Dating of shallow groundwater: comparison of the transient tracers $^3H/^3He$, chlorofluorocarbons, and ^{85}Kr

Brenda Ekwurzel (1), Peter Schlosser (1), William M. Smethie Jr. (1),

L. Niel Plummer (2), Eurybiades Busenberg (2), Robert L. Michel (2),

Ralf Weppernig (1), and Martin Stute (1)

1 Lamont-Doherty Earth Observatory of Columbia
UniversityPalisades, NY 10964, USA

2 United States Geological SurveyMS 431, Reston, VA 22092, USA

WATER RESOURCES RESEARCH, VOL. 30, NO. 6, PAGES 1693-1708, 1994

If you have any comments, please send email to:

brendae@ldeo.columbia.edu
peters@ldeo.columbia.edu

Abstract

This paper describes a direct comparison of apparent ages derived from 3H/3He, chlorofluorocarbons (CCl3F and CCl2F2), and 85Kr measurements in shallow groundwater. Wells chosen for this study are completed in the unconfined surficial aquifers in late Cenozoic Atlantic Coastal Plain sediments of the Delmarva Peninsula, on the east coast of the United States. Most of the apparent tracer ages agree within 2 years of each other for recharge dates between 1965 and 1990. Discrepancies in apparent tracer ages usually can be explained by hydrological processes such as mixing in a discharge area. Recharge rate calculations based on apparent tracer age gradients at multilevel well locations agree with previous recharge estimates. High recharge rates on the Delmarva Peninsula result in nearly complete dissolved-gas confinement in the groundwater. The remarkable agreement between the different tracer ages indicates negligible mixing of water of different ages, insignificant dispersion, minimal gas loss to the atmosphere, and insignificant sorption-desorption processes at this location.

Selected figures from the paper:

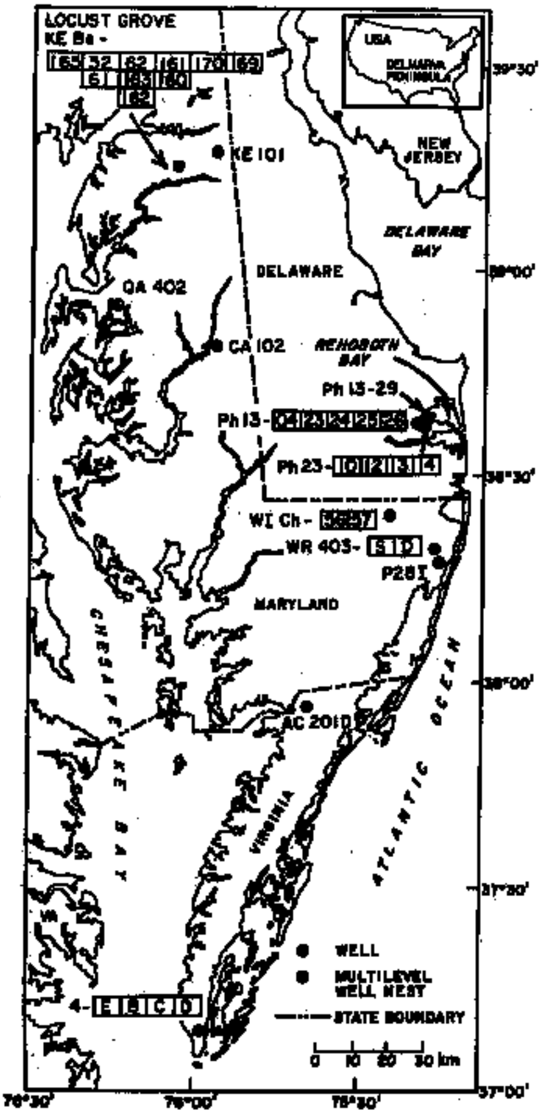

Fig. 1: *Map of the Delmarva Peninsula on the east coast of the United States. Wells having the same series number (i.e., KEBe) are listed as the series number followed by a dash and well numbers listed in order of increasing depth within the boxes.*

