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

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U.S. GEOLOGICAL SURVEY
Open-File Report 87-686

Prepared in cooperation with the
U.S. DEPARTMENT OF ENERGY

Cover illustration shows water-table contours at burial ground 5 for typical late, mid-season condition, July 14, 1983, and general direction of ground-water.

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1988

DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS AND ABBREVIATIONS OF UNITS

Factors for converting inch-pound units to International System of Units (SI) are shown to four significant digits.

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare (ha)
foot per day (ft/d)	0.3048	meter per day (m/d)
square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
degree Fahrenheit (F)	0.5556 x (F - 32)	degree Celsius (C)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929".

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

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ABSTRACT

Burial grounds 4, 5, and 6 were used sequentially from 1951 to the present for the disposal of solid, low-level radioactive waste by burial in shallow trenches and auger holes. Abundant rainfall, a generally thin unsaturated zone, geologic media of inherently low permeability, and the operational practices employed have contributed to partial saturation of the buried waste, leaching of radionuclides, and transport of dissolved matter from the burial areas. Two primary methods of transport from these sites are by dissolution in circulating ground water, and the overflow of fluids in trenches and subsequent flow across land surface.

The waste-disposal areas are underlain by the Conasauga Group (Cambrian age), a complex sequence of mudstone, siltstone, and limestone interbeds grading from one lithotype to the other, both laterally and vertically. Compressional forces that caused regional thrust faulting also caused much internal deformation of the beds. Folds, bedding-plane faults, and joints are widespread. Small solution openings have developed in some areas where the structurally-related openings have provided ingress to ground water.

Both the regolith and bedrock sections of the aquifer are anisotropic, but anisotropy is more pronounced in the bedrock. The lower practical limit of ground-water circulation probably occurs at about 200 to 250 feet depth. A conceptual model of flow is described wherein the primary control on direction of ground-water flow changes from the water-table gradient in the regolith to the hydraulic head distribution within the secondary openings of the bedrock and the three-dimensional geometry of those openings. Locally, the direction of flow in the regolith also is controlled by gradients within openings in certain relatively resistant beds and structurally-related features. Hydraulic conductivities as measured by slug tests of wells range from 2.9×10^{-3} to 6.7 feet per day in the regolith, and 1.5×10^{-4} to 1.9×10^{-1} feet per day in bedrock at depths of 100 to 200 feet.

Whiteoak Creek and its tributaries receive all overland flow from trench spillage, surface runoff from each site, and discharge of ground water from the regolith of each site. Potentiometric data indicate that this drainage system

also receives ground water discharged from the bedrock of burial ground 5. By projection of the bedrock flow patterns characteristic of this site to other areas of Melton Valley, it is inferred that discharge from the bedrock underlying burial grounds 4 and 6 also is to the same drainage system. The differences in potentiometric heads and a comparatively thin saturated zone in bedrock do not favor the development of deep flow through bedrock from one river system to another.

Hydraulic potentials, hydraulic conductivities, and hydrochemical data indicate that most ground water in the aquifer flows through the regolith. A smaller amount of water flows through the bedrock, where the flow paths are longer in distance and the time of travel is considerably greater. In burial ground 5 the regolith section of the aquifer has widespread contamination, principally by iron, tritium, and strontium-90. Contamination decreases substantially with increasing depth in bedrock, particularly below 100 feet.

The sites have received little monitoring because they have not been considered a hazard. As improvements in plant facilities have reduced the discharge of radionuclides to the Whiteoak Creek system, the discharge of contaminants from the burial grounds has become relatively more significant. The burial grounds are now a principal source of ^{3}H and a major contributor of ^{90}Sr in the discharge of Whiteoak Creek to the Clinch River.

INTRODUCTION

Oak Ridge National Laboratory (ORNL) is a nuclear-energy research center, located in eastern Tennessee, about 25 miles west of Knoxville and 150 miles east of Nashville. It is one of three major facilities in the Oak Ridge Reservation that are administered by the U.S. Department of Energy. ORNL, like the other two facilities, resulted from the World War II effort to produce a weapon powered by a fissionable fuel. A by-product of this effort and the many subsequent research programs at the Laboratory has been the production of large volumes of solid, liquid, and gaseous wastes contaminated by radioactive matter. Common practice at ORNL, as well as at several sister federal installations in the United States, has been to dispose of the solid-waste fraction having "low-level activity" by burial in shallow trenches. The trenches are located in dedicated sites termed "burial grounds" or "solid-waste storage areas". To date (1985), five sites at ORNL have been used sequentially, and a sixth site presently receives waste. The first three burial grounds are comparatively small sites, and are located in Bethel Valley (fig. 1) in proximity to what were, at the time of use, the principal sources of waste generation. Burial grounds 4, 5, and 6 are larger, and are sited in Melton Valley, the adjacent valley to the southeast.

Trench disposal of radioactive waste is a modification of the common practice of burying municipal waste in sanitary landfills. The practice presumes that the radioactive contaminants will be stored in the geologic media at least until such time as the natural process of radioactive decay renders those contaminants harmless to

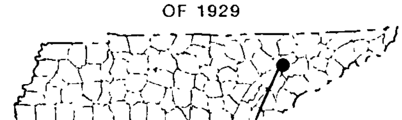
Base from USGS-TVA Bethel Valley, Lenoir City, and Lovell, 1:24,000, 1968

0 1 2 MILES

0 1 2 3 KILOMETERS

CONTOUR INTERVAL 20 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929



OAK RIDGE NATIONAL LABORATORY

EXPLANATION

[2] RADIOACTIVE-WASTE BURIAL GROUND AND SITE NUMBER

P-1 LIQUID-WASTE DISPOSAL PIT (P) OR TRENCH (T) AND SITE NUMBER, IN INTERMEDIATE-LEVEL WASTE AREA

HF-1 • HYDROFRACTURE INJECTION WELL--Wells designated by number

Figure 1.--Topographic features of the Oak Ridge National Laboratory area and location of the waste-disposal areas.

man. Although it is unlikely that the role of water in transporting interred substances was given consideration when this practice began, water now is recognized as the principal mechanism by which contaminants are mobilized and transported to the biosphere. Indeed, the containment of contaminants in the geologic media is a complex function of many hydrologic, geologic, and chemical factors, but of these, those involving water are paramount.

