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Age-Dating Ground Water Beneath Tinker Air Force Base, Midwest City, Oklahoma, 2003-04

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Introduction

Since the 1940s Tinker Air Force Base, near Midwest City, Oklahoma (fig. 1), has been a base for strategic bombers and early-warning radar planes and a major aircraft repair facility. Activities at the Base contaminated the underlying Garber-Wellington aquifer (fig. 2) with volatile organic compounds, metals, and other compounds to depths exceeding 200 feet below land surface. U.S. Air Force environmental staff and civilian contractors have characterized the extent of contamination in the upper part of the aquifer (IT Corporation, 1999).

The aquifer at the Base is divided into layers in the first 200 feet below land surface by numerous discontinuous confining layers (fig. 2). A 30-foot thick layer of shales and siltstones is found at about 200 feet below land surface (shown as the LSZ-PZ confining layer in figure 2), which forms the bottom of the shallow part of the aquifer. This layer may form a continuous confining layer beneath most of or the entire Base. Potentiomet-

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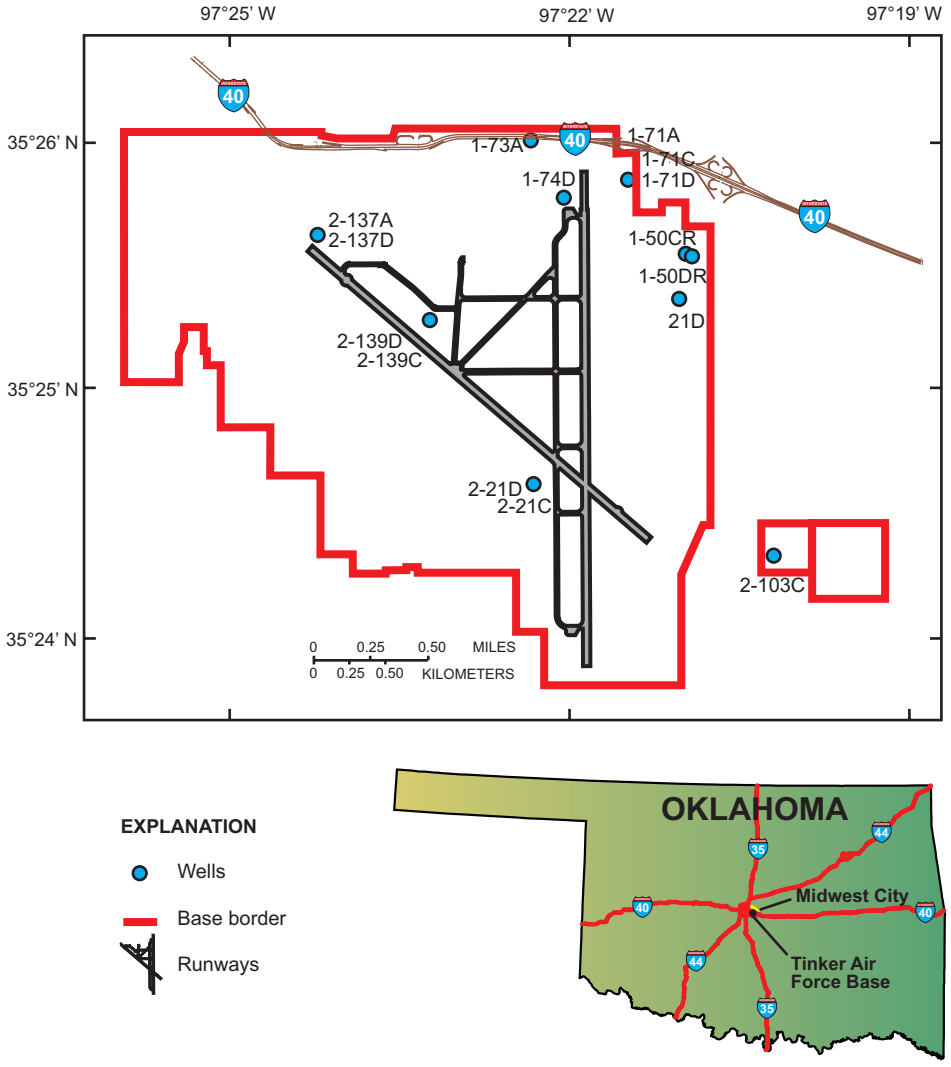

Figure 1. Location of wells sampled for this investigation.

