 feet in thickness. Erosion, prior to the deposition of the sand, locally removed most of the beds above the Todilto limestone and some or all of the Todilto as well.

The uranium deposits in section 30 are in the Todilto limestone, which ranges from a knife edge to about 40 feet in thickness and which averages about 20 feet in thickness. It is a dense medium- to dark-gray fetid limestone that weathers white. It generally is laminated and has thin siltstone layers, along which it parts into slabby beds that range from 1 inch to 6 inches in thickness. It is abundantly fractured and jointed.

The Todilto lies on the Entrada sandstone, which is a reddish-orange fine-grained crossbedded sandstone, about 150 feet in thickness. Although the contact is gradational, it can be located readily within a stratigraphic interval of less than a foot.

Overlying the Todilto limestone is the Summerville formation. It is a soft fine-grained locally argillaceous sandstone that occurs as alternating dark-reddish-brown and pale-orange-yellow beds, each a few feet thick. It has an average thickness of about 150 feet. The contact between the Todilto and Summerville is gradational, and, locally, interfingering of the limestone and sandstone adds to the difficulty of establishing a precise contact. The Bluff sandstone overlies the Summerville and is a pale-yellowish-brown fine- to medium-grained crossbedded sandstone. In the general vicinity of section 30 it is about 150 feet thick. In section 30 the upper part has been removed leaving a maximum thickness of about 100 feet.

Uranium deposits

The uranium deposits in the Todilto limestone are irregular elongate units, as shown on figure 2. They are roughly tabular and consist of concentrations of massive uraninite and the secondary yellow minerals tyuyamunite, metatyuyamunite, uranophane, and some carnotite, along with a gangue of pyrite and some barite and fluorite. Uraninite is distributed along the bedding as irregular seams and disseminated masses. The yellow minerals occur along the joints, fractures, and other open spaces in the limestone.

In section 30 uranium deposits (defined as material having a cutoff of 0.01 percent U_3O_8) range from masses with dimensions of only a few feet to masses as much as 500 feet wide, 1,200 feet long, and 40 feet thick. They probably average about 200 feet in width, 500 feet in length, and 20 feet in thickness. Within the deposits the ore bodies (defined as material with cutoffs of 0.10 percent U_3O_8 and 1 foot in thickness) range from masses with dimensions of only a few feet to masses as much as 250 feet wide, 650 feet long, and 20 feet thick. They average about 100 feet wide, 200 feet long, and 6 feet thick. The ore averages about 0.30 percent U_3O_8. Individual deposits may contain one or more ore bodies.

The deposits in the Todilto limestone occur along anticlinal folds that generally include the lower part of the Summerville formation and, locally, the upper part of the Entrada sandstone. Generally, the deposits have a northerly or easterly trend and locally occur in clusters, where the individual folds are roughly parallel. Individual folds may be only a few feet long or more than 100 feet long; their relief ranges from less than

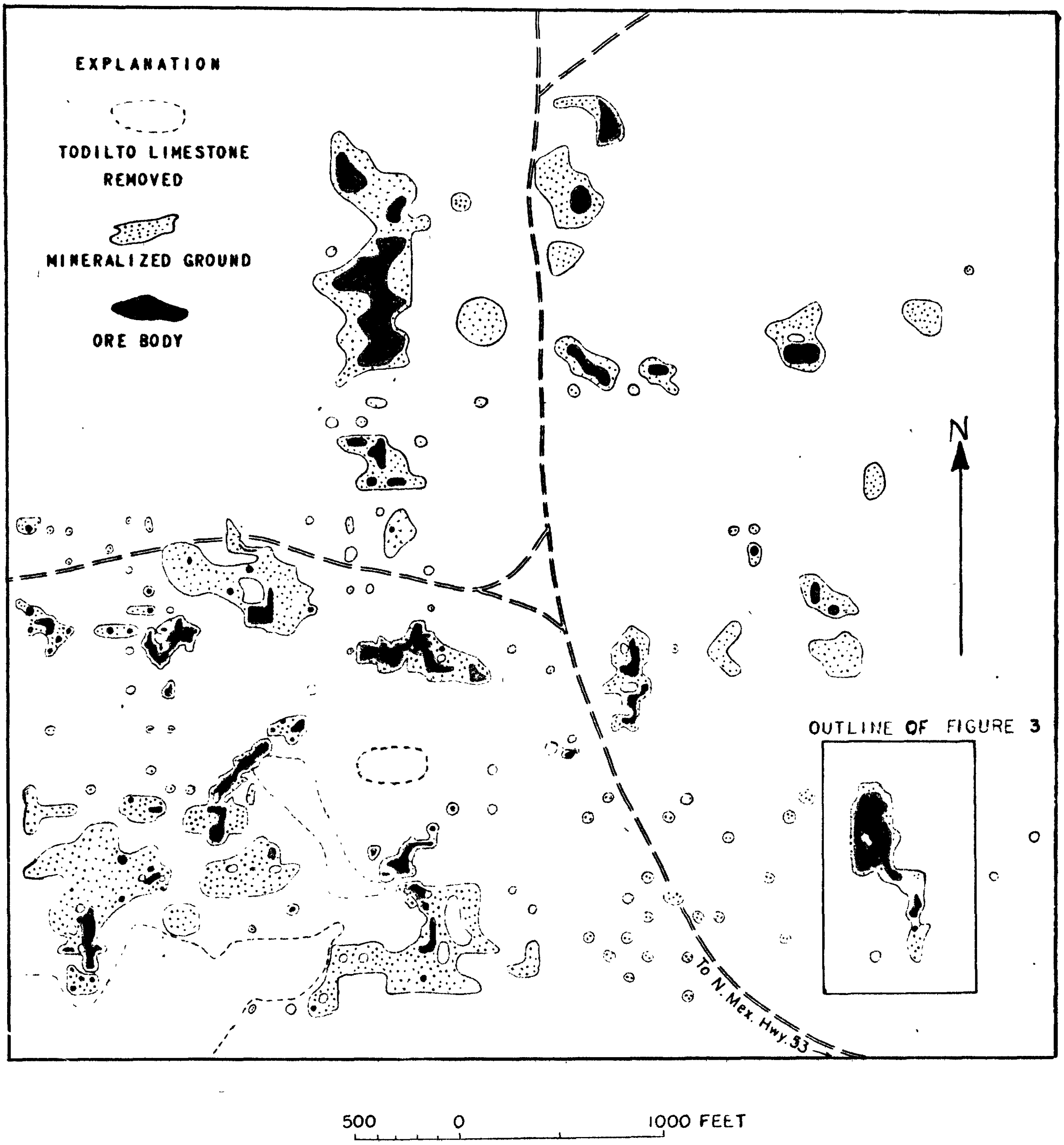


FIGURE 2.--MAP OF SEC. 30, T.13 N., R.9 W., N.M.P.M., SHOWING THE KNOWN URANIUM DEPOSITS AND OUTLINE OF FIGURE 3.