Streams draining the ORNL complex are known to contain radionuclides from several sources. For more than a decade, the ORNL burial grounds have been identified as one of those sources. This implies ground-water transport of contaminants from those sites and discharge into the streams. Recognizing that if the trench burial of contaminated waste is to remain a viable approach to disposal, the Department of Energy, as responsible steward of the nuclear-energy complex, has authorized studies aimed at reducing the mobility of the interred radionuclides, developing improved technology for radioactive waste disposal, and defining the probable pathways of radionuclide migration. The participation of the U.S. Geological Survey in this effort represents one of those studies.

Study of the Melton Valley waste-disposal areas has been made in cooperation with the Department of Energy's Oak Ridge Operations Office.

PURPOSE AND SCOPE

This report discusses the hydrology of burial grounds 4, 5, and 6 in order to provide information leading to (1) the design of surveillance networks for monitoring radionuclide migration from these sites, (2) the development of numerical models that simulate the ground-water flow system at each of them, and (3) the evaluation of measures proposed to reduce the transport of radionuclides in water from the burial grounds. Conceptual models of two- dimensional ground-water flow at burial grounds 4, 5, and 6, and of three- dimensional flow at burial ground 5, are developed. The three-dimensional concept is projected to burial grounds 4 and 6, although potentiometric data of the bedrock in those areas is not available to support the interpretation. Consideration of the surface-water system is included, but is necessarily brief because records are of inadequate duration. The chemical quality of water from 16 wells in burial ground 5 also is discussed and related to the conceptual flow patterns at that site.

The investigation is continuing. Much work remains to be done in order to fully understand the complexly interrelated geology, hydrology, and chemistry of this system. The interpretations provided herein summarize current understanding of the hydrology of these sites and provide a basis upon which others in this and related fields can build.

OTHER STUDIES

Owing to the biological hazard associated with radioactivity and the uncertainty regarding the fate of radionuclides committed to the earth, numerous studies have been made into the field of radioactive-waste disposal at shallow depth and related areas. The investigations cover many disciplines, reflecting the multifaceted nature of the problem. Those studies having a close relation to this one are cited in the following statements. Additional studies are listed under "Selected References".

The first investigator to study a specific area within Melton Valley for its waste-disposal potential was Barnett (1954), who mapped and described the geology of the area between burial grounds 4 and 6. McMaster (1962, 1963) mapped and prepared a short description of the geology of the Oak Ridge Reservation. Haase and Vaughn (1981) identified six formations of the Conasauga Group that underlies Melton Valley, and Haase and others (1985) described those units and the underlying Rome Formation in detail.

The burial grounds have been the subject of several investigations. A study of burial ground 4, after the waste-burial operation had terminated, was made by Lomenick and Cowser (1961). Investigations to determine the suitability of areas that became burial grounds 5 and 6 were made by Cowser and others (1961), and by Lomenick and Wyrick (1965), respectively. A review of hydrologic and geologic conditions at burial grounds 1 through 6, as of 1974, was made by Webster (1976); the current work is an outgrowth of recommendations made therein. In anticipation of need for another burial ground after space in the site currently used becomes exhausted, a study of proposed burial ground 7 has been described by Rothschild and others (1984a).

The former practice of discharging intermediate-level radioactive liquid waste[1] into open pits and trenches, located in the "ILW area" between burial grounds 4 and 6 (fig. 1), has been described in several reports. Among them are papers by deLaguna (1956), and deLaguna, Cowser, and Parker (1958). Recently, a discussion of the chemical, geologic, and hydrologic factors controlling radionuclide migration from ILW trench 7 was prepared by Olsen and others (1983).

The hydrology of the local streams was discussed by McMaster (1967), and water quality of the surface-water system described by Pickering (1970).

Water-level data for wells in burial grounds 3, 4, 5, and 6 from 1975 to 1979 were reported by Webster and others (1981b, 1981a, 1982a, and 1980, respectively). Subsequent water-level data, precipitation data, chemical analyses of well water and stream discharge data are in the files of the U.S. Geological Survey. The data in these reports and files provide part of the foundation for the interpretations herein.

ACKNOWLEDGMENTS

Many persons at Oak Ridge National Laboratory have contributed to this endeavor. In particular, the authors cite C.S. Haase whose concurrent study of the Conasauga Group has provided an understanding of the complex geology of the waste-disposal area, and portions of whose work have been summarized to describe

[1]Intermediate-level radioactive waste is an ORNL term not generally recognized by the nuclear industry. It refers to liquid wastes having activity levels higher than that feasible for treatment in ORNL's waste-water treatment plant.

the geologic setting given herein; personnel of the Plant and Equipment Division who frequently provided logistical support and participated in the construction of numerous shallow wells; R.E. Holmes and others of the Engineering Division, who furnished maps and updated survey data as needed for the interpretation of the water-level data; T.G. Scott, Hugh Parker, and N.M. Ferguson of the Analytical Chemistry Division, who performed radiochemical and trace-metal analyses of water samples; and many persons in the Environmental Sciences Division who supported the work with friendly help, encouragement, and innumerable thoughtful discussions concerning their field of expertise as it pertains to the waste-disposal areas. The authors also express their appreciation to Oak Ridge National Laboratory; Martin Marietta Energy Systems, Incorporated, which operates the Laboratory for the U.S. Department of Energy; and Accu-Air Surveys for permission to include materials from maps prepared by those organizations.

THE OAK RIDGE NATIONAL LABORATORY GRID

The terms north, south, east, and west as used in much of the literature of the waste-disposal areas are referred to the ORNL grid system, a relic of ORNL's World War II years. The orientation of the grid follows that of the ridges and valleys, with north, south, east, and west rotated about 34° counterclockwise of the true compass directions. Directions as used in the text of this report follow standard convention rather than those of the ORNL grid. Arrows depicting both true north and ORNL north are shown on those maps made from an ORNL base. Although geology was not a consideration in devising the grid system, it is not fortuitous that ORNL east-west corresponds to the direction of regional formation strike, and ORNL south, to the direction of regional dip.

PHYSIOGRAPHY

TOPOGRAPHY AND DRAINAGE

ORNL is located in the Tennessee section of the Valley and Ridge Province, (Fenneman, 1938), an area characterized by a series of multiple, northeast-trending valleys and ridges. The Laboratory facilities extend across a succession of alternating ridges and valleys which, starting at the Clinch River and progressing to the northwest, are Copper Ridge, Melton Valley, Haw Ridge, Bethel Valley, and Chestnut Ridge (fig. 1). The valley floors are at altitudes of about 800 feet above sea level; the ridges culminate at altitudes of about 1,000 to 1,300 feet above sea level.

