HYDROLOGY OF THE MELTON VALLEY RADIOACTIVE-WASTE BURIAL GROUNDS AT OAK RIDGE NATIONAL LABORATORY, TENNESSEE

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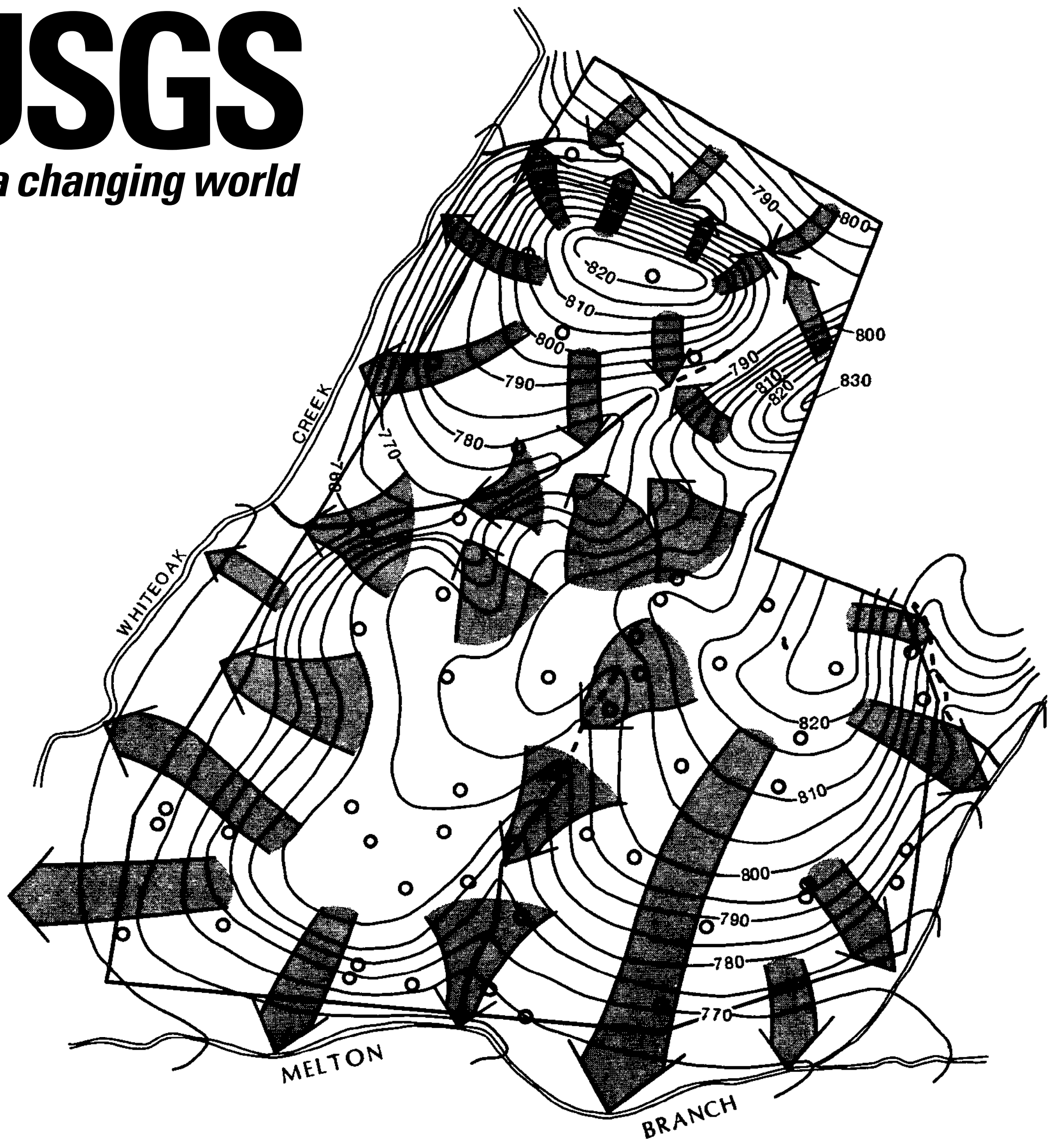

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be made, in 5 wells the hydraulic conductivity of the bottom 10 feet is greater than that of the 50-foot interval. Decreasing hydraulic conductivity with increasing depth was also demonstrated indirectly during the 1950's by measuring the rate of water acceptance in bedrock wells in the ILW area and and in burial ground 5. In these tests measurements were made in 20-foot depth increments and similar occasional reversals to the overall trend were found (deLaguna and others, 1958, p. 107; Cowser and others, 1961, p. 15). The relationship of decreasing hydraulic conductivity with increasing depth is significant to bedrock recharge and discharge.

Values for the 190- to 200-foot interval, with the exception of that for the central cluster, are quite small. The fact that water does recharge wells at this depth, however, indicates that the lower boundary of the aquifer occurs at some greater depth. The variability in recharge rates and K values of that interval implies that the depth to that boundary is variable or, in other words, that boundary is a surface of irregular shape.

Geophysical Logging

Geophysical logs were made intermittenly between 1976 and 1983. The logs include caliper, gamma, gamma-gamma, neutron, acoustic velocity, temperature, televiewer, single-point resistivity, and spectral, but not all of these logs were made of all of the wells. Generally, the logs found most useful to this investigation were the caliper, gamma, neutron, televiewer, and spectral.

Two important applications of logging for investigating ground-water flow in Melton Valley were in establishing the existence and prevalence of secondary features that permit flow through the bedrock, and in identifying certain radionuclides that have been transported by water into bedrock.

The initial logging of the five bedrock wells in burial ground 5 showed occasional zones suggestive of secondary openings in each of the bores. They were also found in nearly all of the piezometers. Logging of the few existing bedrock wells in burial ground 6 also showed their presence there. Additional logging of wells near ILW pits 2, 3, and 4 and of some of the wells used in proving the hydrofracture method of waste-disposal also revealed similar features. Visible secondary openings shown in logs are not numerous in any one well bore, but they are prevalent throughout the Melton Valley area. The more common type opening is an enlargement of the well bore indicative of rock weakened by fracturing, folding, or faulting, and easily torn loose as the drill intercepts that stratum. These zones range from a few inches to as much as a few feet in thickness. Some, but probably not all, represent pathways through which water flows. Small partings and fractures that permit the flow of water also are present, but the logs lack sensitivity to show their detail. The presence of these smaller openings, however, is revealed by completion of some of the piezometers in what the caliper and televiewer logs suggest is "solid rock". That these zones have secondary permeability is evidenced by the response of water levels to slug tests and the normal rise and recession of the water surface within the completed well. The less common type of opening is a solution channel in the limestone. The largest solution cavities found by logging of these wells probably do not exceed one-half foot in height; most are smaller.

The most frequent location of secondary openings, whether due to fractures or other features of structural origin or to the development of solution channels, is within the upper 100 feet of well bore, but they also occur at substantial depths. For example, the caliper log of well 521, cored in the Rutledge Limestone to a depth of 100 feet, shows increases in borehole diameter characteristic of solution openings at 39.5, 40.4, 49.8, 51.0 and 67.2 feet. The bottom 17 feet could not be logged, owing to material that had sloughed in, but might also have intercepted additional openings. The caliper log of well 400-S, cored about 1000 feet southeast of burial ground 5 to a depth of 1020 feet, shows similar features at depths of 53 feet, in the Nolichucky Shale, and, 281, 444, and 893 feet, in the Maryville Limestone.

One of the more significant findings from the logs of the older wells is the existence of an integrated solution channel network near ILW pits 2 and 4. The caliper and televiewer logs show that wells 100, 101, and 118 (fig. 9), located in the Maryville Limestone within 200 feet of each other, intercepted solution cavities in the bedrock; the gamma logs of these wells show some of the highest counting rates of wells logged at ORNL. It appears that this network provided an avenue through the bedrock for a disproportionately large amount of fluid flow from these liquid-waste disposal facilities. The presence of an integrated cavity system such as this is not predictable from surficial features, and can only be established by logging wells that intercept these features by chance. Although a similar system was not found in any of the wells of burial grounds 5 or 6, the potential for its presence there exists by virtue of these sites being underlain by beds of the same formation.

The results of spectral logging of wells in burial grounds 5 and 6 are given in table 8. In these two areas cesium-137 was the only man-made radioisotope found in the wells. This radionuclide was found behind the casing in the regolith, near the regolith/bedrock contact, and at or near the bottom of the deeper wells in bedrock.

The initial finding of cesium-137 in well 176 (burial ground 5) at a substantial depth below the top of bedrock caused concern that this radionuclide is being transported through the rock itself. More recent work suggests, although does not provide proof, that the radionuclide is transported sorbed to very-fine grained particulate matter through secondary openings in the regolith or upper bedrock. Its most likely point of entry into the bedrock wells is immediately below the casing, which typically terminates at the top of bedrock.

In view of what then appeared to be a significant possibility of encountering radionuclides in bedrock, the piezometers at burial ground 5 were constructed in stages to limit potential for the down-hole transfer of radionuclides as drilling progressed. Significantly, logging did not reveal anomalously high levels of gamma activity in any of these wells.