1 foot to about 5 feet. Along the folds the limestone is thicker and more intensely fractured and jointed than away from them, and the thickening has developed mostly in the upper part. The principal joints are parallel to the long axes of the folds. A less well developed set of joints trends roughly normal to the fold axes.

In most deposits the ore is near the base of the Todilto limestone, but in some it occurs in the middle or upper parts and, in a few, it "makes" throughout most of the limestone interval, even extending into the basal part of the overlying Summerville formation. The ore is thicker and higher in grade along the axes of the folds, and it feathers out along the flanks. The ore bodies generally are larger where there are several associated folds.

DRILLING METHODS

It has been the general practice in sec. 30, T. 13 N., R. 9 W., and in the Grants area as a whole, to do exploratory and development drilling in the Todilto limestone with rotary-type drill rigs, using a tricone-type plug bit. The bit size most commonly employed is 4 inches in diameter and the hole is $4\frac{1}{4}$ inches in diameter. To avoid casing the holes, the upper part through the windblown sand is drilled with water, and the lower part, through the lower Summerville and Todilto limestone, is drilled with compressed air. Use of compressed air as the drilling medium is quite effective in section 30 because the rocks in the ore zone lie above the water table.

SAMPLING METHODS

As with drilling, sampling of the Todilto limestone in section 30 in the Grants area as a whole follows a general pattern. Samples of the drill cuttings through the Todilto limestone are collected from each 2-foot run in a cyclone-type sample collector at the hole collar. When a sample shows the presence of uranium minerals or is determined by a conventional gamma counter to have anomalous radioactivity above a specified cutoff, it is packaged for assay. The assay may be determined chemically or radiometrically. Radiometric assays generally are determined by a laboratory scaler.

The drill holes are also probed with a gamma-ray counting instrument, generally of the Geiger-Müller type. Most of these are hand-portable, having a hand-operated reel and a depth indicator. With these instruments the probe (Geiger tube) is lowered and raised through the hole manually and the radioactivity is measured at convenient intervals within the hole, generally every foot, but in some holes every half a foot through mineralized zones. The resultant gamma-ray log of the hole commonly provides supplementary data to what is detected in the drill cuttings and assists in selecting samples of the drill cuttings for assay. Oftentimes, however, the gamma-ray data are used alone to measure the thickness and grade of uraniferous material.

WORK PLAN AND EQUIPMENT USED

Work plan

The area of sec. 30, T. 13 N., R. 9 W., was selected for the experimental work because considerable geologic information was available on the distribution and habits of ore bodies, and because exploration then in progress provided a large number of drill holes and allowed some control over the time intervals between completion of drilling and the logging of drill holes.

The experimental work was planned to determine the distribution and degree of contamination in drill holes, and to test methods of reducing such contamination. To determine the spatial distribution of contaminated drill holes in relation to the distance from deposits and their grade, gamma-ray logs were obtained from 480 drill holes. To determine the degree of contamination as a function of time elapsed after completion of drilling, repeated gamma-ray logs were made in selected drill holes at various time intervals after drilling had been completed.

Two methods of reducing drill-hole contamination caused by the daughter products of radon were tested: (1) blowing out the hole with compressed air for various periods of time, and (2) displacing the air column in the hole with water.

Gamma-ray logging equipment and procedures

The gamma-ray logging equipment used is of the Geiger-Müller type. The equipment is truck mounted and consists of five major components: a 115 volt AC power plant, a reel unit to lower and raise the probe in a drill hole, a 7/8-inch (outside diameter) waterproof brass probe containing a $7\frac{1}{4}$ inch long Geiger-Müller tube, a ratemeter-amplifier that amplifies and indicates the number of electrical impulses received through the cable from the detector tube, and a strip-chart recorder which graphically plots the number of impulses received by the ratemeter versus probe depth in the hole.

The equipment is operated by one man. Before and after logging each hole the operator checks the equipment with calibrated radioactive standards to maintain proper performance and response. The probe is lowered to the bottom of the drill hole and the hole is logged as the probe is withdrawn at a rate of 5 feet per minute. The variation in the quantity of gamma-radiation incident on the probe is recorded by the strip-chart recorder.

Before this study the logging equipment was calibrated to determine the thickness and grade of radioactive layers of uraniferous material. Simulated ore bodies of predetermined grade and thickness were constructed in 4-foot diameter culverts having in the center a 2-inch diameter 1/64-inch-thick aluminum casing. Data obtained from these simulated ore bodies were used to construct graphs showing the relationship of grade, thickness, and count rate. The graphs are used to interpret, in terms of percent U_3O_8 and thickness, the strip charts obtained from exploratory drill holes.

Water and air equipment

A 500-gallon water truck and a tractor-mounted air compressor with a rated capacity of 105 cubic feet per minute were made available to the project by the U. S. Atomic Energy Commission. The compressor was set to operate at 60 pounds air pressure. Installed on the front of the tractor was a reel with 500 feet of 3/4-inch air hose that could be manually lowered or raised in a drill hole. Secured to the lower end of the hose was a 10-foot section of $\frac{1}{2}$-inch (inside diameter) steel pipe, which served to guide the hose into the hole and prevented the end of the hose from whipping when air was forced through it. At the upper end of the hose a coupling was installed that matched either the fitting on the air receiver of the compressor or the fitting on the tank of the water truck, permitting prompt use of the reel-and-hose assembly for either air or water. A fitting was also installed at the top of the water tank so it could be attached to the compressor to increase the rate of discharge of water from the tank to the drill hole.

Water was added to the holes by lowering the hose to the bottom of the hole before releasing the water from the tank. This method prevented material from being washed down the sides of the hole and helped reduce turbulence and frothing, which affect the solubility of radon in water. After sufficient water was added to cover the ore zone, the hose was withdrawn and the hole was gamma-ray logged.

IDENTIFICATION OF "SALTED" HOLES

In some holes the cuttings from high-grade layers have a tendency to stick to the walls of the hole above the ore zone, forming what is generally referred to as a "salted" hole. A "salted" hole gives a gamma-ray log curve that tapers off rather abruptly immediately above a high-grade ore layer or shows a rather pronounced anomaly above the ore zone where the mineralized cuttings collect next to a rock projection or damp zone in the hole. No salted holes were recognized in section 30, and the chances of confusing them with radon-contaminated holes is considered unlikely.