Melton Valley is about $4^{1}/_{2}$ miles long and 1 mile wide. Its northeast and southwest ends are terminated by impounded segments of the Clinch River as that river makes a broad bend around Copper Ridge. Below the steep hills of the ridge along the northwest side of the valley is a line of foothills having a maximum relief of about 100 feet. It is on these hills in the southwest half of the valley that the radioactive-waste disposal operations in burial grounds 4, 5, and 6 have been carried out.

Many valleys of this area are characterized by a high drainage density. In Melton Valley numerous short tributaries to the principal streams occur at intervals seldom greater than 2,000 feet. Because of drainage density and burial ground size, drainages are included within each burial ground, and one or more drainages provides a natural boundary to each site.

Surface drainage in the ORNL area trends to the southwest. Whiteoak Creek, one of several small streams in Bethel Valley, rises from springs on Chestnut Ridge, drains the Bethel Valley section of the complex, passes through a water gap in Haw Ridge to enter Melton Valley, receives the flow of Melton Branch, and discharges to Watts Bar Lake, an impounded section of the Clinch River. Twenty miles downstream from the mouth of Whiteoak Creek, the Clinch River empties into the Tennessee River, the master drainage of the region.

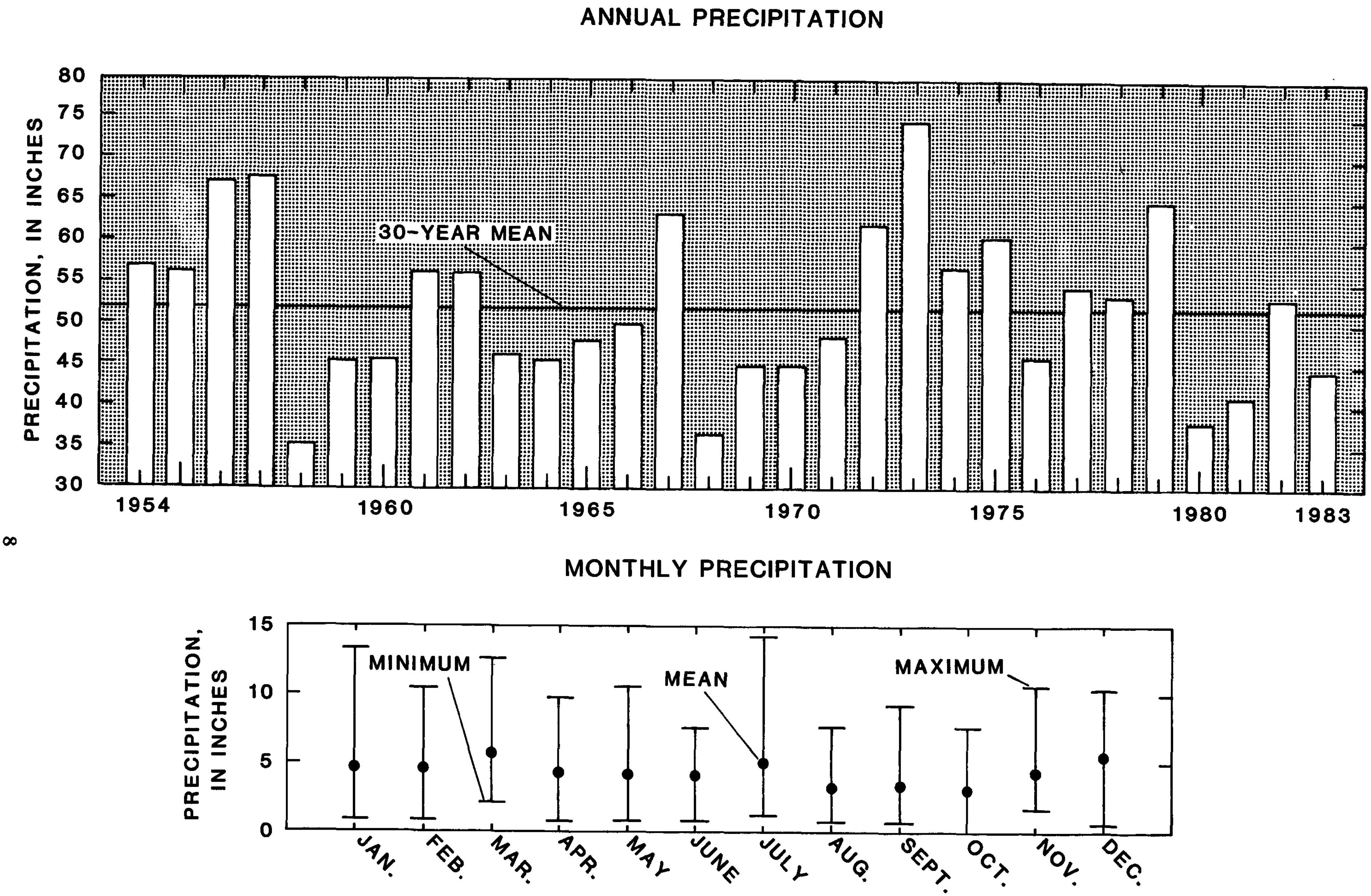
CLIMATE

Eastern Tennessee characteristically has a warm, humid climate. The mean annual air temperature at ORNL for the period 1945-64 was 14.5 °C. Mean annual precipitation at stations in the environs of ORNL during the period 1954-83 was 52.2 inches (Air Resources Atmospheric Turbulence and Diffusion Laboratory, 1972; Gray Henderson, ORNL, written commun., 1976; Webster and others, 1982b; D.A. Webster and B.W. McMaster, U.S. Geological Survey, written commun., 1984). Minimum and maximum precipitation were 35.3 inches and 74.8 inches, respectively, or -32 percent and + 43 percent of the norm. It is worthy of note that the Oak Ridge facilities have the highest mean annual precipitation of all the radioactive solid-waste burial grounds in the United States.

Mean monthly precipitation during the 30-year period ranged from 3.01 inches in October to 5.74 inches in March, but the variability in monthly precipitation is much greater than this narrow range implies. During the period of record, each month has been very dry at least once and also very wet at least once. Variability in both the monthly and annual precipitation is shown in figure 2.

Storm events occur with a relatively high frequency, or conversely, periods having sustained lack of precipitation occur with low frequency. Periods of 5 or more consecutive days without measurable rainfall may occur as many as 20 times per typical year; periods of 10 or more consecutive days, 3 to 6 times; and periods of more than 10 consecutive days, 2 to 4 times. The absence of rain over a 30-day interval is rare.