Table 8.--*Results of spectral logging of wells in burial grounds 5 and 6*

[Position: B, Behind casing; O, Open bore]

Well	Date	Well depth (feet)	Depth of spectra (feet below land surface)	^{137}Cs identified (indicated by X)	Position
Burial Ground 5					
174	02-17-76	125	40.4	X	O
			116.9		
175	02-17-76	148	42.4		
176	02-17-76	143	39.8		
			63.3		
			140.1	X	O
			140.5	X	O
			143.8		
	06-05-78		128.4		
			136.4		
			137.4		
			138.4	X	O
			139.4	X	O
			140.2	X	O
			142.0	X	O
	05-18-82		0.7		
			16.0		
			24.9		
			36.0		
			37.2		
			113.8		
			125.6		
			138.4		
			139.5	X	O
			140.6	X	O
			144.2 (in mud)		
177	02-17-76	149	72.5		
			97.4		
			142.8		
178	02-18-76	153	43.2		
			151.7	X	O
419	02-18-76	17	9.5	X	B
			12.2	X	B
458a	06-06-78	150	105.8		
			123.5		
			141.2		
459a	06-06-78	150	8.1		
			70.8		
460	06-06-78	100	19.2		
			51.8		
			90.6		
Burial Ground 6					
107	05-19-82	122	15.0	X	B
109	02-20-76	126	50.6		
			121.1		
110	02-20-76	125	28.7	X	B
279	02-20-76	10	4.8		

It is important to note that the logging equipment used is able to identify only those gamma emitters with sufficient energy to appear above the Compton continuum. Alpha, beta, and low-energy gamma emitters appearing below that continuum, if present in the well, would not be detected.

Radiochemical Analyses of Ground Water

Water samples were taken from 17 wells in the piezometer arrays in August 1983 for analyses of many stable ions and selected radionuclides. Three wells (461, 462, and 463) were not sampled at that time because the casings had recently been extended to a height of 20 feet above land surface which made them inaccessible to pumping, and one well (465), after evacuating the water stored in the casing, was found to recharge so slowly that a valid sample could not be obtained. The analyses of the radioactive constituents are considered here because these substances provide information about ground-water flow, particularly at depth; the analyses of the stable ions are considered later under the heading, Ground-Water Quality.

Analyses were made for the following radiochemical parameters: total alpha, gross beta, tritium, strontium-90, cobalt-60, cesium-137, and antimony-125. Each of these radionuclides and types of radioactivity had been found in samples of well water and seepages analyzed during previous studies of this site.

Tritium (^{3}H) is a radioactive isotope of hydrogen that is produced naturally in small quantity in the atmosphere. It is usually found in very small concentrations in the ground and surface waters of the Earth as a result of recharge (precipitation) entering these systems. Tritium also is widely produced in the nuclear industry, and waste containing large amounts of this radionuclide have been interred in burial ground 5. Strontium-90, cobalt-60, cesium-137, and antimony-125 are associated with nuclear research and development activities. Unlike tritium, these isotopes do not occur naturally in water and, when found in that medium, are uniquely associated with waste-disposal activity.

The analytical results are given in table 9 in four groups, with each successive group representing a greater depth interval. The analyses show that the concentrations of total alpha, ^{60}Co, ^{137}Cs, and ^{125}Sb were below or close to the threshold level of detection in the well water sampled. However, water from five wells contained gross beta activity, which includes ^{90}Sr, at levels higher than background; water from four wells contained very low concentrations of an unidentified beta emitter; and water from nearly all of the wells contained tritium in concentrations that range from very high to background.

It is the depth of occurrence and concentration of tritium in the well water that is of particular interest to developing a conceptual model of ground-water flow. When dissolved in ground water, tritium becomes part of the water molecule and then is transported in the form of HTO (where one atom of hydrogen [H] has been replaced by an atom of tritium [T]) at essentially the same velocity as ground water. The amount removed from the migrating solution by replacement of nontritiated water on clays and other hydrated soil constituents is marginal (Ames and Rai, 1978, p. 3-222). Thus, the present distribution and concentration of this radionuclide in ground water are useful as indicators of the relative amount of total recharge entering bedrock from the regolith (the place of waste burial) and the depth of ground-water circulation.

The data show that the highest concentrations of tritium were found in the shallow regolith wells, moderately high concentrations were found in the 100-foot piezometers of the central and north clusters, and very low or background concentrations were found in the 150- and 200-foot piezometers. At the west cluster, which is about 250 feet from the burial area, relatively little tritium was found in the regolith well and

Table 9.--*Radiochemical analyses of well water, burial ground 5*

[Cluster identification: C, Central; S, South; W, West; N, North; E, East. Analyses were performed under the supervision of T.G. Scott, Analytical Chemistry Division, Oak Ridge National Laboratory, Tennessee. Results are reported in Bq/L]

Well No.	Cluster	Depth interval (feet)	Total alpha	Gross beta	^{3}H	^{90}Sr	^{60}Co	^{137}Cs	^{125}Sb
Samples collected during February-March 1979:									
458B	C	150-202	1.2 ± 1.3	< 33.3	3.7×10^{2}	5			
460A	C	44-100	1.0 ± 1.3	< 50	4.7×10^{5}	3.0 ± 3.7			
Samples collected during August 1983:									
439	C	24-34	1.6 ± 3.8	< 20	$1.6 \times 10^{6} \pm .1 \times 10^{6}$	.30 ± .23	< .06	.087 ± .018	< .1
440	C	26-36	9.2 ± 8.3	44 ± 28	$6.4 \times 10^{5} \pm .1 \times 10^{5}$	29 ± 2	< .02	.10 ± .07	< .2
464	S	6-11	5.6 ± 6.2	26 ± 25	$2.2 \times 10^{7} \pm .1 \times 10^{7}$	5.6 ± .8	< .05	< .04	< .09
468	W	10-15	2.7 ± 4.8	< 20	350 ± 60	.08 ± .15	< .09	< .07	< .1
472	N	15-20	1 ± 3	25 ± 25	$5.2 \times 10^{4} \pm .1 \times 10^{4}$	.27 ± .25	< .08	.057 ± .048	< .2
476	E	25-30	5.7 ± 5.8	500 ± 60	$5.3 \times 10^{5} \pm .1 \times 10^{5}$	410 ± 10	.14 ± .06	.048 ± .027	< .1
460	C	90-100	3 ± 3	< 25	$2.2 \times 10^{4} \pm .1 \times 10^{4}$	.24 ± .18	< .07	< .05	< .1
467	W	91-101	2.3 ± 3.9	19 ± 24	14 ± 37	.12 ± .14	< .1	< .1	< .2
471	N	89-99	3.5 ± 4.8	47 ± 27	$8.1 \times 10^{5} \pm .1 \times 10^{5}$	.29 ± .39	< .07	.036 ± .033	< .1
475	E	90-100	1.3 ± 2.7	39 ± 26	740 ± 70	.07 ± .12	< .08	< .06	< .1
459	C	130-140	2 ± 3	25 ± 24	250 ± 50	.38 ± .22	< .06	< .05	< .1
466	W	142-152	1.3 ± 3.2	.57 ± .21	33 ± 38	.15 ± .17	< .09	< .07	< .1
470	N	141-151	1 ± 3	< 25	77 ± 41	.24 ± .15	< .1	< .08	< .2
474	E	142-151	1.1 ± 2.5	70 ± 30	33 ± 38	.05 ± .12	< .1	< .09	< .2
458	C	190-202	3 ± 3	< 20	21 ± 37	.99 ± .33	< .09	< .8	< .2
469A	N	191-201	4 ± 3	21 ± 24	190 ± 50	< .2	.085 ± .076	.10 ± .07	< .2
473	E	190-200	3.1 ± 5.2	< 20	92 ± 42	.03 ± .10	< .09	< .07	< .1

essentially none in the bedrock wells. Bedrock wells of the south cluster were not sampled. The data show a pronounced decrease in tritium concentration as depth increases, and the decrease is marked between the 100- and 150-foot levels.

To a lesser extent the analyses of the other radionuclides also are indicators, but they are not as useful because much smaller quantities of them have been buried and the metallic isotopes listed in the table have distribution coefficients significantly higher than that of tritium, indicating that sorption or ion exchange will retard their transport in circulating ground water. Strontium-90, which has the lowest distribution coefficient of the four metals for the local clays, is present in concentrations greater than 1 Bq/L (Bequerel per liter) only in wells 440, 464, and 476, the regolith wells of the central, south, and east clusters, respectively. In only one bedrock well does its concentration approach 1 Bq/L. The gross beta data generally follow the ^{90}Sr data except at the east cluster where an unidentified beta emitter is present in water from the 150-foot piezometer.

The analytical results reveal that most of the dissolved radionuclides transported from the buried waste are contained within the regolith part of the aquifer. Some of the activity has been carried as deep as 100 feet, which is substantially below the top of bedrock. Only minor concentrations are found at depths of 150 and 200 feet.

CONCEPTUAL MODEL OF FLOW: THE BEDROCK

Burial ground 5

The initial concept of the bedrock hydrology of the Conasauga Shale resulted from studies made of the Four-Acre site (fig. 1) and the ILW-disposal area during the 1950's. Those studies are reviewed here because they provide the foundation for the conceptual model of ground-water flow in the bedrock given in this report.

The hydrologic characteristics of the bedrock underlying the Four-Acre site were investigated by drilling a well 300-feet deep, and coring four satellite wells, each of 200 feet depth, at points 200 feet to the east and west (along strike) and north and south (normal to strike) of the deeper well. The north well probably terminated in the Pumpkin Valley Shale; the others, in the Rutledge Limestone. In a water injection/packer test, the water levels in the wells along strike rose more than those normal to strike. Conversely, in a 48-hour pumping test, the water levels in the wells along strike declined about 7 to 20 times as much as those normal to strike. A tracer test, where chemicals were introduced into the west well and the central well was continuously pumped, provided a breakthrough time of 80 hours, but the tracer was still present in the discharge at 280 hours when the test was discontinued. Conclusions of the three tests were that (1) rock in the vicinity of the wells is virtually impermeable below a depth of 100 feet and incapable of transmitting water under natural hydraulic gradients; (2) the water-bearing fractures are interconnected to some degree;

(3) water moves more readily along strike than across it; (4) the porosity of the rock is quite small; and (5) the rock between the two tracer-test wells contains a number of separate but interconnecting passageways, enabling some of the tracer to come through directly while some of it follows more circuitous routes (deLaguna and others, 1958; unpublished manuscript in files of USGS).