RESULTS

Relations of contamination to grade and to elapsed time after drilling

Evaluation of gamma-ray logs from the 480 drill holes revealed that 102, or 21 percent, of the holes were contaminated. These data are listed in table 1, which shows a higher proportion of contaminated holes in the higher grade classes and an increasing number of contaminated holes as the time between drilling and logging increases. If all holes had been logged more than 24 hours after drilling, it is likely the number of contaminated holes would have been considerably greater than 102.

Chemical assays and laboratory radiometric assays of the drill cuttings were available for comparison with the inhole gamma-ray data for many holes. Chemical data were used in classifying holes as to grade (table 1) when available and when sample recovery was considered reliable. Laboratory radiometric data showed good correlation with the chemical assays and were used when chemical data were not available. Inhole gamma-ray data, although corrected and reduced by the recognizable amounts of radon contamination, generally showed thickness-times-grade figures about 50 percent higher than the chemical figures. When no chemical or laboratory radiometric data were available or were considered unreliable, the inhole gamma-ray data were used. The equivalent U_3O_8 cutoffs in table 1 refer only to inhole gamma-ray data. The higher cutoffs for these data were selected to be roughly comparable to the cutoffs used for the chemical and laboratory radiometric data.

Table 1.--A listing of the numbers of holes logged and the number and percentage found to be contaminated, relative to grade and the elapsed time of logging after drilling.

Elapsed time after drilling	Number of holes logged, and number and percent contaminated									Total elapsed time brackets		
	Grade cutoffs											
	<0.1 pct. U_3O_8 or <0.02 pct. eU_3O_8 1/			0.01 to 0.099 pct. U_3O_8 or 0.02 to 0.149 pct. eU_3O_8 1/			0.1 pct. or more U_3O_8 or 0.15 pct. or more eU_3O_8 1/					
	Logged	Contaminated		Logged	Contaminated		Logged	Contaminated		Logged	Contaminated	
	no.	no.	pct.	no.	no.	pct.	no.	no.	pct.	no.	no.	pct.
<1 hour	68	1	1	41	2	5	71	3	4	180	6	3
1-24 hours	55	2	4	42	11	26	40	10	25	137	23	17
>24 hours	68	9	13	43	19	44	52	45	87	163	73	45
Totals and averages of totals by grade brackets	191	12	6	126	32	25	163	58	36	480	102	21

1/ Note: eU_3O_8 cutoffs refer only to inhole gamma-ray data

In addition to the influence of grade and time on contamination in drill holes, there is also a spatial relation to ore deposits. Most complete logging coverage was obtained for the deposit shown on figure 3. Of the holes shown within the mineralized area, 75 percent were contaminated. Nearly all of these contaminated holes were logged several days after they were drilled, whereas all but one of the uncontaminated holes were logged within an hour of drilling. Outside of the mineralized area only seven holes showed contamination. One of these was logged within an hour after it was drilled; the other six were logged two weeks or more after drilling. It seems noteworthy that none of these seven contaminated holes is farther than about 50 feet from known mineralized ground.

Probe-contaminating holes are shown on figure 3. This contamination was caused by the deposition on the probe of solid short-lived gamma-emitting daughter products of the radon. It resulted in a count rate above normal background when the probe was removed from the drill hole and an abnormally high count rate when the probe was checked against calibrated radioactive standards. In general, these holes showed the highest radon concentration, and all are in or near the largest ore body (fig. 3).

Degree of contamination

The degree of contamination of the drill holes ranged from barely detectable amounts on the logs to amounts that gave count rates as high as those given off by ore-grade material. Figure 4, log 1, illustrates a contaminated hole. This log shows a count range from about 6,500 counts per minute in the ore zone to 500 counts per minute at the hole collar.