The ability of each site to hold radionuclides buried in shallow trenches is related to climatic factors. The relative abundance of rain throughout the year (1) sustains the water table at shallow depth; (2) contributes to the development of a high drainage density, thereby reducing the distance of contaminant travel and the period of contaminant residence below ground; (3) enhances lower soil pH's and influences the development of specific clay minerals, factors that can control or modify the transport of radioactive ions; and (4) less directly, influences the composition of the natural biological community, which also is a factor in contaminant mobility (Richardson, 1963).



1954-71: Air Resources Atmospheric Turbulence and Diffusion Laboratory, 1972; 1972-75: Gray Henderson, ORNL, written commun., 1976; 1976-80: Webster and others, 1982b; 1981-83: D.A.Webster and B.W.McMaster, USGS, written commun, 1984.

Figure 2.--Variability in annual, monthly, and mean monthly precipitation at Oak Ridge National Laboratory, 1954-83.

SOILS AND VEGETATION

Soils developed in the warm humid climate of this area are strongly leached and low in organic matter. Soils in the burial ground areas are silty, although considerable clay is present, and acidic in reaction with a range in pH from about 4.5 to 5.7 (Carroll, 1961, p. 12). The depth of true soil development generally is thin. The subsoils in which waste is buried usually consist of moderately- to highly-weathered rock.

Natural vegetation at the sites consists of mixed stands of deciduous and coniferous trees. Burial ground 4, located in a lowland, probably was a cultivated field or pasture before being incorporated in the Oak Ridge Reservation in 1942. Burial grounds 5 and 6 were heavily-wooded areas before they were developed as disposal sites.

The significance of vegetation is two-fold. First, the trees have been replaced by grasses which transpire less water from the subsurface, thereby altering components of the hydrologic budget from the natural condition. Second, if the burial grounds were not maintained in grasses, trees would re-establish themselves in these areas through natural succession. Their deep roots would extend into the buried waste, contaminated subsoils, and in some places the zone of saturation, and bring radioactive contaminants to land surface in woody material and leaf litter, which upon decay could be transferred to the atmosphere as airborne dust and debris and to the drainages as particulate matter. Trees thus have potential to provide a major new pathway for contaminant transport that is not further considered herein.

SUMMARY OF SITE CHARACTERISTICS

Some of the more pertinent physical characteristics and historical data of burial grounds 4, 5, and 6 are summarized in table 1. The reader is referred to publications cited under "Selected References," particularly those by Webster (1976, 1979) and Evaluation Research Corporation (1982), for greater detail.

Two non-standard conventions pertaining to descriptions of burial grounds 4 and 5 have been used in this report. First, one of the maps of burial ground 4 (fig. 6) includes two boundaries on the south and east perimeter of the site. The exact boundary of this burial ground is not known because maps and other records of the disposal site were destroyed in a fire. It is thought that the boundary based on ORNL drawing 58754 more closely approaches the actual perimeter of the site inasmuch as it is based on earlier record. The other indicated boundary reflects the perimeter of the disposal area based on present features. Second, the description of burial ground 5 in table 1 of this report is divided into two sections. The southern section, referred to as the "5-south" area, is where disposal operations continued after burial ground 4 was closed. The "5-north" area, a later addition to burial ground 5, contains the facilities for the retrievable storage of transuranic (TRU) waste.

Surprisingly little detail is known of the waste that has been consigned to burial owing to the difficulty and impracticality of describing and assaying the materials that become contaminated trash. A summary statement can be made that the waste consists of a wide variety of

Table 1.--*Summary of burial-ground characteristics, by site*

Site	Size, in acres (hectares)	Period of use	Characteristics
4	23 (9.3)	1951-1959	Developed near the bottom of a small drainage basin adjacent to Whiteoak Creek and a small tributary stream. Central part of site is crossed by three drainages with ephemeral flow. Trenches in some areas, particularly in central area and low-lying areas were excavated below the water table. Fill and other construction debris were deposited over trenches after site closure, principally on eastern end where land surface has been raised by as much as 10 feet. French drain excavated in 1983 along sections of Lagoon Road (north boundary of site) to intercept surface runoff from Haw Ridge and some of ground-water recharge to site.
5-south	57 (23.1)	1958-1973	Developed on hillside of gentle to moderate slope; total relief about 100 feet. About 70 percent of site perimeter lies adjacent to drainages (Whiteoak Creek, Melton Branch, and two tributaries); south face bisected by tributary with nearly perennial discharge. Trenches in low-lying areas penetrate the water table.
5-north	25 (10.1)	1970-present	Contains 9-acre section referred to as the "TRU area" for the retrievable storage of Class B Transuranic Waste (wastes having measurable radiation greater than 10uCi/kg). TRU area is developed on hillside of gentle to moderate slope; bordered on west by Whiteoak Creek and to north and south by tributaries having seasonal flow.
6	68 (27.5)	1973-present	Developed on hillside of gentle to moderate slope. Bounded on south by Whiteoak Lake and on east by a drainage having seasonal flow. Site is crossed by three small drainages having seasonal flow. Trenches in some areas have been cut below the water table; since 1975, effort has been made to restrict length and depth. French drain 826 feet long, 30 feet deep, constructed in central part of site in 1983, now intercepts local ground-water flow.

material; it has been packaged in an assortment of containers, or often in no container at all; it has originated at facilities nationwide; it includes a broad spectrum of radionuclides; and it contains levels of activity ranging from very low to high, even though the ORNL waste does not meet the nuclear industry's definition of "high-level waste"; succinctly, the waste is heterogeneous and it is radioactive.

The waste materials for the most part have been loosely dumped into trenches that usually are not over 15 feet deep but are of variable length, width, and orientation. Auger holes as much as 3 feet in diameter have been used for the disposal of certain categories of waste. Trenches with alpha emitters in burial ground 4 and initially those in burial ground 5, and the auger holes in burial grounds 4, 5, and 6, have been capped with concrete and then covered by spoils from the excavation. Trenches with beta-gamma activity at all three sites have simply been backfilled with spoils.

From the standpoint of hydrology, the two most significant factors are (1) the existence in the subsurface of a loosely-packed, potpourri of radioactive trash differing greatly in physical properties from the native material that surrounds it; and (2) its interment in some areas below the present water table.