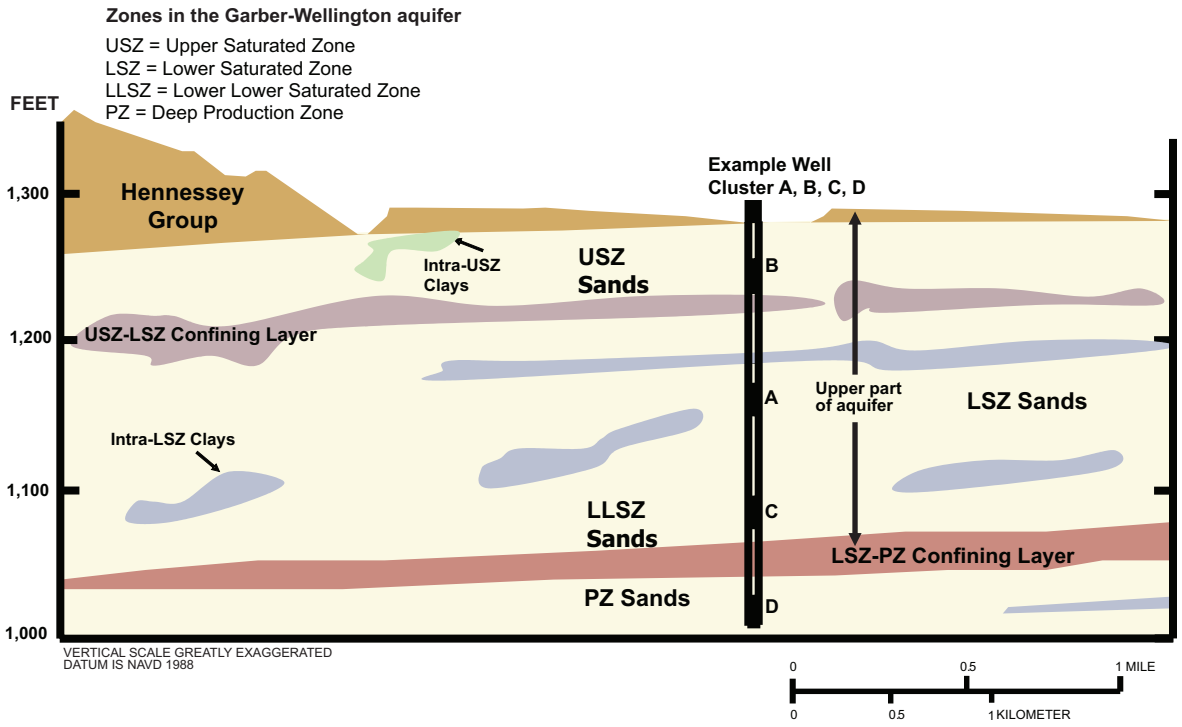

Figure 2. Diagramatic section through Tinker Air Force Base.

ric heads decrease by about 40 feet from land surface to the base of the shallow part of the aquifer (S. Bowen, U.S. Air Force, written commun., 2005).

Public-supply wells at the Base and surrounding areas are completed in a layer of the Garber-Wellington aquifer known as the "deep production zone," which lies beneath the 30-foot-thick LSZ-PZ confining layer. Potentiometric heads in the deep production zone are about 50 feet below those in the shallow part of the aquifer above the LSZ-PZ confining layer, which indicates a substantial potential for downward seepage of contaminated ground water from the shallow part of the aquifer to the deep production zone (S. Bowen, U.S. Air Force, written commun., 2005).

In 2003-04, the U.S. Geological Survey (USGS), in cooperation with the Oklahoma Water Resources Board and the U.S. Air Force, conducted an investigation to determine the age of ground water in the shallow, contaminated part of the aquifer and in the deep production zone beneath the Base. These ages are useful for assessing the vulnerability of the deep production zone to contaminants in ground water in the shallow part of the aquifer.