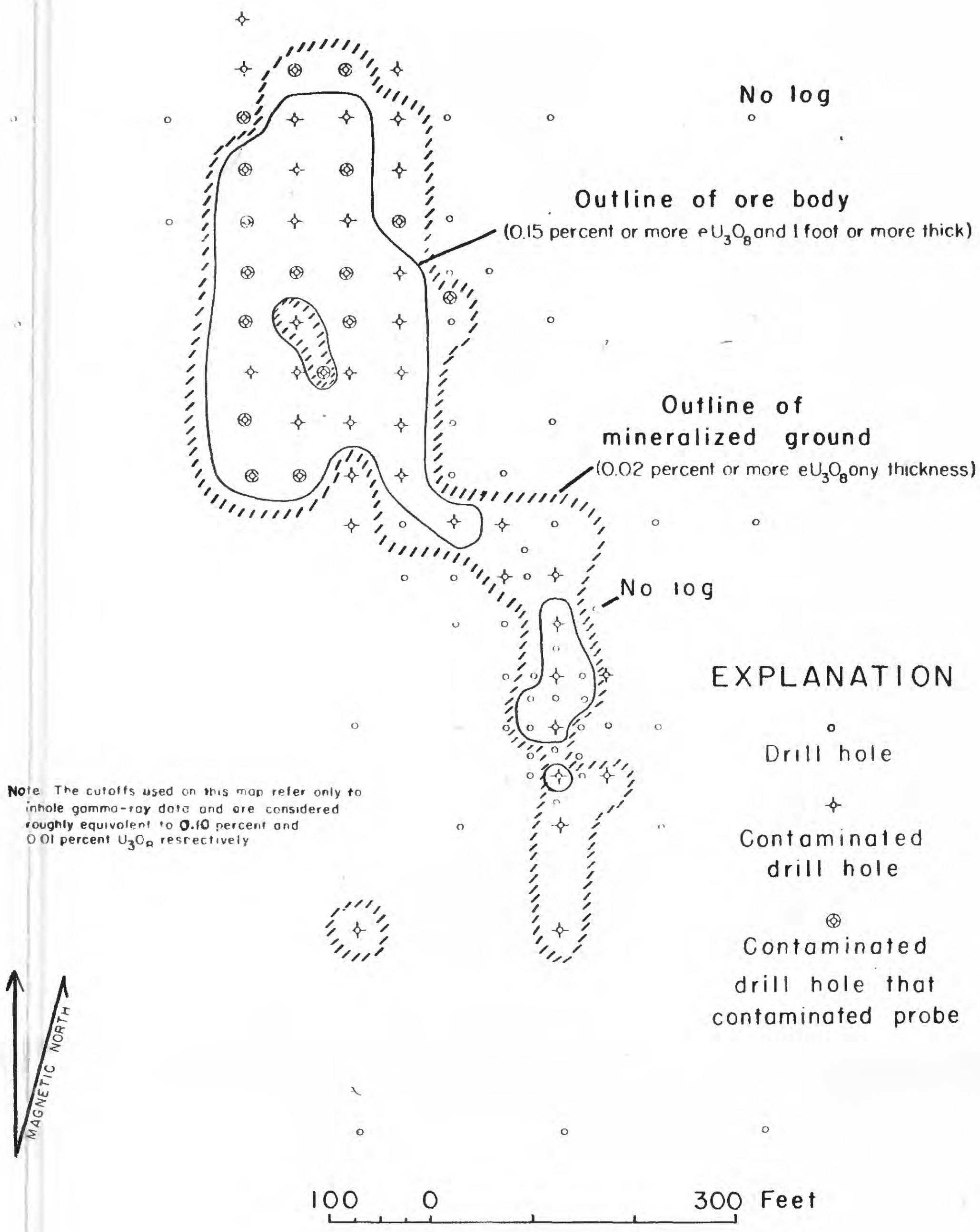
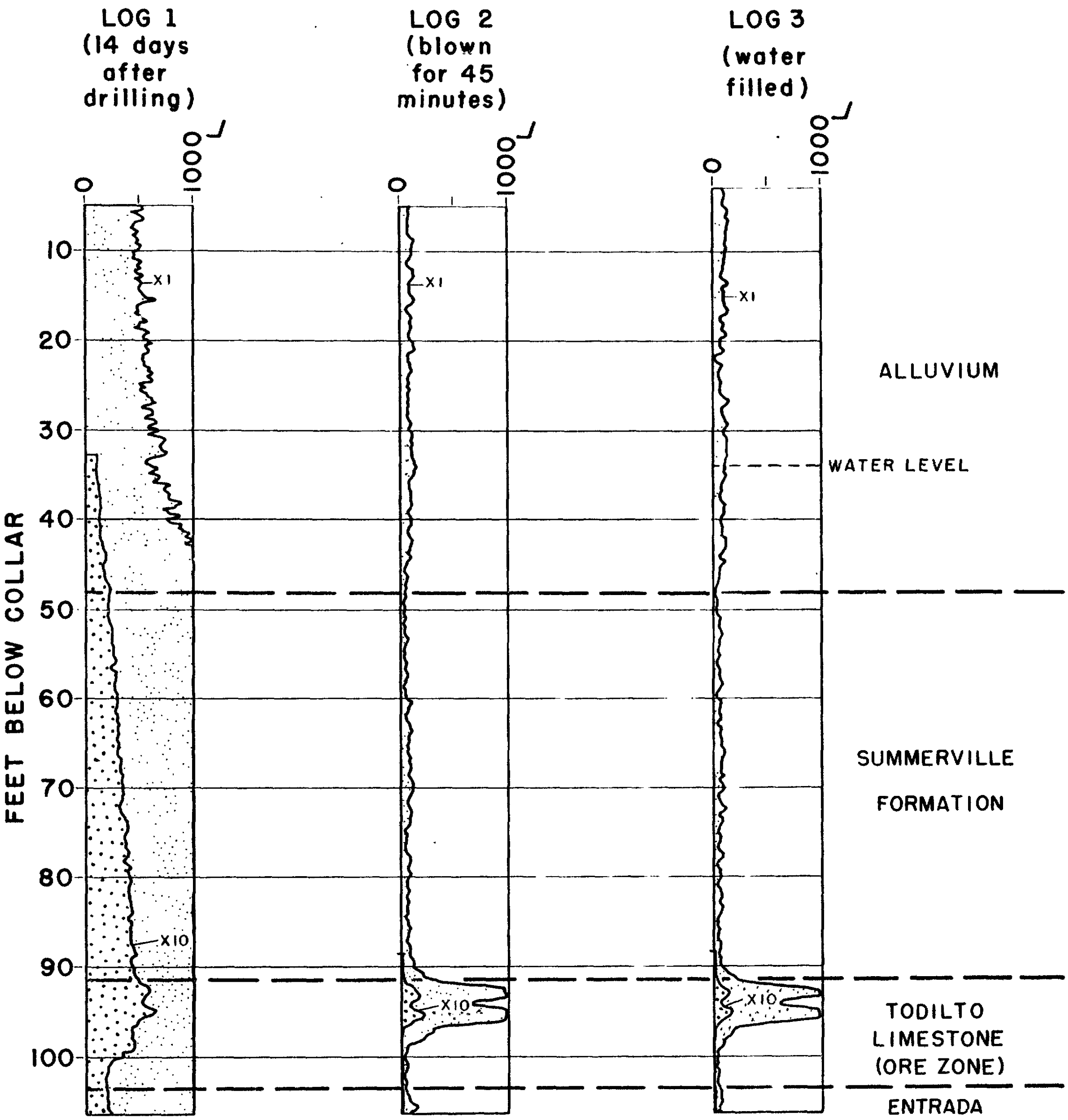


Figure 3.--MAP SHOWING THE RELATIONS OF RADON-CONTAMINATED DRILL HOLES TO A URANIUM DEPOSIT



⅃ Counts per minute.
Curve X1 read direct; curve X10 multiply reading by 10

Figure 4.--THREE GAMMA-RAY LOGS OF HOLE J-9.5 SHOWING EXTREME RADON CONTAMINATION, AND EFFECTS OF BLOWING OUT HOLE WITH AIR AND FILLING HOLE WITH WATER.

Between the depths of 75 and 100 feet below the collar, or through a thickness of 25 feet, the count rate converted to equivalent uranium is in the grade range from 0.1 to 0.2 percent. Log 2, taken after the hole was blown out with compressed air, shows a peak of about 2,000 counts per minute for a thickness of about 2 feet. This is about equivalent to 0.05 percent uranium.

Figure 5 shows examples of an extremely contaminated hole. Log 3, for example, shows the lowest count, about 5,000 counts per minute, immediately above the ore zone. It increases upward in the hole through the barren Summerville formation and alluvium to about 10,000 counts per minute at the hole collar. Converted to equivalent uranium this log would indicate more than 100 feet of material with a grade that ranged from several percent in the ore zone to about 0.3 percent at the hole collar. Actually, this hole contained about 7 feet of ore that averaged 1.0 percent eU_3O_8, as interpreted from gamma-ray log 2. Chemical assay of the cuttings showed 10 feet of ore that averaged 0.55 percent U_3O_8.

Eliminating contamination

After the initial logs were taken, the more highly contaminated holes were blown out with compressed air for periods that ranged from 15 minutes to 2 hours, to find if the holes could be decontaminated and, if so, how long it would take. In general, most holes could be decontaminated by blowing them out for about 30 minutes; a few extremely contaminated holes, however, required 1 to 2 hours.