Later, a similar array of wells was constructed at the site for ILW pit 4 before the pit was excavated. All of the wells were drilled in the Maryville Limestone; again, all of the observation wells were 200 feet deep. Injection tests showed that the rate of acceptance of water at depths greater than 120 feet was very low (maximum of 0.4 gpm at 30 lb/in^2 head per 10-foot interval of well) in three wells and zero in the other two wells. Response of the satellite wells to injection at the central well is undocumented by available records. Several pumping tests indicated that the permeability of the rock between the central well and the north well (normal to strike) is very low and less than that in the direction of strike (the east-west wells), and that no hydraulic connection exists in the "deeper" rock between the central well and the south well. The latter may be due to a fault that is thought to lie between the two wells (deLaguna and others, 1958, p. 106-108).

The results of the aquifer tests at these sites and other evidences of flow that pertain mainly to the regolith were interpreted by later investigators to mean that the principal direction of fluid flow in the Conasauga Group of Melton Valley is parallel to formation strike. This projection of the results to other areas in the valley should be viewed with caution inasmuch as (1) the natural hydraulic gradient at the ILW area does not differ greatly from strike and, therefore, the concept was not put to a rigorous test; (2) a suspected fault just south of ILW pit 4, where gradient and strike are approximately normal to each other, was thought to be a hydraulic barrier and, therefore, the pumping test analyses and absence of a waste plume in that direction do not provide results representative of the entire formation; (3)the direction of flow under natural gradients may or may not replicate that under the stressed conditions of an aquifer test; and (4) the beds have secondary openings both between and across them which logically should permit multidirectional flow.

It is this last factor that is considered in some detail here. The principal pathways for flow in the bedrock are fractures, joints, faults, and solution openings. The openings between the beds--largely bedding-plane faults, fractures, and to some extent solution openings--have developed along zones of inherent weakness. They tend to have lateral continuity, although the lengths of individual openings are highly variable, and lineation that trends in the direction of formation strike. Joints and fractures, in terms of numbers, are the principal openings that cross the beds, but they are not persistent over distance. Haase (AAPG proceedings, 1981, unpublished), in discussing the Pumpkin Valley Shale, observed that even though that formation is locally highly fractured, any one joint or fracture is contained within only a few beds. This probably is true of the majority of joints and fractures in other formations of the Conasauga Group, although those in the more substantial limestone beds probably are somewhat longer because the beds are thicker. The longest openings across the bedding result from faults, but faults in this direction are much less numerous than joints or fractures. Additional complexities arise from the tendency for certain lithologies to favor one type of opening over another, and a possible relationship between lithology and the amount of secondary mineralization filling the openings. There also is variability with depth, although the trend is for openings to become tighter and to pinch out as depth increases. This is evidenced by the packer/injection tests of the 1950's and the measurements of hydraulic conductivity in this study.

The picture that emerges from the results of the various field studies is a heterogeneous, anisotropic aquifer in which the laterally-continuous openings between the beds provide the more significant pathways for flow. Superimposed upon them are openings that cross the beds, but in the bedrock these openings appear to be less numerous than they are in the regolith, and most are of short length. Consequently, other factors being equal, fluids move with greater ease between the bedding planes than across the beds. This was demonstrated by the pumping tests and the packer/injection tests. Flow also must occur across the beds when a potentiometric gradient in that direction exists, although it is relatively more difficult for fluid to do so because of the spacing, width, and discontinuous nature of the openings. Although flow in the bedrock may appear to parallel strike over relatively short distances (i.e., 200 feet) between observation wells, actual net pathways of flow in areas as large as an entire burial-ground where hydraulic gradients cross the bedding probably occur at some angle to strike. If a particle of water could be traced as it moves through the bedrock, its overall path probably would be found to follow an irregular stair-step pattern as suggested for some of the more resistant intervals of the lower regolith. The actual path taken must be governed by the three-dimensional geometry of the network of openings and the distribution of hydraulic head within that system.

The conceptual model described under "Hydrology of the regolith" can thus be developed further by adding a third zone as follows:

(3) A zone comprising the water-bearing section of the bedrock where the largest component of flow occurs in openings between the beds and, therefore, its vector trends in the direction of formation strike; where a potentiometric gradient crosses the beds, which probably is characteristic of much of the disposal areas, a smaller secondary component of flow and its vector also crosses the beds, and the resultant direction of flow is at some angle to strike and toward points of lower hydraulic head. This zone extends to more than 200-feet depth, giving it the greatest thickness of the three zones, but the total flow through this zone probably is less than that in zones (1) and (2) combined.

This interpretation of results from previous and on-going studies implies that it is quite possible for the direction of ground-water flow to change with depth. In the uppermost part of the saturated zone, the direction of the largest component of flow corresponds to the inferred water-table gradient throughout much of the area. (The actual direction of flow is determined by the real gradient within the network of pathways through which water flows.) As depth below the water table increases, the direction of flow becomes increasingly governed by the hydraulic gradients within the partings, joints, fractures, solution openings, and other pathways of flow. Thus, the overall direction of ground-water flow in the regolith may differ from that at a point 100 or 200 feet below. The potential for difference is greatest where the gradient inferred from water-level data of wells trends normal to strike. This may be illustrated by diagrams (fig. 31) showing conceptual flow paths in both the regolith and bedrock with gradients equal in magnitude but 90 degrees different in direction. In both diagrams strike is assumed to be east-west. The gradient in (a) is north to south, normal to strike. Flow in the regolith is fairly direct from point P to point P′, being skewed to a comparatively minor degree by anisotropy of the regolith. Flow in the bedrock trends to the southwest, following openings in the bedrock from point P to point P″. Without more detail on the magnitude and direction of the gradient than that given, the direction of flow from point P also could be to the southeast in a similar pattern instead of to the southwest. The distance between points P′ and P″ is a function of the difference in degrees of anisotropy between the regolith and bedrock. In figure 31(b) the gradient is from east to west, parallel to strike. Again, flow in the regolith is fairly direct. Flow in the bedrock under this condition is primarily through openings between beds, being diverted where individual openings constrict or terminate or by local changes in hydraulic gradients within the bedrock system. The potential for differences in the direction of flow paths between regolith and bedrock then becomes much less than in (a).

All fluid flow is three-dimensional, having both lateral and vertical components. The overall direction of the lateral component of flow in the burial ground 5 bedrock can be inferred by plotting the altitude of the static potentiometric surfaces at the 100-, 150-, and 200-foot wells of each cluster. For dates when head data are available, the net gradient thus shown at the site is toward the southwest part of the burial ground and beyond. This is consistent for each horizon, although data for some of the 200-foot piezometers are limited and have to be estimated on the basis of other record. Because the potentiometric heads decrease to the southwest, it is inferred that the net direction of the lateral component of flow must be to the southwest. Individual pathways of flow, of course, may change direction many times along their length, such as is shown in figure 31 (a).

The vertical component of flow can be illustrated by constructing sectional diagrams of the potentiometric heads, as is shown in sections A-A′ and B′-B of figure 32. Section A-A′ shows the vertical distribution of heads along a line from Whiteoak Creek, through the west, central, and east clusters, to a point just east of the drainage on the east side of the burial ground. It is based on water-level data of the water-table wells throughout the site and the piezometers on July 14, 1983. This is the only date reflecting typical mid-season conditions that data from both the water-table wells and most of the piezometers are available. The altitudes of the potentiometric surfaces in the 200-foot piezometers in the east and west clusters for this date have been estimated, as stated previously. A waste-slurry injection at the hydrofracture plant on the previous day caused potentiometric