GEOLOGIC SETTING

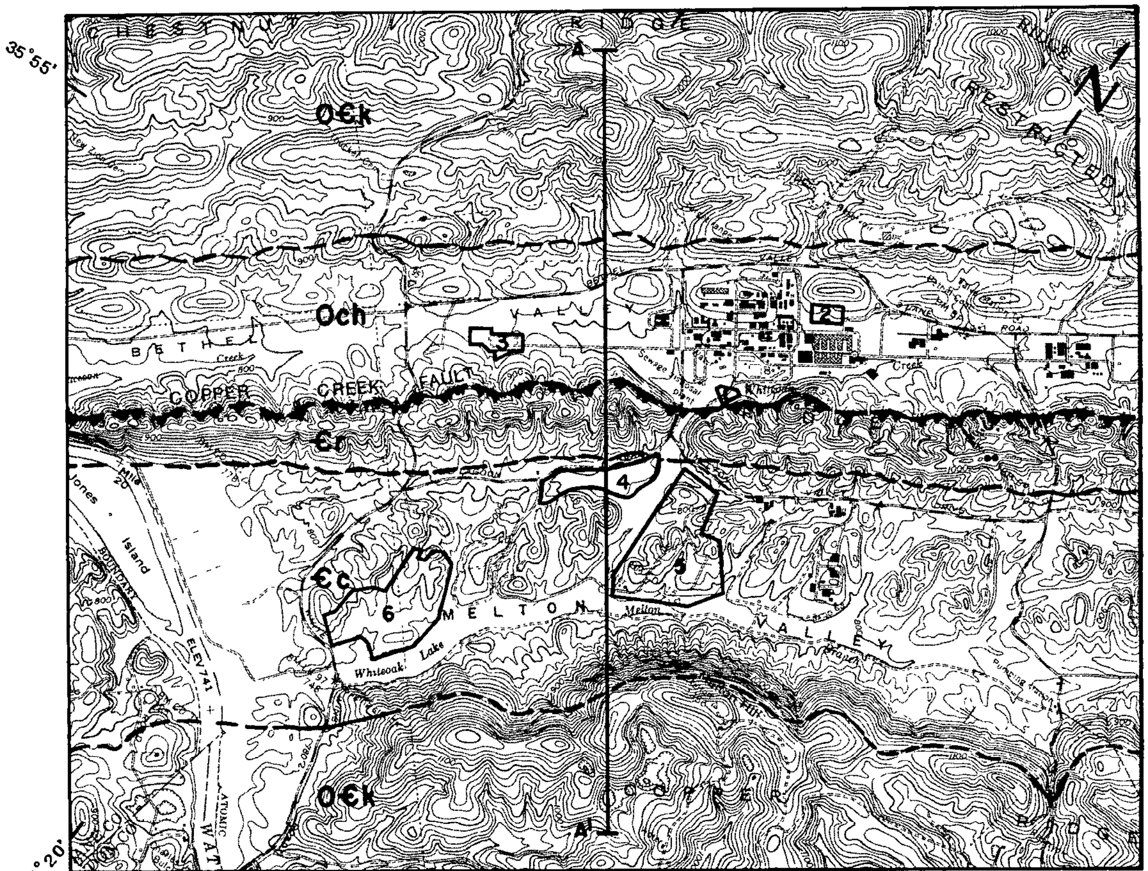
STRATIGRAPHY

The ORNL area spans, in ascending order, four major geologic units: the Rome Formation of Early and Middle Cambrian age, the Conasauga Group of Middle and Late Cambrian age, the Knox Group of Late Cambrian and Early Ordovician age, and the Chickamauga Limestone of Middle and Late Ordovician age (McMaster, 1962). These units underlie Haw Ridge, Melton Valley, Chestnut Ridge and Copper Ridge, and Bethel Valley, respectively (fig. 3). All of the Melton Valley waste-disposal facilities have been developed on the Conasauga.

The Conasauga Group is a marine, shelf deposit of variable lithology. In the east central part of Tennessee, the Conasauga consists of a complex sequence of clastic-rich units alternating with carbonate-rich units, representing a transitional zone between the shallow-shelf and deep-shelf environment. Estimates of its thickness in the Oak Ridge area range from about 1,500 feet (McMaster, 1963, p. 10) to nearly 1,900 feet (Haase and others, 1985).

Six formations assigned to the Conasauga Group have been recognized in core from numerous wells in Melton Valley and in Bear Creek Valley, which lies immediately northwest of Chestnut Ridge (Haase and Vaughn, 1981, p. 8). The formations are, in ascending order, the Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, Maryville Limestone, Nolichucky Shale, and Maynardville Limestone.

Summary descriptions of the formations, from the work of Haase and others (1985), follow. The Pumpkin Valley Shale is informally divisible into a lower member, consisting of non-calcareous siltstone with interbeds of mudstone, siltstone, and fine-grained sandstone, and an upper member, consisting of mudstones and



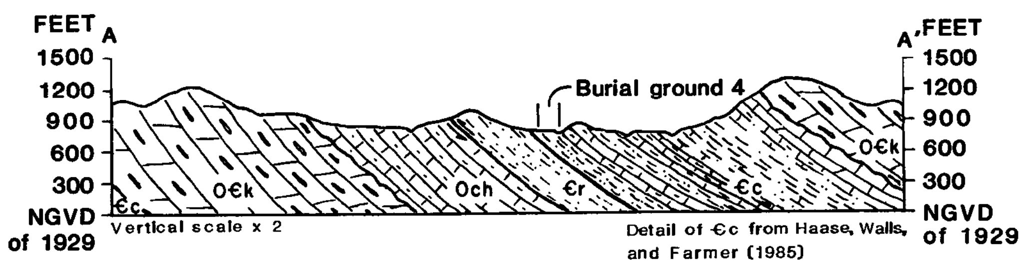
Base from USGS-TVA Bethel Valley, Tennessee, 1:24,000, 1968

Geology by W. M. McMaster, 1962

0 1000 2000 3000 4000 FEET

0 500 1000 METERS

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL
DATUM OF 1929



EXPLANATION

Och	CHICKAMAUGA LIMESTONE
O€k	KNOX GROUP
€c	CONASAUGA GROUP
€r	ROME FORMATION

BURIAL GROUND AND NUMBER

CONTACT

THRUST FAULT--Sawteeth on upthrown block

FAULT--Arrows indicate relative direction of movement

Figure 3.--Geologic map of the Oak Ridge National Laboratory area and section along line A-A'.

shales interbedded with siltstone. Major constituents of the Rutledge Limestone are calcareous mudstone and shale, and limestone with clastic impurities. Mudstone and siltstone are interbedded with these rocks. Much of the Rogersville Shale is comprised of mudstones and siltstones. Geophysical logs show a distinct carbonate-rich interval about 5-feet thick near the center of the Rogersville that has not been reported elsewhere. The Craig Limestone Member, another carbonate-rich interval found over a wide area of eastern Tennessee, occurs close to the top of the formation.