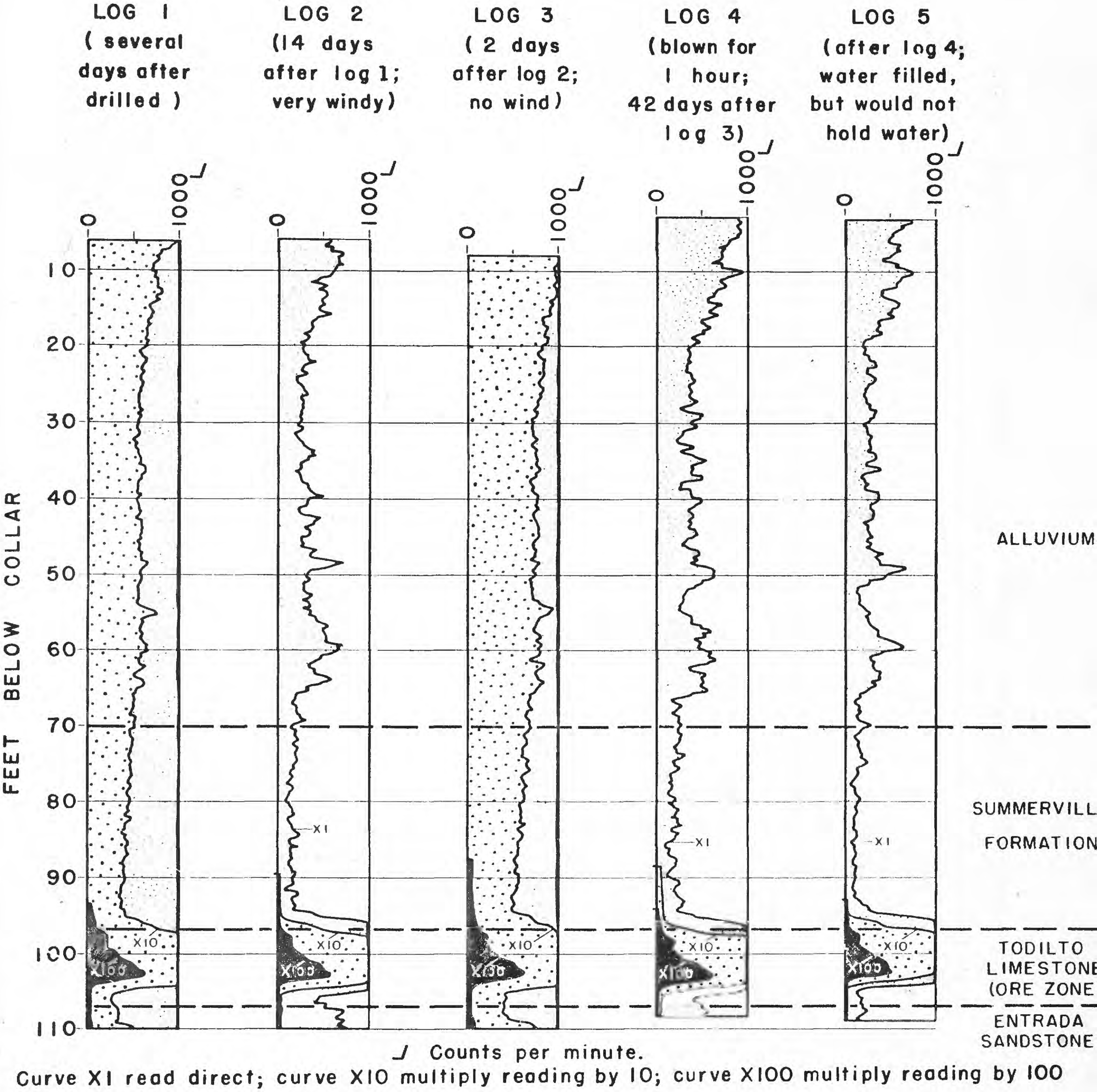


Figure 5.--FIVE GAMMA-RAY LOGS OF HOLE J-10 SHOWING EFFECTS OF A WINDY DAY ON RADON CONTAMINATION, AND OF BLOWING OUT HOLE WITH AIR AND FILLING HOLE WITH WATER.

Log 1 of figure 6 shows moderate radon contamination in a hole logged 18 hours after it was drilled. After this log was taken the hole was blown out in four successive 15-minute intervals and logs 2, 3, 4, and 5 were taken immediately after each of these intervals. For the rocks above and below the Todilto limestone the count rate on log 5 is near the normal background. These logs were taken to illustrate the response of the contamination to the period of blowing. Actually one continuous 30-minute period of blowing probably would have cleared the hole, as the contamination may have built up between logging setups. After blowing out the hole it required about 5 to 10 minutes to remove the equipment and get the logging instrument in position to start logging. The logging time was about 30 minutes for each log. The entire operation took $3\frac{1}{4}$ hours.

A few holes were not readily decontaminated by blowing. Log 2 of figure 7 shows a contaminated hole 18 days after it was drilled; log 1 was taken immediately after it was drilled. Four hours after log 2 was taken the hole was blown out for 20 minutes and then relogged (log 3). On this log much greater contamination is indicated. Log 4 shows some decontamination after the hole was blown out for an additional 45 minutes, but the contamination still shows at least 1,000 counts per minute above the normal background. An additional 55-minute period of blowing reduced the contamination to near background above the ore zone, but a significant amount still remained in the hole below the ore zone.

Log 3 of figure 8 is another example of contamination that was not reduced materially after an hour of blowing. In the upper part of the hole the count was actually higher. Log 4 of figure 8 illustrates how