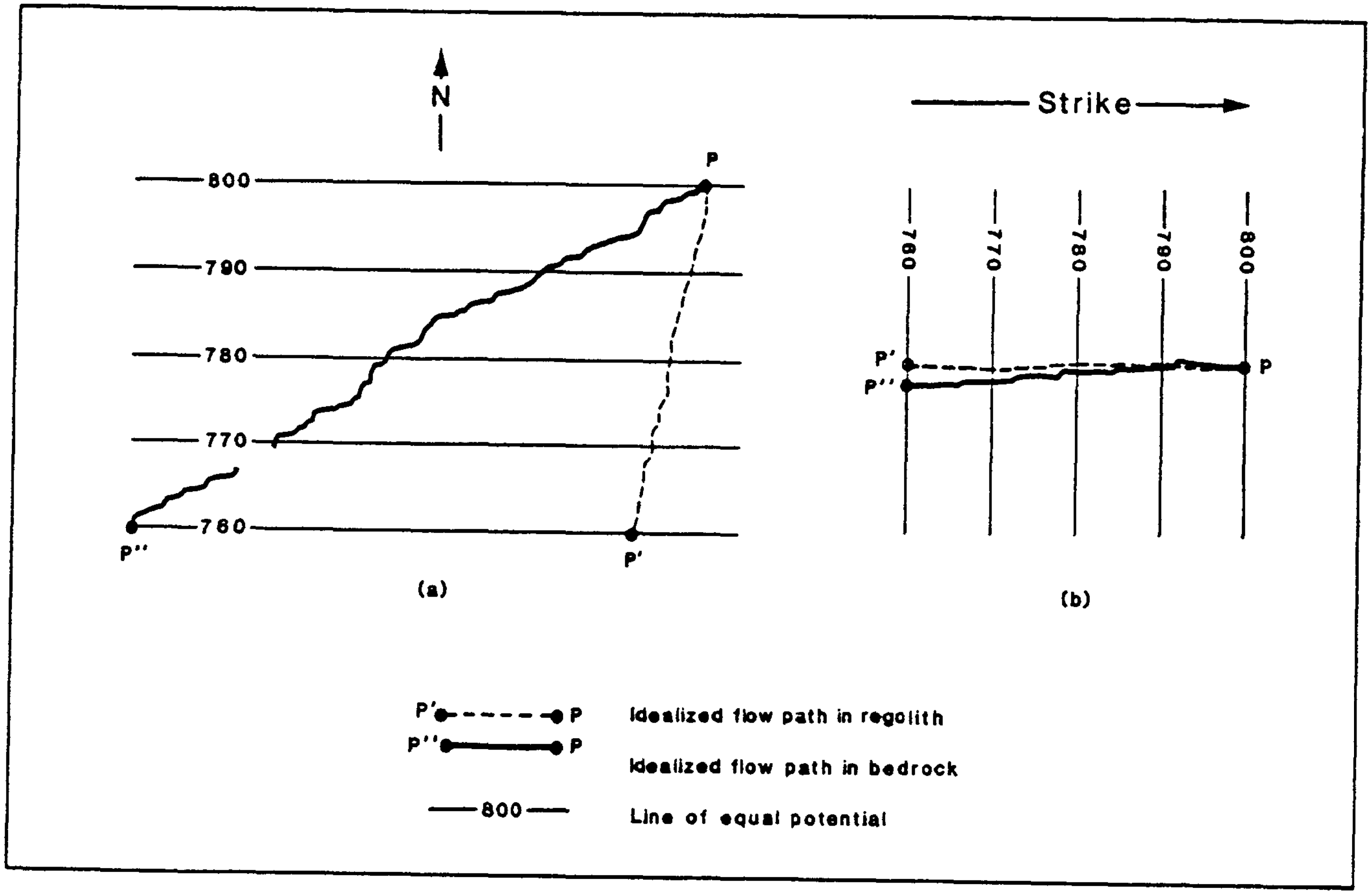
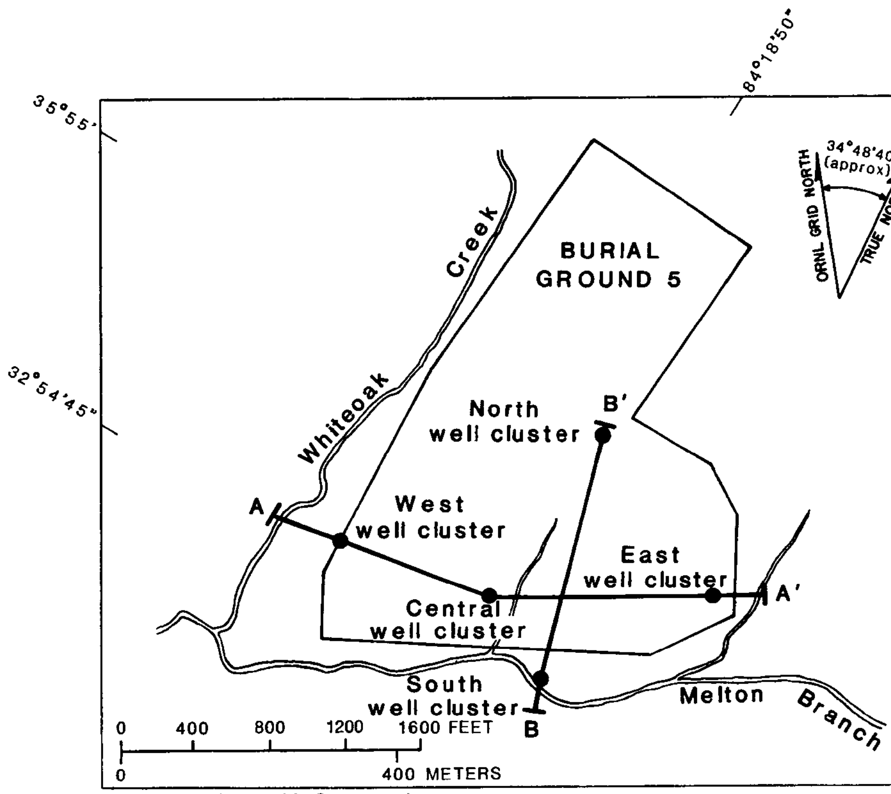


Figure 31.--Diagrams illustrating conceptual pathways of ground-water flow in the regolith and bedrock where the inferred water-table gradient is (a) normal to strike, and (b) parallel to strike.



Base from Accu-Air Surveys, Inc.
Whiteoak Creek Watershed 1:200, 1978

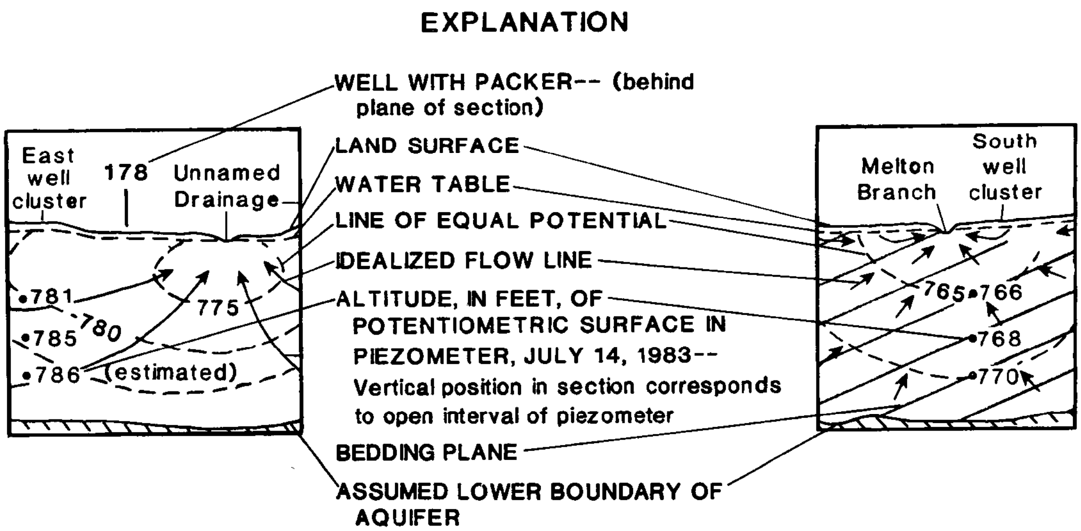
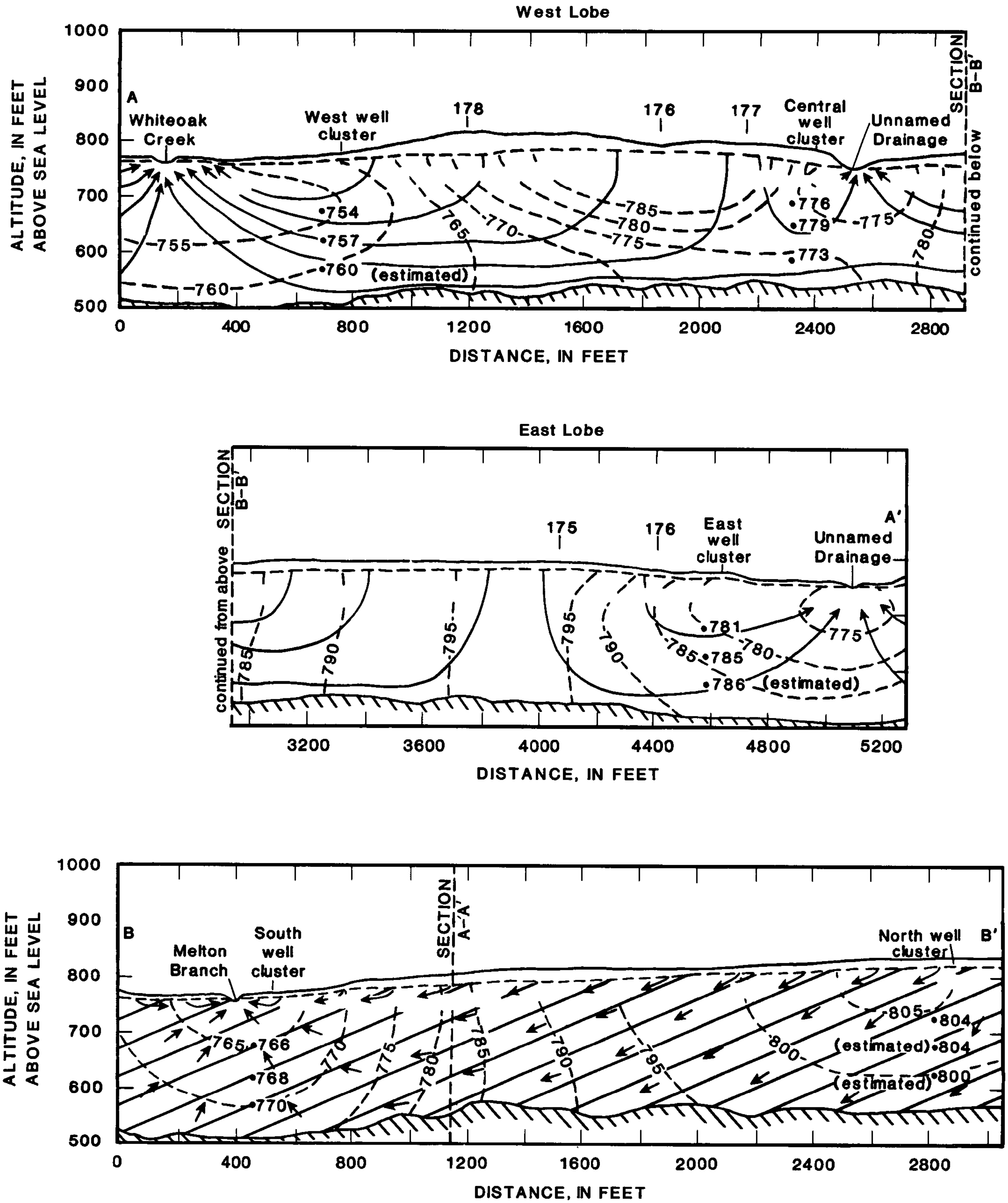


Figure 32.--Diagrammatic sections of burial ground 5 showi



head distribution and idealized flow paths in the vertical direction.

surfaces in some of the piezometers to change more than would have been normal over one day, but the continuous data show that the extent of changes are minor and insufficient to alter the head relationships shown. In well 458, the piezometer that available record shows is most affected, the water level had declined by about 0.3 foot on this date. Four hydrologic boundaries are shown on the illustration. One is the water table; the second is an irregular surface at about 250 feet depth representing assumed, impermeable bed-rock, a no-flow boundary; the third is a ground-water divide under the east lobe; and the fourth is the network of streams along three sides of the site (Whiteoak Creek and the unnamed stream east of burial ground 5, as shown in section A-A′, and Melton Branch, shown in section B′-B). Inasmuch as the same water-level data were used to construct the ground-water contour map (fig. 17), the equipotential lines in this diagram are an extension in the vertical plane of the same equipotential lines that are shown in the two lateral dimensions of that map. The flow lines do not cross the equipotential lines at right angles because of the anisotropy that exists in the bedrock, as has been demonstrated by the hydraulic tests.