Age-Dating Methods

Chemicals and isotopes that are dissolved in ground water can be used to determine the apparent age of ground water. These chemicals and isotopes are referred to as "age-dating tracers" in this report. The apparent age of ground water is considered to be the amount of time determined from an age-dating tracer that has elapsed since the water was last in contact with the atmosphere. Modern ground water generally is more susceptible to contamination than old ground water because of the many man-made contaminants introduced during the 20th century (Plummer and Friedman, 1999).

Three age-dating tracers were used at the Base to determine the age of ground-water samples from wells completed beneath the Base:

Tritium: Tritium is a short-lived radioactive isotope of hydrogen with a half-life of 12.32 years. Tritium forms naturally as cosmic radiation interacts with the upper atmosphere, and all precipitation that falls to Earth has small amounts of tritium. During the 1950s and early 1960s, global atmospheric testing of nuclear weapons raised the atmospheric concentrations of tritium hundreds of times above the normal background concentration (Plummer and others, 1993). After the early 1960s, when the Nuclear Test Ban Treaty was signed and atmospheric testing of nuclear weapons ceased, tritium concentrations in the atmosphere have decreased and are approaching natural levels. Tritium concentration alone generally cannot be used to quantitatively date ground water, but can be used to qualitatively determine if ground water is modern (less than about 50 years in age) or pre-modern (older than about 50 years in age) (Clark and Fritz, 1997).

Ground-water samples were collected for tritium analysis from monitoring wells at the Base on September 9 and 10, 2003. Sampled wells were completed in both the shallow part of the aquifer and the deep production zone. Samples were analyzed by electrolytic enrichment and gas counting at the USGS Tritium Laboratory in Menlo Park, California.

Helium-3/Tritium: Tritium, as part of a water molecule, is transformed by radioactive decay to helium-3. By measuring both the tritium and helium-3 content from a ground-water sample, an apparent age can be determined because the rate that

tritium decays to helium-3 is known (Lucas and Unterwager, 2000).

Ground-water samples were collected for helium-3/tritium analysis from four monitoring wells at the Base on February 12, 2004. Samples were collected from wells that were thought to be producing modern ground water on the basis of the results of the tritium analyses. Helium isotopes were analyzed on a magnetic sector mass spectrometer (Bayer and others, 1989) and tritium was measured by the helium in-growth method (Clark and others, 1976 and Bayer and others, 1989) at the USGS Noble Gas Laboratory in Denver Colorado.

Carbon-14: Carbon-14 is the radioactive isotope of carbon with a half-life of 5,730 years. Carbon-14 is widely used and is well-known to the public as a tool for dating archeological sites, but carbon-14 also can be used to date ground water. Like tritium, carbon-14 is produced in the upper atmosphere and thus occurs naturally. Atmospheric carbon-14 concentrations were elevated by as much as 20 percent by the testing of nuclear weapons in the 1950s and 1960s. Radioactive carbon-14 in ground water is diluted by reactions that introduce non-radioactive carbon-12 into ground water, which results in apparent carbon-14 ground-water ages that are too old. Geochemical modeling is used to correct for the effects of dilution to obtain better estimates of ground-water age (Plummer and others, 1994).

Ground-water samples were collected for carbon-14 analysis from 11 monitoring wells at the Base on March 15 and 16, 2004. Samples were collected from wells that were thought to be producing pre-modern ground water on the basis of the results of the tritium analyses, and from some additional wells on the basis of the site hydrogeology and well completion reports. Samples were analyzed by accelerator mass spectrometry at the Environmental Isotope Laboratory at the University of Waterloo, Waterloo, Ontario, Canada.

All three methods are subject to measurement errors and age dates cannot be considered to be absolute. Ground water collected from a well may be a mixture of water from several sources of different ages. The apparent age determined by one tracer may not be equal to an apparent age determined by another tracer because of the methods by which the apparent ages are determined. The water samples were collected from some wells at the Base for analysis using different age-dating tracers to provide a basis for comparison of methods.