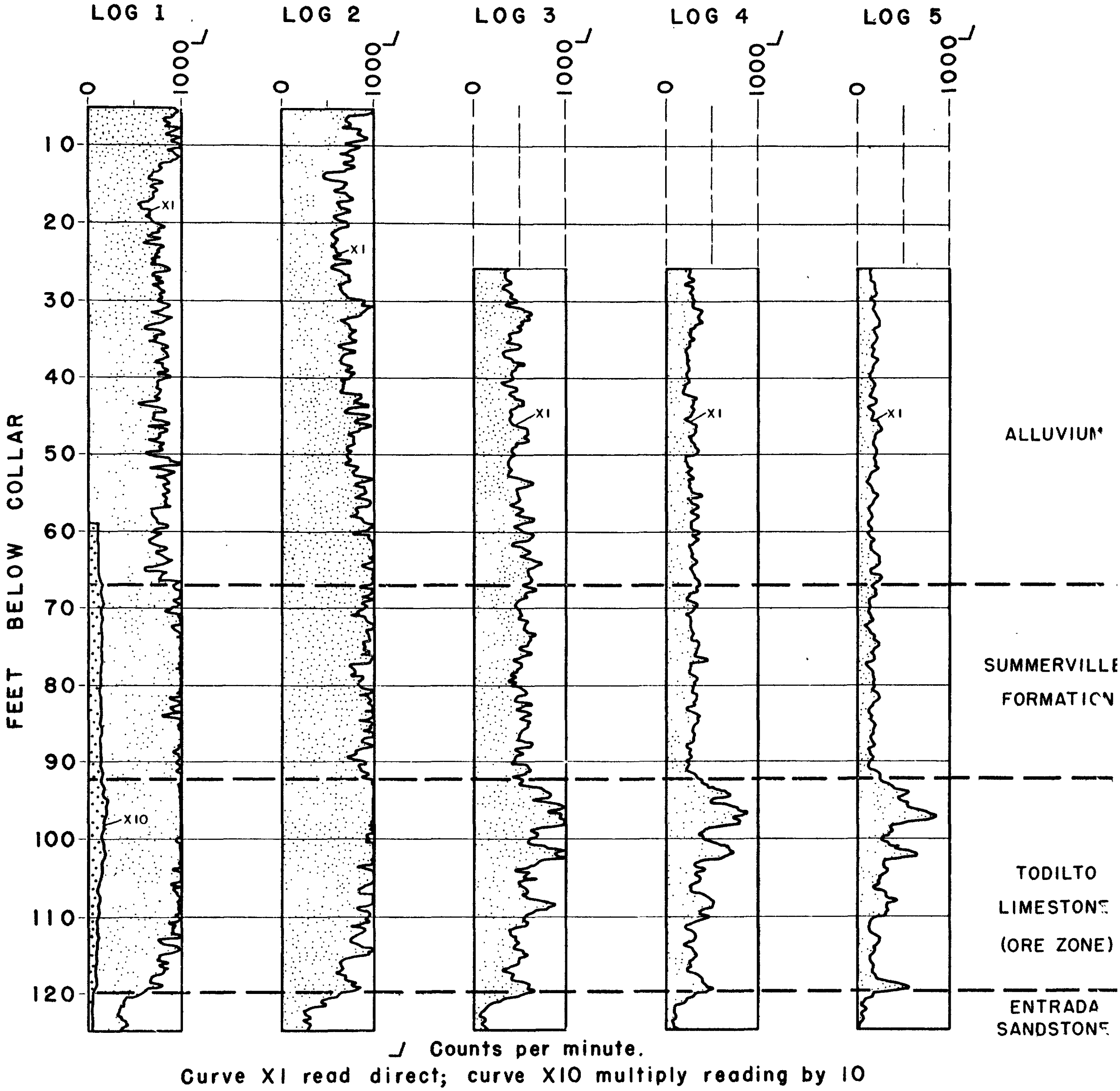


Figure 6.-- FIVE GAMMA-RAY LOGS OF HOLE H.5-9.75 SHOWING RADON CONTAMINATION AND ITS PROGRESSIVE ELIMINATION BY BLOWING OUT HOLE WITH AIR IN FOUR SUCCESSIVE 15-MINUTE INTERVALS. LOG I TAKEN 18 HOURS AFTER HOLE WAS DRILLED.