The illustration reveals several features about ground-water flow in the bedrock below the site. First, the flow lines show that this part of the burial ground is underlain by four local flow cells. In the TRU area to the north, the number of cells probably is less, as will be shown in figure 33. The depth to the lower boundary of the aquifer is simply too shallow relative to the difference in potentiometric heads between top and bottom for regional or even intermediate distance flow systems to develop.

The flow lines also indicate that the bedrock receives recharge from the regolith along more than 80 percent of the line of section; only along strips adjacent to the drainages does the bedrock discharge water to the regolith and the drainages. Discharge along this section is into three drainages: Whiteoak Creek, the drainage that divides the burial ground into east and west lobes, and the drainage near the east perimeter of the site. Had the section been made more southerly along Melton Branch, it would indicate discharge into that stream, as is implied in section B′-B. Had the section been made more northerly across the nearly perennial stream in the TRU area (for which potentiometric head data at depth are not available), it probably would indicate discharge into that stream and Whiteoak Creek. Within the flow cells illustrated there may be some local, anomalous flow patterns (or small cells) resulting from bands of very-low permeability rock, structural dislocations, or solution cavities may occur within this system. These anomalies, if present, are superimposed upon the overall flow pattern and are analagous to eddy currents in a stream.

The section also shows that in the vertical plane the "area of influence" of each drainage is related to the magnitude of its discharge. The equipotential lines within the influence of Whiteoak Creek, the principal stream of this area, extend at depth across the width of the west lobe. Those within the influence of the unnamed drainage on the east, a smaller drainage, extend only about half that distance, and those within the influence of the central drainage, which conveys the least flow of the three, have a still smaller area and do not even extend to the lower boundary. This observation can be useful in projecting a section to other parts of Melton Valley for which potentiometric data are lacking.

The diagram illustrates the interpretation of the potentiometric head relations discussed earlier and reveals why the vertical component of flow changes direction at certain depths below the west and central clusters. At the west cluster, water in the upper bedrock moves both down and toward Whiteoak Creek, whereas in the lower part of the saturated zone water moves both up and toward that drainage. At the central cluster, water moves from the regolith into the upper bedrock and then discharges from it into the central, unnamed drainage. Water reaching the lower part of the saturated bedrock from points east and west of the upper zone's recharge area flows westerly to discharge to Whiteoak Creek.

The wells in which packers were placed are at varying distances to the north of section A-A′. Although these wells are not in the plane of the section, and those water-level measurements were made before the measurements used to construct this illustration, their data also support the flow patterns shown.

Section B′-B (fig. 32) is a conceptualization of bedrock flow along a line of section from the north cluster, through the south cluster, to a point a short distance southeast of Melton Branch. Used in conjunction with section A-A′, it describes flow patterns in a generally north-south direction. This section is based on the water-level data of July 14, 1983, the flow pattern shown in section A-A′, and the conceptual model described earlier. Because the potentiometric surfaces in the 150- and 200-foot piezometers of the north cluster had not reached static levels at that date, estimates of their mid-July 1983 altitudes are made (804 and 800 feet, respectively), based on later record. The attitude of the bedding planes as they typically cross the line of section is shown lightly in the background, although in actuality many folds, faults, and departures from average dip are likely intercepted within this line. In addition, joints and fractures, which are not shown, cross the beds, but for the most part lack continuity over any substantial sequence of rock.

Part 3 of the conceptual model states that the largest component of flow in bedrock occurs between beds and a smaller component of flow crosses them. In this line of section, a potentiometric gradient exists from the north cluster to Melton Branch. Flow characteristics as conceptualized are that (1) the greatest amount of flow occurs in the regolith, and this is shown by the numerous short, nearly horizontal arrows at shallow depth; (2) the regolith supplies water to the underlying material throughout the section except in the vicinity of the south cluster; (3) water moves into bedrock throughout most of the section, but as it moves downward, some portion of it continually turns from the plane of the paper to points of lower potential in the bedding planes, which cross the paper at a sharp angle; consequently, only a very small fraction of the water entering bedrock moves as deep as 250 feet, the assumed lower boundary; (4) water also crosses the beds through joints and fractures, but it is more difficult for flow to occur in this direction than between the beds because these openings have a smaller total area than those along the bedding planes and they lack continuity. With regard to (3) and (4), the reader should not interpret the diagonal arrows as representing linear, continuous, downward flow between the beds to the lower boundary of the aquifer. The net direction of flow by compositing sections A-A′ and B′-B would be drawn, if it were possible to portray three-dimensional flow in two dimensions, as arrow shafts crossing the beds at low to moderate angles, with the heads of the arrows curling out of the paper toward the viewer.

As considered previously, most water between the 100- and 150-foot zones at the north cluster probably moves laterally (that is, at an angle to the paper). This would be westerly toward the downstream half of the drainage between the 5-north and 5-south areas and southwesterly toward Whiteoak Creek. Recharge to the 200-foot level then must come from points of higher potential to the northeast, and discharge is into Whiteoak Creek. In the mid-section of section B′-B water in the upper and middle parts of the saturated zone discharges to the unnamed drainage between the east and west lobes, as indicated in the discussion of section A-A′, and water that reaches the deeper part of the saturated zone in this area probably discharges to Whiteoak Creek. Near the south cluster and Melton Branch the direction of the potentiometric gradient reverses. Water in the deeper zone rises through whatever openings exist between and across the beds. The discharge point is Melton Branch, but because the openings are discontinuous, the net direction of flow probably is not to the drainage directly above as the two-dimensional diagram suggests, but to the drainage at numerous points downstream. This would suggest that the water in the piezometers of the south cluster is not entering those wells by flow along the line of section B′-B as the topography of the burial site would suggest, but by flow from points of higher potential which lie to the north or northeast. It also can be inferred from the section that the pressure gradient in the bedrock of the area southeast of Melton Branch does not permit the flow of water from burial ground 5 to points under Copper Ridge and subsequent discharge to Melton Hill Lake.

Melton Valley

Data from numerous water-table wells and piezometers would be required to accurately construct detailed flow sections across the length of Melton Valley. Although such data are not available, the conceptual model of ground-water flow at burial ground 5 can be extended to other parts of Melton Valley on the basis of the relations described. On figure 33 three sections are shown. Section A-A′ is a vertical section across burial ground 4, Whiteoak Creek, the TRU storage area of burial ground 5, and the western part of the ridge to the east. Section B-B′ extends from the summit of one of the ridges on the east side of burial ground 6, across the ILW-disposal area and Whiteoak Creek, to a point inside burial ground 5. Section C-C′ extends from a point just west of Watts Bar Reservoir (the Clinch River) at Jones Island to the drainage between burial ground 6 and the ILW pit area.

The assumed water-table position through the three sections is based on water-level measurements of the burial grounds and adjacent areas that have topography generally similar to the areas depicted. For example, the position of the water table through much of section A-A′ is based on typical mid-season data of burial ground 4, the Whiteoak Creek flood plain, and the TRU area of burial ground 5. In the area east of the burial ground 5 boundary, for which data are not available, its position reflects the same slope as that below the TRU area and the relation found in the Melton Valley disposal sites that depth to water increases as surface altitude increases. Similarly, the water-table position at the end points of sections B-B′ and C-C′ is based on typical mid-season water-level data of burial grounds 5 and 6, and its position across the intervening area upon the depth-to-water/surface-altitude relation. The location of the equipotential lines as they cross the vertical plane is approximate. At their intersection with the assumed water table, their location corresponds to water-table contours (or equipotential lines) of the same value. Their position and character in depth is based on observations noted previously under the discussion of burial ground 5 bedrock hydrology, particularly the relation between magnitude of discharge of a drainage and the subsurface area (or size of the flow cell) influenced by that drainage. The lines showing vertical flow in figure 33 thus are not based on actual potentiometric data at depth, but upon generalized data and projection to these areas of the interpretation of the burial ground 5 flow model. While the construction of numerous piezometers and a period of data collection would be required to refine the location of the equipotential and flow lines, the illustration provides the foundation for an initial conceptualization of ground-water flow beyond burial ground 5 that may be modified by the results of continuing study.