Age-Dating Results

Samples analyzed for tritium alone ranged in concentration from <0.3 to 9.6 picocuries per liter (pCi/L). Tritium concentrations below 1 pCi/L were considered to indicate that ground water was at least 50 years old (pre-modern) and tritium con-

Table 1. Results of age-dating analyses at Tinker Air Force Base

[pCi/L, picocuries per liter; --, not analyzed; ND, not determined; color denotes well clusters]

Site	Well depth (feet)	Tritium concentration (pCi/L)	Helium-3/ tritium age	Tritium age category	Carbon-14 modeled age (years before 2004)
1-50CR	120	7.2	March 1982	Modern	2,600
1-50DR	250	0.3	--	Pre-modern	3,100
1-71A	125	6.8	May 1968	Modern	--
1-71C	187	<0.3	--	Pre-modern	1,100
1-71D	243	1.3	--	Modern	2,900
1-73A	81	9.6	May 1987	Modern	--
1-74D	198	--	--	ND	690
2-103C	177	--	--	ND	1,700
2-137A	78	5.4	--	Modern	--
2-137D	250	<0.3	--	Pre-modern	1,100
2-139C	136	0.3	--	Pre-modern	1,600
2-139D	237	<0.3	--	Pre-modern	--
2-21C	151	1.0	--	Modern	Modern
2-21D	245	6.5	September 1990	Modern	560
21D	212	--	--	ND	460

centrations equal to or greater than 1 pCi/L were considered to indicate modern ground water (table 1).

For the samples analyzed for the helium-3/tritium age, all four samples contained measurable amounts of tritium and tritiogenic helium (helium derived from tritium decay). Sample apparent ages ranged from 13.4 to 35.7 (+/- 0.7) years in age from the time of sampling, giving recharge dates that range from 1990 to 1968. These dates are consistent with modern recharge; however, a comparison of tritium plus helium (original tritium recharged) to historical tritium measurements in precipitation show that there was some deviation from the measured results. Samples that fall below the tritium input curve were interpreted as mixed ground waters that have been diluted with older, pre-modern waters. Because the helium-3/tritium age is based on the daughter to parent ratio measured in the sample, the calculated apparent age represents the younger (modern) component and older (pre-modern) component is considered tritium dead; no tritium or tritiogenic helium is added to the mixing system, preserving the modern apparent age.

The measured carbon-14 concentrations range from 52 to 93 percent modern carbon (pmc). The carbon-14 concentration of water that recharged the aquifer prior to atmospheric nuclear testing is assumed to be 100 percent modern, or less if chemical reactions diluted the dissolved carbon pool with low carbon-14 carbon. For radioactive decay to decrease the carbon-14 value from 100 to 50 percent modern requires one half life, or about 5,700 years. Thus, without any corrections for chemical reactions, the maximum carbon-14 age of any ground water sampled is less than about 5,700 years. Chemical reactions may have occurred in the water after it fell as precipitation and entered the Garber-Wellington aquifer. In all cases, accounting for the effects of chemical reactions tends to decrease the calculated age of the ground water. The program NETPATH (Plummer and others, 1994) was used to generate inverse models that account for the evolution of pure water (approximation of precipitation) to each of the sample compositions. A reaction-corrected carbon-14 concentration was calculated by using NETPATH. The difference between the reaction-corrected concentration and the observed concentration is assumed to be caused by radioactive decay, and the adjusted age is calculated as the number of years necessary to reduce the reaction-corrected concentration to the observed concentration, given the half-life of carbon-14 (5,730 years).

The adjusted ages based on the carbon-14 data and NETPATH model for these samples are between modern and 3,000 years. There are uncertainties in these adjusted ages caused by analytical errors and by the assumptions in the calculation.

The results from the three age-dating tracers are not completely consistent (table 1). For example, water samples from Well 1-50CR had a tritium concentration of 7.2 pCi/L, which implies that some fraction of the water in this sample is modern, and the calculated helium-3/tritium age is March 1982. However, the modeled carbon-14 age for the well is 2,600 years before present, indicating that some fraction of this water is pre-modern. This indicates that water from this well probably is a mixture of modern and pre-modern water. Detectable tritium implies a fraction of the water must have recharged in the last 50 years. Some of the water appears to be modern, either because of the presence of tritium or by the carbon-14 age estimate. Although some samples have carbon-14 ages that are estimated to be 500 to 3,000 years, these ages are at the youngest end of the spectrum of ages that can be measured by carbon-14. Thus, it is possible that all the water samples collected from the Garber-Wellington aquifer at the Base contain some fraction of water that is modern, even water samples that have ages greater than 50 years by tritium and carbon-14 estimates. The mixing of modern and pre-modern ground water could occur by natural ground-water gradients or gradients induced by pumping of supply wells.

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