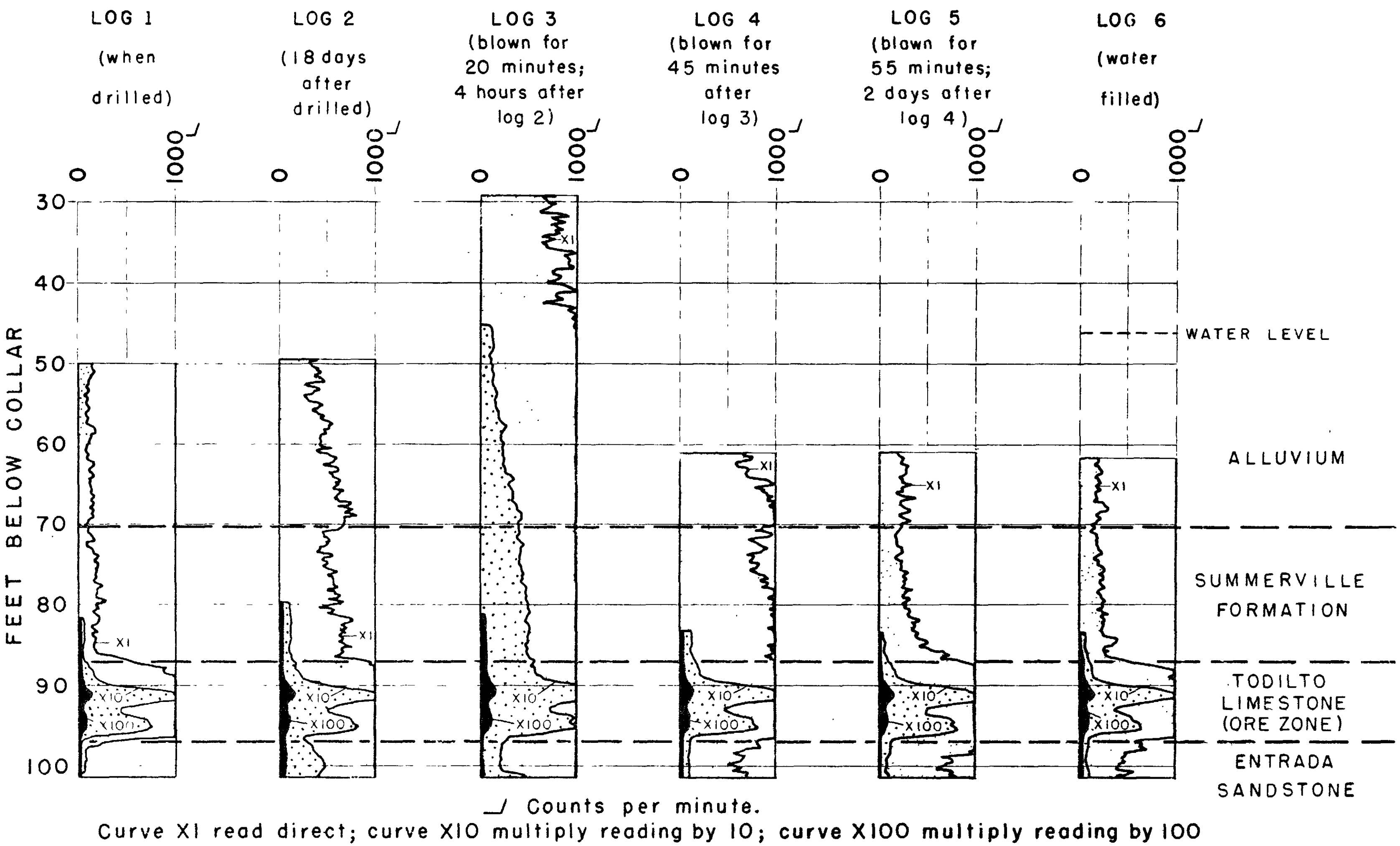


Figure 7.-- SIX GAMMA-RAY LOGS OF HOLE J5-8.5 SHOWING RADON-FREE HOLE WHEN DRILLED, RADON CONTAMINATION AFTER 18 DAYS, AND EFFECTS OF BLOWING OUT HOLE WITH AIR AND FILLING HOLE WITH WATER.

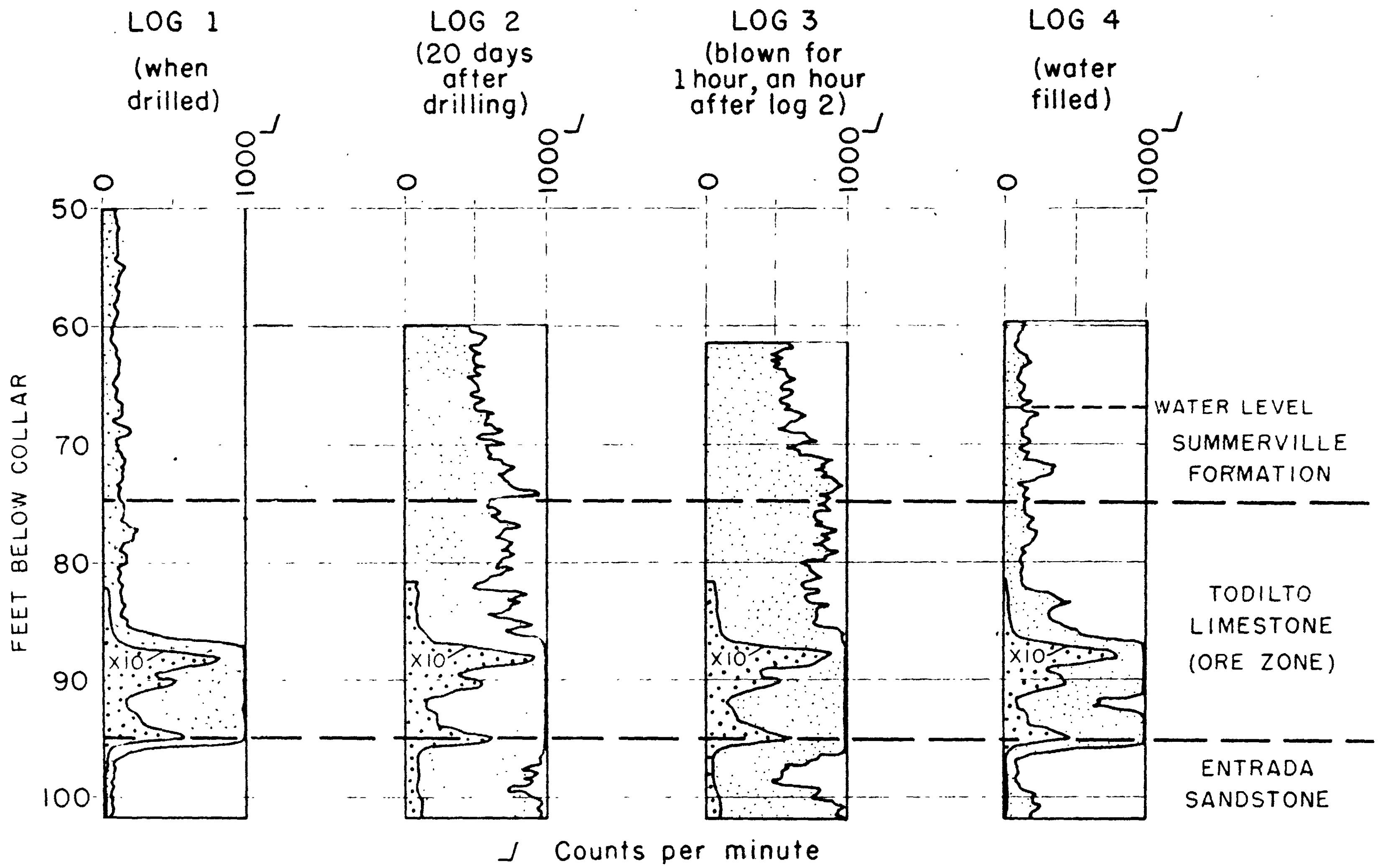


Figure 8.--FOUR GAMMA-RAY LOGS OF HOLE J5-8 SHOWING RADON-FREE HOLE WHEN DRILLED, RADON CONTAMINATION AFTER 3-WEEK PERIOD, AND EFFECTS OF BLOWING OUT HOLE WITH AIR AND BY FILLING HOLE WITH WATER.

water reduces contamination that is not materially affected by blowing. Immediately after log 3 was taken the hole was filled with water and log 4 was taken. Log 4 shows the contamination reduced to near background, as shown on log 1.

Effects of water on count rate and apparent thickness of material

The data presented below cannot be directly compared with data from other areas because of varying physical conditions. For example, variations in the distance between the probe and hole wall and, equivalent in effect, variations in hole diameter within drill holes or among a group of drill holes will alter the results. Drilling fluid, of a density different from water, remaining in the hole will also affect the results.

Although filling a drill hole with water tended to decontaminate it, it also reduced the count rate and the indicated thickness of the individual mineralized layers to less than that obtained in air. Log 6 of figure 7 and log 4 of figure 8 show some reduction below the peak count rates of the respective peaks shown on log 1. Some contamination remaining in these holes before and after they were filled with water, however, hides the general relation somewhat. Log 2 of figure 4 shows a hole that is uncontaminated. Log 3 shows it after it was filled with water. The peak counts in the ore zone have been reduced, and the thickness of the anomalies has been reduced slightly.

Many holes would not hold water throughout the logging. Even so, the contamination was generally reduced, and the count rate as well as the indicated thickness of the individual mineralized layers fell to less than precontamination levels in some holes. Log 5 of figure 5 is an example.