The lower part of the Maryville Limestone consists of calcareous mudstone interbedded with other clastic and impure carbonate beds. The upper part of the formation is more carbonate rich. It contains the thickest and purest carbonate beds underlying the burial grounds, with limestone beds as much as 10 inches thick having been reported at burial ground 5-south (Cowser and others, 1961, p. 9).

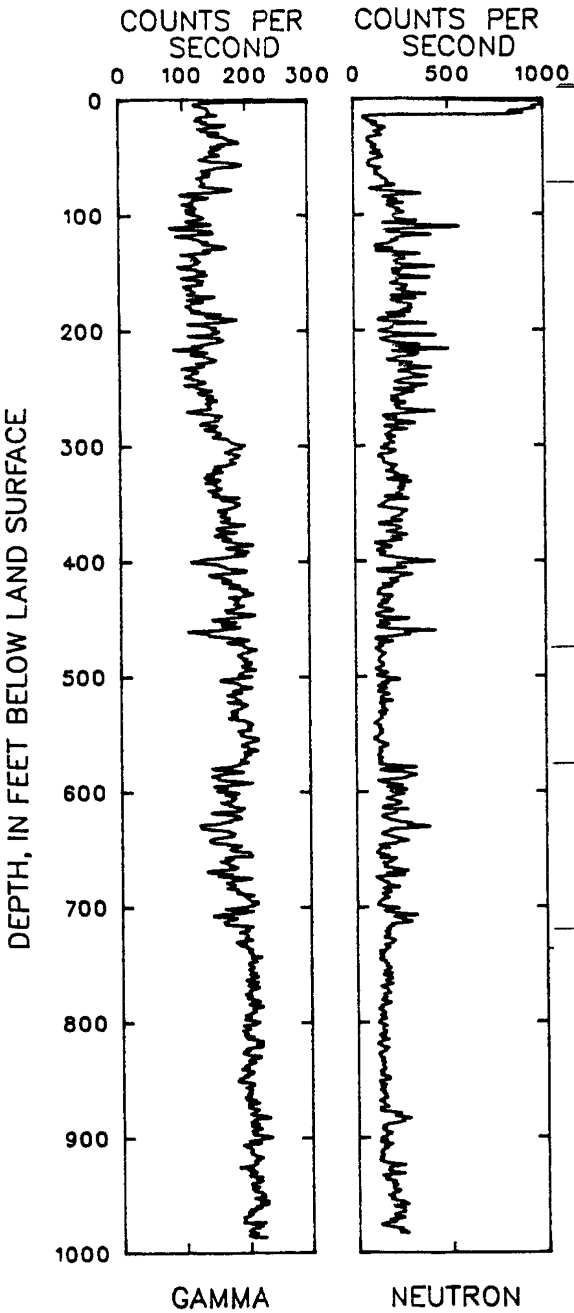
About four-fifths of the Nolichucky Shale is assigned to the lower shale member. It consists of cycles of mudstone or shale interbedded with limestone. The clastic components are the dominant lithology, particularly in the lower part. This lower member is overlain by a middle member, predominantly carbonate, and the upper shale member, consisting of calcareous mudstone interbedded with siltstones and carbonates.

The Maynardville Limestone is a transitional unit between the shale of the Nolichucky and the dolomite of the Knox Group, and consists of two carbonate members. The lower member is characterized by limestone with interbedded impure carbonate strata; the upper member, by oolitic and dolomitic limestone.

Bedding has considerable variability, both within a formation and from formation to formation, and has been described by such terms as thick, thin, wavy, lenticular, ribbon-like, bioturbated, planar, nodular and pelloidal.

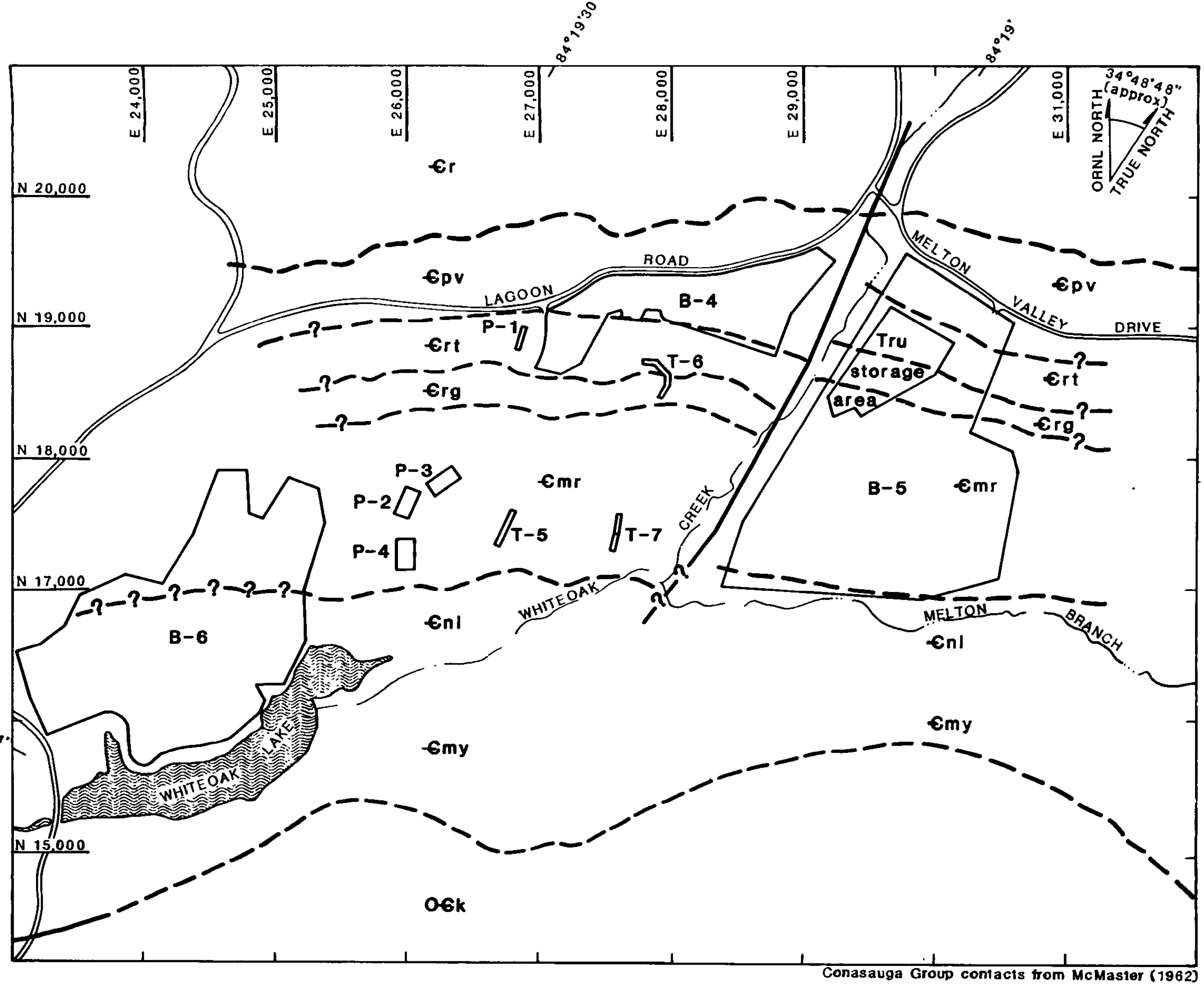
The variable lithology of the middle and lower formations of the Conasauga is shown in figure 4 by the gamma and neutron logs of well OW-6, located in the center of Melton Valley near burial ground 5. Lithologic description, based on core from the Joy No. 2 well, has been added to the illustration. A close comparison of geophysical logs of wells in the waste-disposal areas often shows some degree of lateral change in lithology, even over relatively short distances. Many also show a thickening or thinning of beds. These are normal changes characteristic of the depositional environment. Logs examined of some wells are sufficiently different that they can not be correlated to specific intervals within a formation although the formation they represent can be identified. The difference in log responses may represent significant changes in facies or post-depositional structural adjustments such as folding or imbrication.