Section A-A′ shows virtually horizontal flow through the bedrock underlying burial ground 4, with discharge into Whiteoak Creek. Only near the western end of the site (near point A) is there any potential component of recharge, and this is to the shallow rock. The deeper rock is recharged from points of higher head on Haw Ridge (fig. 1). The three small drainages that cross the site, therefore, are not thought to contribute to bedrock recharge. To the east, the higher ridges east and north of the 5-north area are the source area for recharge in the deeper bedrock below the TRU storage area. The shallower rock is recharged by local flow cells from the ridge inside the TRU area. Discharge from the bedrock of these areas is to the local drainage within the TRU area and to Whiteoak Creek.

Section B-B′ illustrates the effects of topography upon the development of flow patterns. Note that the water table below each summit occurs at about the same altitude; consequently, the heads through this area are about equal. Flow then is from the ridges (the recharge areas) to the nearby drainages. The difference in heads from ridge to ridge is too small to provide the driving force required for the development of deep flow to points beyond the local drainage system. One point in particular may be noted. In view of the apparent relation between a stream's magnitude of discharge and "area of influence", this model suggests that Whiteoak Creek at points near its confluence with Melton Branch may receive effluent from ILW trench 7 by virtue of deeper flow under the spur east of that disposal facility. This is in addition to shallow flow known to discharge to the small drainages east and west of ILW trench 7.

Section C-C′ shows a ground-water divide in the bedrock underlying the ridge in the

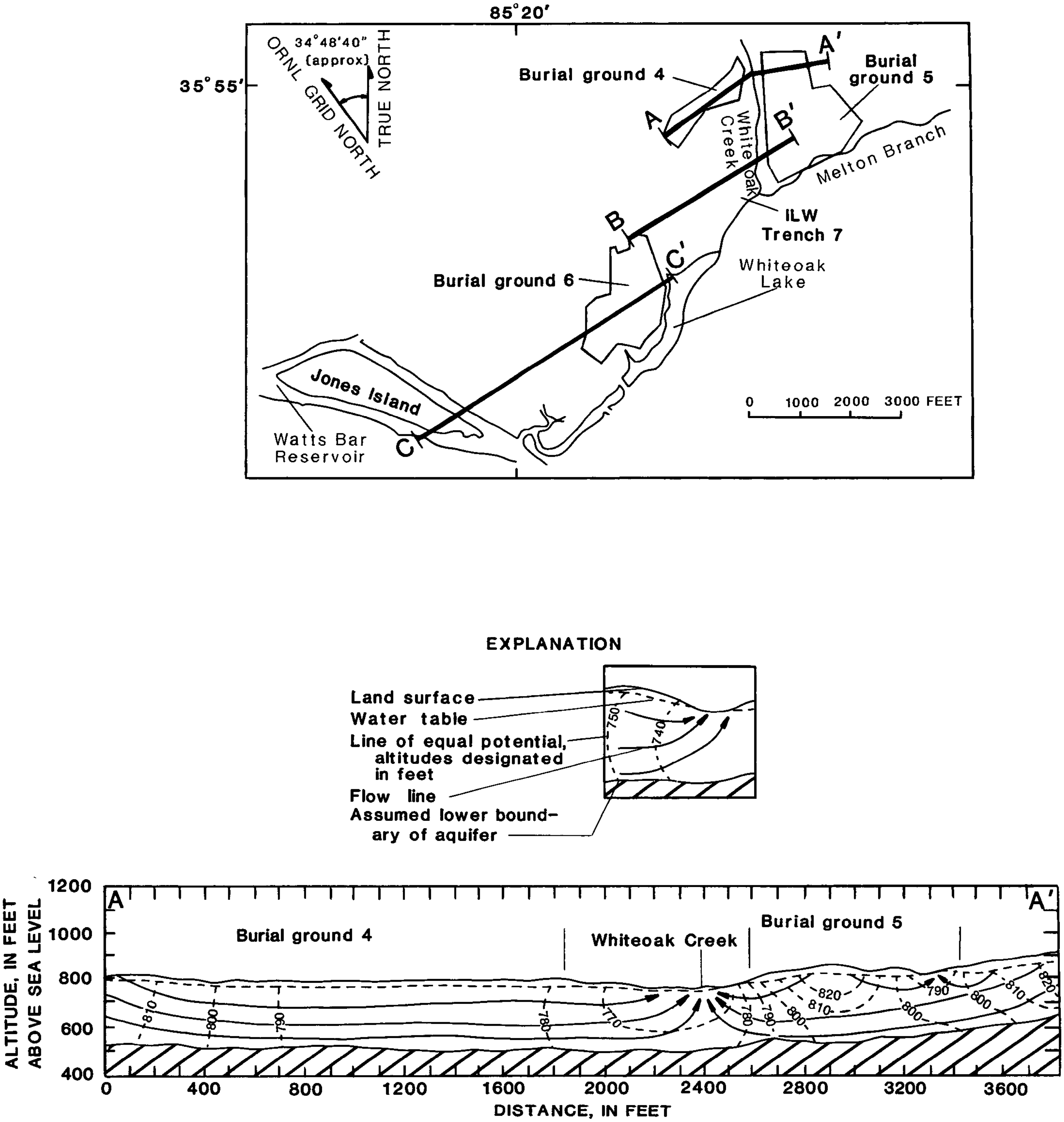
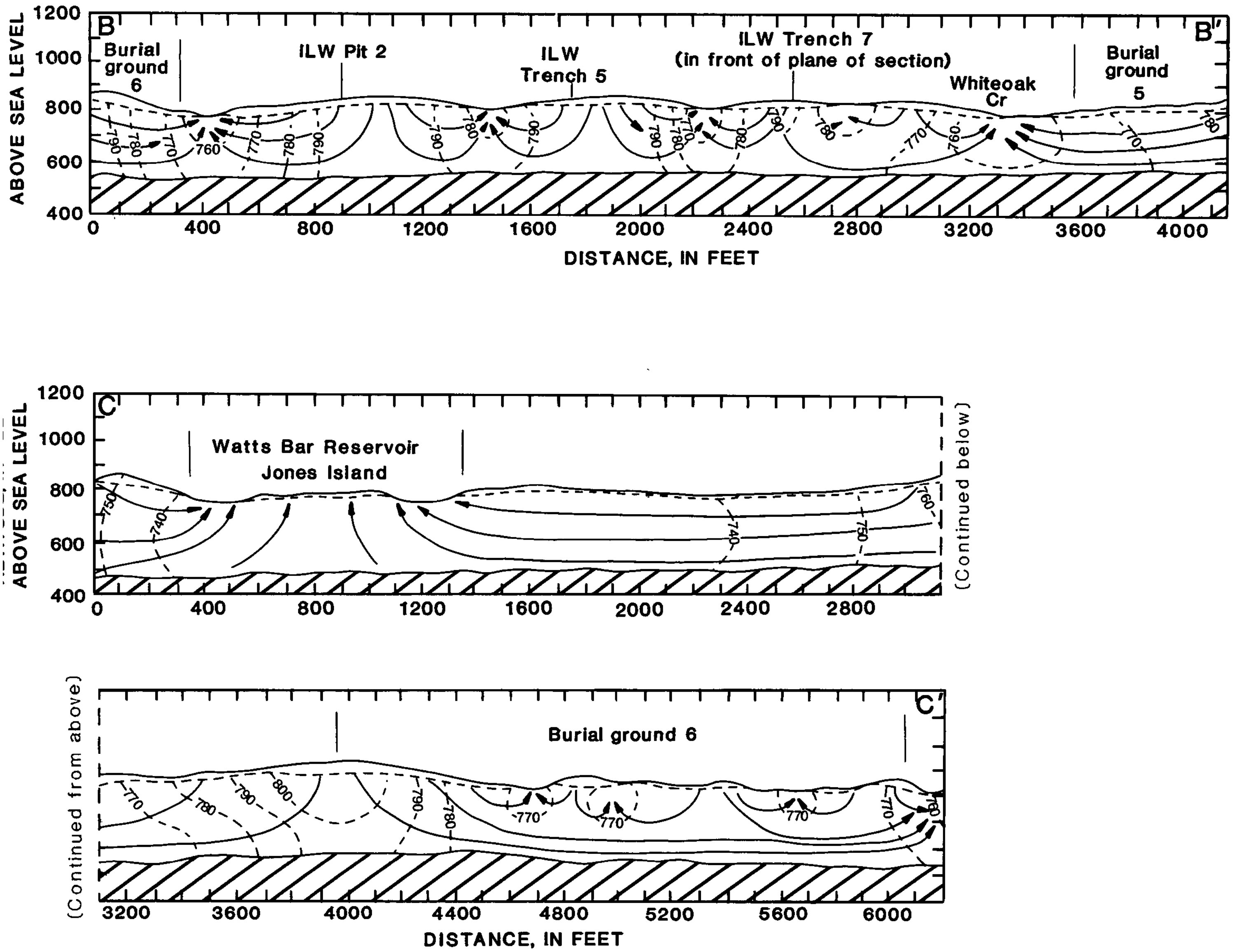


Figure 33.--Diagrammatic sections across burial grounds 4 and 6 and ti
ground-water flow patterns in the bedrock by projectic



intermediate-level liquid waste (ILW) disposal area showing hypothesized
of the conceptual model of burial ground 5.

northwest corner of burial ground 6. Water flowing northeasterly from the divide area recharges the deeper bedrock, flows under the site, and discharges to the drainage on the east side between burial ground 6 and ILW pits 2, 3, and 4. Some component of this recharge probably discharges to Whiteoak Lake also. Areas within burial ground 6 provide recharge to the shallower bedrock and discharge to the small drainages within the site and to the lake. Water flowing southwesterly from the divide area recharges the deeper bedrock of that locale and discharges to Watts Bar Reservoir and the regolith below the Clinch River flood plain.