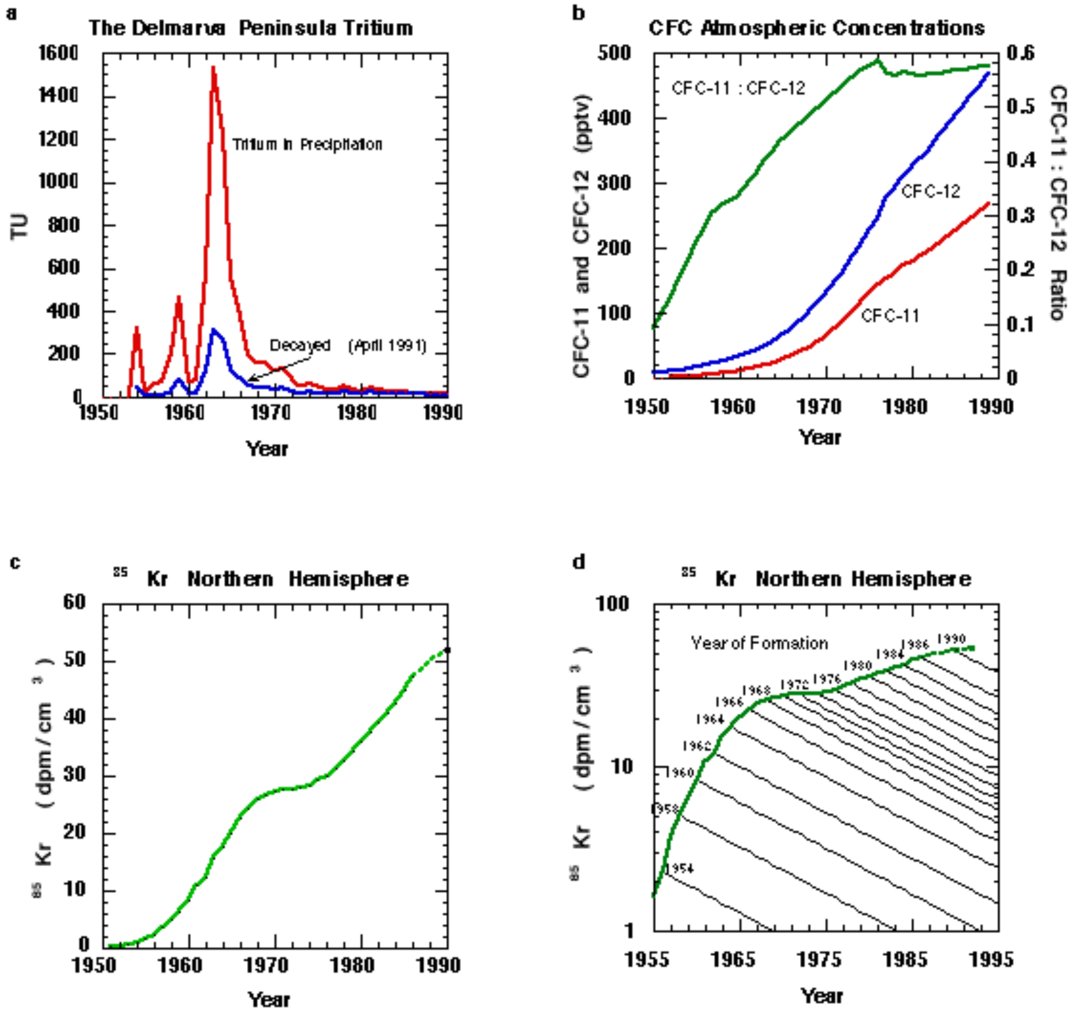

Fig. 2: *(a) Average tritium concentration in precipitation on the Delmarva Peninsula [Michel, 1989]. The tritium curve was based on the assumption that recharge from precipitation occurred only from Novermber through April [Dunkle et al., 1993]. As a result, the concentrations obtained are lower than if a weighted yearly average was used. Residual tritium concentration due to radioactive decay is calculated for April 1991. (b) Atmospheric concentrations of CFC-11 and CFC-12 in parts per trillion volume per volume air and the ratio CFC-11:CFC-12 [Busenberg et al., 1993; Elkins et al., 1993]. (c) 85Kr specific activity (i.e., the ratio*

of 85Kr to stable krypton: disintegrations per minute per cubic centimeter krypton) in the troposphere of the Northern Hemisphere between 40o and 50o N as a function of time [Sittkus and Stockburger, 1976; Rozanski, 1979; Weiss et. al., 1983]. The 85Kr specific activity is extended to pass through the atmospheric specific activity measured at Locust Grove in November 1991. (d) Same curve as (c), but plotted on a logarithmic scale. Diagonal lines represent radioactive decay after groundwater is isolated form the atmosphere [Smethie et al., 1992].