With the logs of several wells in the waste-disposal area, the contacts of the formations intercepted by the wells can be correlated, and those contacts projected to land surface to prepare an elementary geologic map of the area (fig. 5). The contacts shown on that map should be regarded as approximate in view of the inconsistency in angle of dip. The contact of the



Formation	Apparent thickness, in feet (a) Joy No. 2 well (b) Waste-disposal area; * where unknown	Summary description of core from Joy No. 2 well, 2.8 miles northeast of well OW-6 (from C.S. Haase, E.C. Walls, and C.D. Parmer, 1985)
Nolichucky Shale	(a) 551 (b) *	Lower shale member; repeated cycles of shale and limestone (calcarenites, packstones, wackestones, and conglomerates).
Maryville Limestone	(a) 463 (b) as much as 390	Conglomerates interbedded with mudstone, micrite, dolomitic wackestone, calcarenite, and packstone. Calcareous, mudstone interstratified with wackestone, calcarenite and calcareous siltstone.
Rogersville Shale	(a) 130 (b) 70 - 110	Mudstone, calcarenite, and siltstone.
Rutledge Limestone	(a) 101 (b) 80 - 140	Micrite, wackestone, packstone, calcarenite, and mudstone. Mudstone, shale, and subarkosic siltstone. Wackestone, calcarenite, interbedded with shale and mudstone.
Pumpkin Valley Shale	(a) 309 (b) 240 - 300	Mudstone and shale interbedded with siltstone. Siltstone interbedded with mudstone and siltstone.

Figure 4.--Gamma and neutron logs of well OW-6, and lithologic summary of corresponding interval at Joy No. 2 well.



EXPLANATION

0 400 800 1200 1600 FEET
0 400 METERS

ORDOVICIAN	OЄk	KNOX GROUP	
CAMBRIAN	-Єmy	MAYNARDVILLE LIMESTONE	CONASAUGA GROUP
	-Єnl	NOLICHUCKY SHALE	CONASAUGA GROUP
	-Єmr	MARYVILLE LIMESTONE	CONASAUGA GROUP
	-Єrg	ROGERSVILLE SHALE	CONASAUGA GROUP
	-Єrt	RUTLEDGE LIMESTONE	CONASAUGA GROUP
	-Єpv	PUMPKIN VALLEY SHALE	CONASAUGA GROUP
	-Єr	ROME FORMATION	

B-4 BURIAL GROUND AND NUMBER

FAULT

FORMATION CONTACT--Approximately located

N 19,000 OAK RIDGE NATIONAL LABORATORY GRID COORDINATE

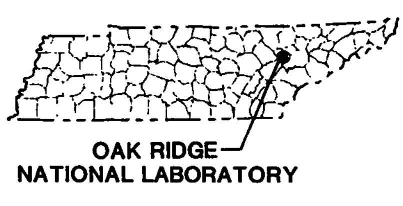


Figure 5.--Geologic map of the Conasauga Group in the Melton Valley waste-disposal area, based on projection of contacts interpreted from geophysical logs.

Nolichucky Shale with the Maynardville Limestone on the lower northwest slope of Copper Ridge is not shown on figure 5 because log or core data are not available for this area.

The geologic map is useful for determining the formations that underlie each disposal site. Much of burial ground 4 is underlain by the Pumpkin Valley Shale; its southwestern extremity and possibly a small area near the drainage along its southern border are underlain by the Rutledge Limestone. The TRU area of burial ground 5 is underlain by the Rutledge Limestone and the Rogersville Shale. Much of the 5-south area of burial ground 5 is underlain by the Maryville Limestone; the low area near Melton Branch is underlain by the lowermost beds of the Nolichucky Shale. ILW pits 2, 3, 4, and ILW trenches 5 and 7 are underlain by the Maryville Limestone. Burial ground 6 is underlain by the upper Maryville Limestone and the Nolichucky Shale, although the location of the contact between the two formations across the site is tentative owing to inexact correlations between logs of only three wells at this site with those of well OW-6.