Although the small scale of the illustrations makes it difficult to compare the thickness relations, it can readily be seen that the peak count in the ore zone as well as the background count above and below the ore zone have been reduced.

The use of water as a decontaminant and as a drilling medium raises the question: what is the net effect of water on the count rate and the apparent thickness of the mineralized layers?

To make a comparison, 13 holes were selected that had been logged both when they were air filled and when they were water filled. The rocks above and below the ore zone did not show a count that was more than twice their normal background of about 100 counts per minute, either before or after the holes were blown out with compressed air, thus providing reasonable assurance that none of the holes had any significant amount of contamination when the logs were taken. Sample thicknesses and peak counts were determined for each anomaly showing 1,000 counts per minute or more, roughly equivalent to 0.02 percent or more U_3O_8. Under the present system of interpreting gamma-ray logs in terms of the thickness and grade (eU_3O_8) of a layer, the thickness of a layer is determined to be the width of the anomaly at two-thirds of the peak deflection of the anomaly. Counts per minute have been retained for statistical purposes to avoid some loss of accuracy that would result from converting the counts to equivalent U_3O_8, especially in the high-grade ranges.

Table 2 compares the apparent thickness and grade relations of water-filled versus air-filled holes. For individual holes, apparent thickness differences between water and air of about 5 percent or less are probably not significant. For several holes the totals are more significant.

Table 2.--A comparison of sample thickness and grade relations, in counts per minute, of 13 air-filled versus water-filled holes, as interpreted from gamma-ray logs.

Drill-hole number	Air-filled holes			Water-filled holes			Percentage differences of water-filled versus air-filled holes		
	Sample thickness (feet)	Sample thickness (feet) times peak counts/min.	Weighted arithmetic mean counts/min.	Sample thickness (feet)	Sample thickness (feet) times peak counts/min.	Weighted arithmetic mean counts/min.	Sample thickness (feet)	Sample thickness (feet) times peak counts/min.	Weighted arithmetic mean counts/min.
J.5-8	7.7	26,500	3,700	6.0	23,500	3,900	-22	-18	+5
J.5-9	8.3	101,500	12,200	7.1	86,000	12,100	-14	-15	-1
J-9.5	2.0	4,000	2,000	1.8	3,000	1,700	-10	-25	-15
J.5-9.5	7.0	146,000	20,800	6.1	104,500	17,100	-13	-28	-18
J.5-10	6.6	185,000	28,000	5.9	157,500	26,700	-11	-15	-5
J-10.5	5.4	96,500	17,900	4.5	76,000	16,900	-17	-21	-6
J.5-10.5	5.9	121,500	20,600	7.0	100,500	14,400	+19	-17	-30
J.5-11	8.6	91,000	10,600	3.5	65,000	18,600	-60	-29	+75
S.5-21.75	3.3	9,500	2,900	3.4	8,500	2,500	+3	-11	-14
S.75-18.75	16.6	261,500	15,800	12.2	200,000	16,400	-27	-24	+4
T-19	11.9	205,500	17,300	10.6	149,500	14,100	-6	-27	-18
T-19.25	8.2	145,000	17,700	8.4	114,000	13,600	+2	-21	-23
T-20.25	4.2	71,500	17,000	4.8	56,500	11,800	+14	-21	-31
Totals and averages of totals	95.7	1,467,000	15,300	81.3	1,144,500	14,100	-15	-22	-8

The total apparent sample thickness for the 13 holes shows a difference of about 14 feet between air-filled and water-filled holes, which is about 15 percent. Of the 13 holes, 9 show a reduced sample thickness for water versus air. Of the 4 that show an inverse relationship, only 2 show a difference great enough to be significant. These two, holes J.5-10.5 and T-20.25, both produced rather complex log curves, and it is probable that these inverse thickness relations reflect a difference in interpretation of the respective logs.

The thickness-times-peak figures of table 2 which actually are measures of the total material in the sample, afford a significant comparison of gamma-ray data taken in water- and air-filled holes. On table 2 the figures represent the total for all samples for each hole that make the specified cutoff of 1,000 counts per minute. The table shows that the figure for each of the 13 holes is less in water than in air, and the differences range from 11 to 29 percent. The average difference for the 13 holes is 22 percent. From these figures it can be expected that gamma-ray logs taken in water-filled holes of about 4 inches in diameter, and using a 7/8-inch logging probe, will produce readings that will range from about 10 to 30 percent below the readings taken in air and will average about 20 percent less.

In order to show the counterpart of the sample thickness relations, the weighted arithmetic mean counts per minute (grade of the hole in counts per minute) are listed in table 2 for each drill hole. Of the 13 holes logged, 10 show a reduced mean count in water. The other 3 show an increased count. Those that show an increased mean count in water also show a marked reduction in apparent sample thickness. The average weighted arithmetic mean counts per minute for the 13 holes in water is 8 percent less than in air. The table shows that the rather wide variations in the percentage differences between individual holes is not significant, as they are compensated for by the sample thicknesses within each hole. Therefore, the figure of sample thickness times peak counts per minute is the most significant.

CONCLUSIONS

Geologic conditions favorable for contamination by radon and its daughter products in drill holes are: proximity to uranium deposits, and fractured or highly permeable rocks above the water table. Contamination should be suspected where:

1. Gamma-ray logs indicate higher grade (equivalent U_3O_8) and greater thickness of a radioactive layer than is indicated by chemical and radiometric analyses of drill cuttings or core samples.
2. Gamma-ray logs show a radiation intensity significantly higher than background for the barren rocks above and below the ore zone.
3. Gamma-ray logs taken at different times from the same drill hole show rather wide variation in radiation intensity.
4. The probe of the logging equipment, when removed from the drill hole, gives an abnormally high counting rate, which decreases to normal after 2 to 3 hours.

Radon has contaminated drill holes in sec. 30, T. 13 N., R. 9 W., because of the fractured nature of the Todilto limestone, which provides passageways for the radon to migrate in air currents away from the parent-mineral faces to the drill holes, and because the ore zone lies above the water table.

Most drill holes can be decontaminated by blowing them out with compressed air for about 30 minutes. Some of the more highly contaminated holes require blowing for an hour or more. They might be decontaminated more effectively by evacuating the air. Filling holes with water also appears to be an effective means of decontaminating them, although more tests should be made to find out if consistent results can be expected.

On the basis of a comparison of the logs taken in air and water, respectively, from 13 selected holes, it was found that water reduced the total thickness-times-grade figures by about 20 percent. This effect, however, cannot be directly compared with similar effects in other areas because of varying physical conditions.

To avoid most contamination effects holes should be logged immediately after they are drilled.

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