Each of the three sections hypothesizes that water flows through the bedrock in flow cells of local area, as has been shown for burial ground 5. Discharge from the bedrock throughout the system is to the local drainages. Deep interbasin flow through the bedrock, extending from one river system to another, does not develop because the saturated interval of bedrock is relatively thin and the head differences required are not present.

GROUND-WATER QUALITY

Water samples were taken for chemical analyses from wells 460 and 458 at the close of the 24-hour pumping tests in February and March 1979. At that time the wells were open from about 44 to 100 feet and 150 to 203 feet, respectively. During August 1983, water samples were collected from 17 wells in the piezometer arrays of burial ground 5. These wells were constructed with open intervals of 5- to 13-feet between depths of 6 feet and 203 feet.

All water samples were analyzed at ORNL for selected radionuclides (table 9). The 2 samples taken in 1979 and 15 of the 17 samples taken in 1983 were analyzed by the USGS for physical properties, principal ions, minor constituents, and trace metals (table 10). The samples taken from wells 464 and 476 in 1983 were analyzed at ORNL for trace metals. The dilutions necessary to reduce the tritium and strontium-90 concentrations, respectively, in those two samples to acceptable levels for trace-metal analysis by flame chromatography at the Geological Survey's laboratory would have jeopardized the integrity of the analyses. Although an analysis was made at the USGS Laboratory of the sample from well 470, the results are not included in the tabulation because the data do not meet quality-control criteria.

All of the wells listed in table 10 derive their water from the Maryville Limestone, except well 464 which receives its water from the Nolichucky Shale, and well 469A which is recharged by the Rogersville Shale.

Analyses of water from wells 439, 440, 468, and 472, all less than 40 feet deep, reflect the chemical character of water in the regolith of this site. The dissolved solids concentration in water from three of these wells ranged from 360 to 570 mg/L (milligrams per liter). The specific conductance of the fourth sample (well 468) implies a dissolved solids concentration of somewhat less than 360 mg/L. The water is composed of high percentages of calcium and bicarbonate, and ranges in pH from slightly acidic to slightly basic. This is typical of ground water from shallow wells

Table 10.--*Principal-ion, minor constituent, and trace metal analyses of water samples from piezometers, burial ground 5*

[*Analyses performed under supervision of N.M. Ferguson, Analytical Chemistry Division, Oak Ridge National Laboratory]

Well No. (ORNL)	Date of sample (y-m-d)	Sampling depth (feet)	Temperature (Deg. C)	Turbidity (NTU)	Color (platinum-cobalt units)	Specific conductivity, field (μmhos)	Specific conductivity, lab (μmhos)	pH, field (standard units)	pH, lab (standard units)	Alkalinity, field (mg/L as $CaCO_3$)	Alkalinity, lab (mg/L as $CaCO_3$)	Nitrogen nitrite, dissolved (mg/L as N)	Nitrogen $NO_2 + NO_3$, dissolved (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Carbon inorganic, total (mg/L as C)
Regolith wells, less than 50 feet deep															
439	83-08-26	24-34	16.5	3.0	3	875	--	6.7	7.2	250	378	0.030	0.690	0.030	99
440	83-08-23	26-36	21.0	> 1,000	1	885	310	6.4	7.1	420	315	.050	2.00	.020	85
*464	83-08-26	6-11	20.0	--	--	730	--	6.6	--	360	--	--	--	--	--
468	83-08-25	10-15	21.0	1,300	1	525	440	6.7	7.4	250	219	<.010	<.100	<.010	60
472	83-08-17	15-20	21.0	160	2	1,200	--	6.2	7.1	650	--	.050	<.100	.15	140
*476	83-08-26	25-30	17.0	--	--	890	--	7.3	--	450	--	--	--	--	--
Bedrock wells, open at about 100 feet below land surface															
460	83-08-22	90-101	16.0	45	4	930	812	6.8	7.7	220	191	.050	<.100	<.010	48
467	83-08-25	91-101	15.0	1.4	2	310	290	9.4	9.4	126	139	<.010	<.100	<.010	29
471	83-08-23	89-99	15.5	22	6	210	150	9.3	8.7	--	37	.050	<.100	<.010	9.6
475	83-08-24	90-100	15.5	28	1	340	300	8.6	7.9	138	141	<.010	.830	<.010	34
Bedrock wells, open at about 150 feet below land surface															
459	83-08-22	130-140	15.5	24	3	305	270	9.2	8.5	82	75	.050	<.100	<.010	16
466	83-08-25	142-152	15.0	6.0	5	540	520	9.3	9.6	246	261	<.010	<.100	<.010	56
474	83-08-24	142-151	15.5	8.3	2	700	610	10.6	10.5	245	254	<.010	<.100	<.010	38
Bedrock wells, open at about 200 feet below land surface															
458	83-08-22	190-202	15.5	7.4	2	380	344	7.9	8.4	200	185	.050	<.100	<.010	46
469A	83-08-19	191-201	16.5	7.8	45	950	870	10.2	10.1	--	417	.060	<.100	.040	59
473	83-08-24	190-200	15.5	9.7	3	3,900	4,260	11.8	11.9	1,010	--	.020	<.100	<.010	44
Bedrock well, open 44 to 100 feet below land surface															
460A	79-02-15	44-100	15.0	--	5	570	569	6.8	7.8	--	270	--	--	--	--
Bedrock well, open 150 to 203 feet below land surface															
458B	79-03-20	150-203	19.0	--	5	320	333	7.3	8.0	--	140	--	--	--	--

Table 10.--*Principal-ion, minor constituent, and trace metal analyses of water samples from piezometers, burial ground 5*--Continued

Well No. (ORNL)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 °C dissolved (mg/L)	Arsenic, total (µg/L as As)	Barium, total recoverable (µg/L as Ba)	Cadmium, total recoverable (µg/L as Cd)	Chromium, total recoverable (µg/L as Cr)	Cobalt, total recoverable (µg/L as Co)
Regolith wells, less than 50 feet deep														
439	150	15	26	0.12	22	24	0.30	20	573	3	300	1	15	3
440	150	17	18	2.1	36	33	.10	14	540	1	1,000	1	51	3
*464	--	--	--	--	--	--	--	--	--	< 10	370	< 1	--	3
468	86	11	7.8	1.3	2.2	19	.10	12	--	1	< 100	2	11	3
472	180	24	43	2.2	32	23	.20	25	496	4	200	1	< 1	13
*476	--	--	--	--	--	--	--	--	--	< 10	250	< 1	--	25
Bedrock wells, open at about 100 feet below land surface														
460	92	40	12	6.0	170	7.6	< .10	15	525	< 1	500	1	10	6
467	2.3	1.2	60	4.2	1.5	8.2	.10	5.1	160	1	100	2	6	1
471	6.1	.17	18	12	11	15	.20	2.0	89	< 1	< 100	1	9	2
475	12	20	20	4.7	1.8	22	< .10	2.3	164	1	100	2	7	1
Bedrock wells, open at about 150 feet below land surface														
459	15	13	14	11	32	23	< .10	13	172	1	100	< 1	2	2
466	1.6	.52	120	2.6	1.8	13	.30	2.5	292	1	100	2	2	1
474	.82	.08	110	13	1.5	15	.20	5.1	296	1	100	1	5	1
Bedrock wells, open at about 200 feet below land surface														
458	8.8	7.7	65	4.4	2.2	12	.30	10	227	1	400	< 1	4	3
469A	1.1	.07	190	7.1	2.1	30	.20	10	499	1	< 100	1	23	2
473	110	< .10	300	44	3.4	46	.90	3.0	1,040	1	300	1	8	1
Bedrock well, open 44 to 100 feet below land surface														
460A	82	21	8.8	2.8	14	10	0.0	24	337	0	300	0	--	--
Bedrock well, open 150 to 203 feet below land surface														
458B	23	18	17	5.7	7.6	15	.1	18	182	2	300	0	--	--

Table 10.--*Principal-ion, minor constituent, and trace metal analyses of water samples from piezometers, burial ground 5*--Continued

Well No. (ORNL)	Copper, total recoverable (µg/L as Cu)	Iron, suspended recoverable (µg/L as Fe)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Lead, total recoverable (µg/L as Pb)	Manganese, suspended recoverable (µg/L as Mn)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)	Nickel, dissolved (µg/L as Ni)	Strontium, dissolved (µg/L as Sr)	Zinc, total recoverable (µg/L as Zn)	Aluminum, dissolved (µg/L as Al)	Lithium, dissolved (µg/L as Li)	Mercury, total recoverable (µg/L as Hg)
Regolith wells, less than 50 feet deep														
439	18	--	12,000	78	30	150	330	180	18	240	30	300	30	<.1
440	360	390,000	390,000	450	500	11,000	11,000	270	21	270	1,300	400	8	.2
*464	10	--	300	--	40	--	730	500	44	700	120	260	10	<.2
468	47	14,000	16,000	2,200	36	40	110	68	4	190	130	<100	16	<.1
472	25	7,000	33,000	26,000	46	0	1,400	1,400	50	400	200	100	140	<.1
*476	20	--	22,000	9 ,600	480	--	14,000	13,000	35	700	200	40	30	<.2
Bedrock wells, open at about 100 feet below land surface														
460	3	7,800	13,000	5,200	11	0	150	160	2	900	50	100	29	.2
467	11	4,200	4,200	13	52	--	40	<1	1	160	420	100	70	<.1
471	13	18,000	18,000	10	56	--	140	<1	1	270	190	100	50	<.1
475	8	11,000	11,000	5	30	100	110	14	1	1,300	120	100	28	<.1
Bedrock wells, open at about 150 feet below land surface														
459	4	7,400	7,400	8	7	--	30	<1	2	680	110	100	46	<.1
466	12	3,100	4,200	1,100	47	30	40	11	1	63	400	200	60	<.1
474	20	4,400	4,400	19	200	--	30	<1	1	31	130	100	94	<.1
Bedrock wells, open at about 200 feet below land surface														
458	3	3,800	3,900	150	5	1	20	19	1	990	50	<100	39	.1
469A	15	6,200	6,200	28	50	--	50	<1	1	33	160	<100	82	.1
473	19	1,500	1,600	100	96	--	30	<10	4	1,000	70	1,100	380	<.1
Bedrock well, open 44 to 100 feet below land surface														
460A	9	--	3,200	20	9	--	60	60	--	--	480	--	--	<.5
Bedrock well, open 150 to 203 feet below land surface														
458B	5	--	430	10	9	--	60	10	--	--	250	--	--	<.5

and springs in the Conasauga Group of eastern Tennessee (DeBuchananne and Richardson, 1956).