STRUCTURE

The predominant structural feature in the Tennessee section of the Valley and Ridge Province is a series of sub-parallel, northeast trending thrust faults. These faults have broken the substrata into a series of thrust blocks, with the block on the southeast overriding the adjoining block to the northwest. The trace of the Copper Creek fault, one of the regional thrust faults, traverses the northwest face of Haw Ridge (fig. 3) and extends across the width of Tennessee. Along this plane the Copper Creek fault block, which includes Melton Valley and the area to the southeast, was displaced northwesterly about 7,200 feet over the White Oak Mountain fault block, on which Bethel Valley has developed (McMaster, 1963, p. 19). As a result of spasmodic thrusting, the beds in the blocks were tilted to the southeast, and further broken and internally deformed by folds, faults, and other structural features of local extent.

It is these secondary features that are of hydrologic interest. Folds are a common, although inconsistent feature of the Conasauga Group through Melton Valley. They have been found in trenches excavated at burial grounds 4, 5, and 6, in drill core at the Four Acre Site and at proposed burial ground 7, in pits at the ILW area, and in exposures along road cuts. The folds vary in type, intensity, and continuity. The strata most affected are the thin-bedded shales and mudstones, but all lithologic types have been deformed to some degree.

Joints and fractures are prevalent. Joints are particularly associated with the shale and siltstone strata. While fractures are found in all of the lithologies present, small-scale fractures are particularly common in the thicker, carbonate-rich members. The degree of joint openness may be related to lithology. Haase and others (1985, p. 63), in examining core from the Joy No. 2 well, noted that joints in limestone and siltstone were partially to completely filled by secondary mineralization. Fractures in the limestone units are the most likely to be filled by secondary mineralization.

Faults are a common structural feature of this area. Perhaps the most common type of fault are the bedding faults where beds have slid over each other along bedding planes. These faults are particularly associated with the thin- and medium-bedded strata. They are evidenced by drag folds and other signs of disturbance in trench cuts; slicksided discs, mylonite zones, and rubble zones in core from deeper horizons; and televiewer logs of wells. There are also many high-angle faults of short length and displacement. Such faults have been observed in several shallow trench cuts in burial ground 6, along the excavation for the French drain at that site (Davis and Stansfield, 1984, p. 41-53), and in core from deeper horizons elsewhere. Haase and others (1985, p. 60) found this type of fault to be more abundant in the lower three formations of the Conasauga than in the upper three.

A transverse (or tear) fault appears to underlie the water gap through Haw Ridge and the Whiteoak Creek flood plain to the south. The fault is evidenced by the displacement of the formations to the east and west of Whiteoak Creek (fig. 5) and the non-alignment of the resistant peaks of the Rome Formation across the water gap (fig. 1). The displacement of the formations indicates that the east block moved northerly relative to the west block, whereas the non-alignment of peaks indicates the opposite relative direction of movement, which suggests that other complicating structural conditions are present. Haase (ORNL, written commun., 1981) has sugggested that the sub-block containing burial ground 5 has been tectonically rotated so that it is out of alignment with other areas of Melton Valley. To the east, Rothschild and others (1984a, p. 22) found that a series of thrust faults in proposed burial ground 7 resulted in the imbrication of strata at that site. To the west, deLaguna and others (1958, p. 106) believed that a fault, possibly a thrust fault related to the Copper Creek fault, lies to the south of the 200-foot wide belt of crumpled rock found at ILW pit 4. Although yet unproven, it is thought that a few of the north-south tributary drainages that have been etched into the line of low hills on the northwest side of the valley may have developed over transverse faults that have broken the bedrock into additional sub-blocks.

The formations strike northeasterly at about 55 degrees; dip is to the southeast at angles commonly ranging from 20 to 25 degrees at the Four Acre Site (Barnett, 1954, p. 2) and from 30 to 40 degrees in the ILW area and at burial ground 6 (deLaguna and others, 1958, and Lomenick and Wyrick, 1965, p. 3, respectively). Rothschild and others (1984a, p. 30) reported a mean dip from 29 measurements of 23^{o}SE at proposed burial ground 7. Because of the deformation of beds, however, there are many departures from the range cited, and locally the angle of dip may range from horizontal to vertical. On the limbs of folds dip may even reverse direction.

Dip also changes with depth. The overall trend is from an average dip of perhaps 20 to 25 degrees at land surface to nearly horizontal at a few thousand feet depth.

Dip between widely-spaced points can be calculated from stratigraphic correlations of the geophysical logs. The elevations of the Maryville-Rogersville contact and the Rutledge-Pumpkin Valley contact at several wells were determined and dips were calculated for groups of three wells each by solving three-point problems (table 2). Dips in Melton Valley between the wells cited range from 14 to 18 degrees southeast. Dip determined by this approach includes the effect of compression of strata by folding and faulting as well as possible fault-block movement between the three points, and thus is expected to be somewhat less than dip measured at outcrops. The range in dips reported by the several studies reflects the structural complexity of Melton Valley.

Table 2.--*Calculated approximate areal dip of strata in the waste-disposal area, based on contacts picked from gamma and neutron logs of wells*

Maryville-Rogersville contact				Rutledge-Pumpkin Valley contact			
Well numbers			Approximate dip	Well numbers			Approximate dip
400-S	600-N	OW-6	16° SE	OW-6	400-S	600-N	18 1/2° SE
400-S	469	OW-6	14 1/2° SE	OW-6	400-S	E-362	18° SE
400-S	600-N	113	16° SE	OW-6	600-N	E-362	18° SE
465*	OW-6	114	17° SE				

*Depth of contact estimated.

HYDROLOGIC UNITS

The variations in lithology, differences in bedding characteristics, and innumerable folds, faults, joints, and fractures make the Conasauga Group a highly-complex hydrologic medium. In order to describe the two-dimensional and three-dimensional movement of water below land surface, the geologic materials are divided into two hydrologic units, the regolith and the bedrock. They should not be conceived as two separate aquifers, however. The two units are hydraulically connected with water moving from one unit to the other.

REGOLITH

The regolith is the mantle of decomposed earthen materials that rests on bedrock. It is in this unit that all of the radioactive solid waste at ORNL has been buried.

The regolith in the Melton Valley area consists largely of in situ mixtures of clay, silt and rock fragments that have been derived from the weathering of bedrock. Its physical composition is highly variable. Auger holes north of Lagoon Road revealed it to consist largely of finely-powdered rock, whereas borings within burial ground 4 showed it to consist of wet, heavy clay containing many small pebbles. Trench excavations in burial ground 5-north exposed thin, very fissile, partially weathered shale beds lacking any substantial clay component, even close to land surface. In burial ground 6, trench excavations commonly exposed alternating deformed beds of