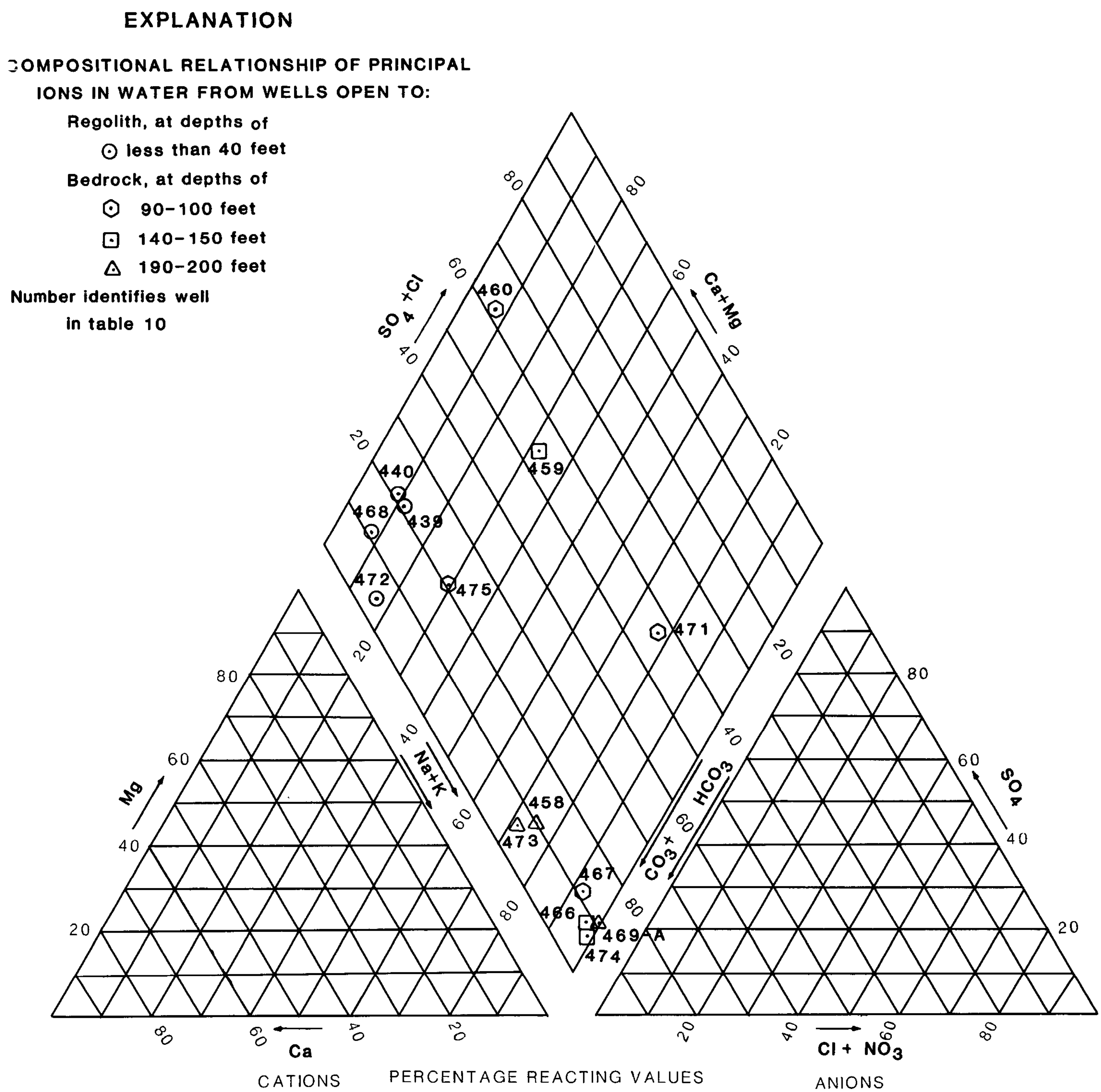
Principal ion data are plotted on a trilinear diagram (fig. 34) to show the difference in composition between water from the regolith and that from the bedrock. The close grouping together in the diamond's left corner of the four points representing the regolith wells shows a uniformity in the major constituents of water from the regolith. It also shows that water in this part of the aquifer is rich in calcium-magnesium/carbonate-bicarbonate.

Water from all of the regolith wells was enriched in dissolved manganese and nickel relative to water from the bedrock wells. Relatively high concentrations of strontium, zinc, suspended iron, dissolved iron, barium, chromium, copper, and lead were found in water from some of the regolith wells. While the presence of many of these metals and trace elements in ground water results partly from slight dissolution of the aquifer skeleton as water passes through it, it is highly probable that much of the mineralization in this area is due to the leaching of buried waste as infiltrating water passes through the trenches and is assimilated into the ground-water reservoir.

The other analyses in table 10 represent water from the bedrock. Analytical results of the well 458 sample in 1979 show a different principal ion composition than that of 1983. This probably is due to the presence of drilling water in the aquifer, even after slow pumping for 24 hours. The two analyses of water from well 460 four years apart are generally similar, although that of 1979 might also have been influenced to some extent by drilling water.

Dissolved-solids concentrations of samples taken in 1983 show that the water from most of the bedrock wells has relatively little mineralization. The average concentrations were 222 mg/L in water from the 100-foot piezometers, 255 mg/L in water from the 150-foot piezometers, and 357 mg/L in water from the 200-foot piezometers.

Although the mineralization is low, water in the bedrock is composed of high percentages of sodium and bicarbonate. The concentration of calcium, the predominant cation in the regolith water usually is much less than that of sodium, the predominant cation in the bedrock water. Magnesium content also tends to be less and potassium content tends to be greater, but the differences are not as pronounced as the calcium-sodium difference. The trilinear diagram (fig. 34) shows the difference in water composition between the regolith and at three horizons in the bedrock. Points for three 100-foot wells and one 150-foot well are scattered across the diamond, indicative of water having a mixed composition. Points for one 100-foot well, two 150-foot wells, and three 200-foot wells are clustered in the lower corner of the diamond, indicative of high sodium-potassium/carbonate-bicarbonate content of water. The diagram reveals a definite trend for the principal cationic composition of ground water below the site to change



Note: For each sample analysis, the percentage of cations and anions are plotted in the two triangles and the points are projected to the diamond. The location of the points within the diamond indicate the principal-ion composition (Piper, 1944).

Figure 34.--Trilinear diagram showing principal-ion composition of ground water at four depth intervals, burial ground 5.

with increasing depth from calcium in the regolith to sodium in the deeper part of the aquifer.

There is also a tendency indicated for the pH of water to increase with depth. The field pH of water from seven wells was greater than 9; that of three wells 150 to 200 feet deep was greater than 10.

Water from a few of the bedrock wells had relatively high concentrations of strontium, dissolved iron, aluminum, and lithium. The variety and amount of metals in water from bedrock is less than that of water from the regolith because high pH inhibits the solubility of many of the metals.

Analyses of water from two bedrock wells differ from the trend. Well 460, open to the aquifer from 90 to 100 feet, has water that in principal ion composition, trace metal concentration, pH, and tritium concentration more closely resemble that of the regolith than that of the bedrock. This well apparently receives fairly direct recharge from the regolith. This suggests that its open interval intercepts or lies close to a fracture or fault through which water is readily transmitted. Well 473 has water that is highly mineralized for this area. The water may be of connate origin and coming from greater depth via a concealed fault. Haase and others (1984, p. 33-34) reported finding a Na-K-Ca-Cl brine underlying fresh water in wells as much as 1,500 feet deep in a nearby area, and suggested its source is the lower Rome Formation or the underlying Chickamauga Limestone (fig. 3). It is also possible that some of the constituents in the water may represent water of dehydration from the grout used to set the casing. Less likely possibilities are that the well is receiving water that bleeds from the grout sheets injected at the hydrofracture plant, "relic water" migrating from the hydrofracture-test site to the east, or fluids from waste ponds in the reactor area of Melton Valley. The low hydraulic conductivity and depth of the open zone, the relatively long, slow flow path indicated in section A-A' of figure 32, and relative lack of tritium, despite the well's location in an area where thousands of curies of tritium have been buried, do not favor an interpretation of water tainted by the burial of waste at shallow depth.

The principal-ion data reflect depth of circulation and support the conceptual model of flow offered earlier. Sodium and potassium are among the most soluble constituents of rock, and are removed early in the rock-weathering process. The increasing prominence of these ions in water as depth increases indicates that relatively small amounts of water are circulating at depth. Consequently, the sodium and potassium in solution in the bedrock part of the aquifer have not been flushed out. In contrast, the concentration of these ions in regolith water is comparatively low because much of the sodium and potassium have already been leached and discharged from the system and, to perhaps some minor degree, the higher effective porosity of the regolith affords a slightly greater dilution factor. It is possible too that some fraction of the sodium ions in solution in the regolith have been exchanged for calcium ions on the mineral faces. The change in principal ion composition between 40 and 100 feet suggests that most of the water flows through the system at some depth less than 100 feet.