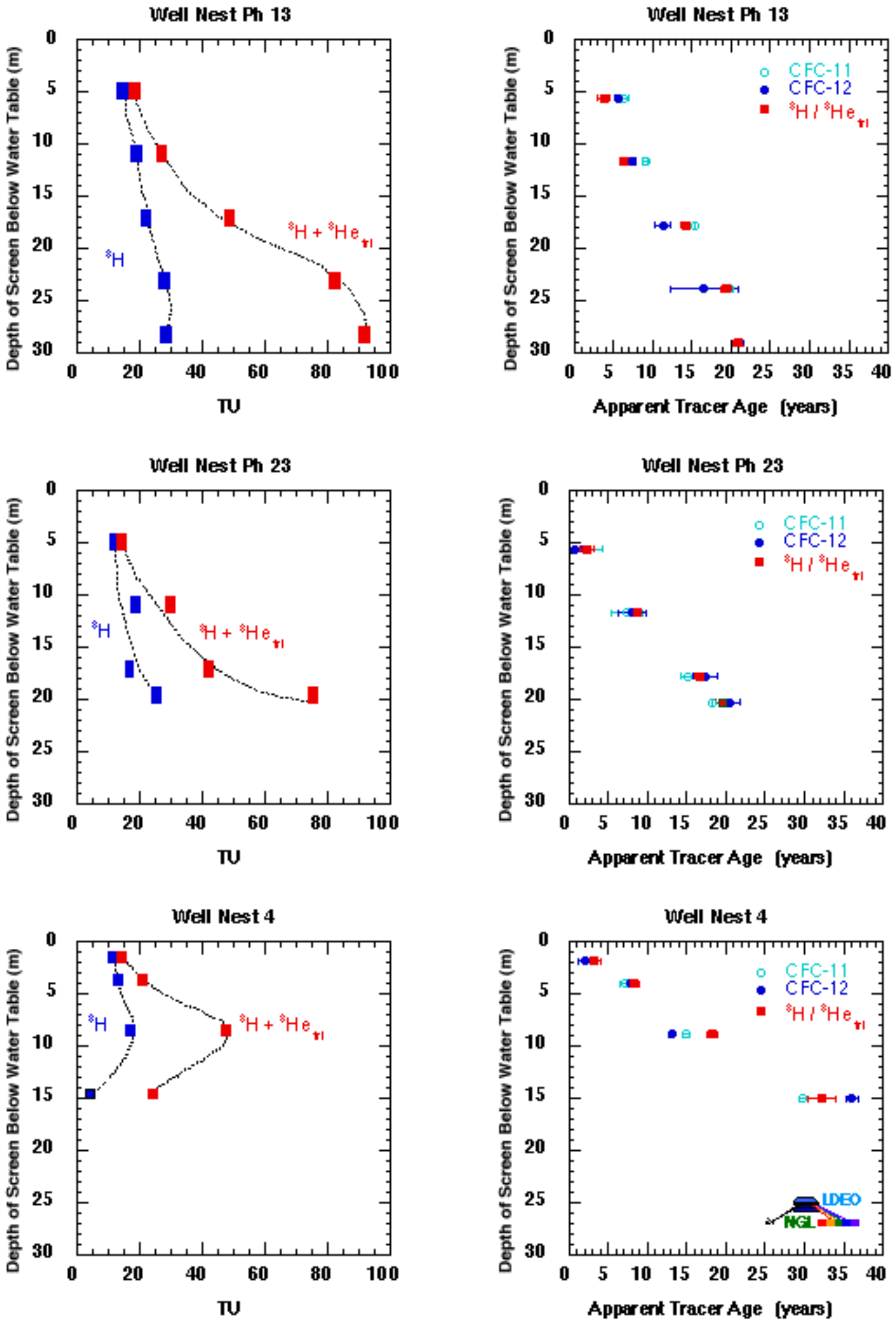

Fig. 4: *Depth profiles of tritium, 3H + 3Hetri (tritium units), and apparent tracer ages from well nests Ph13 and Ph23 and well 4.*

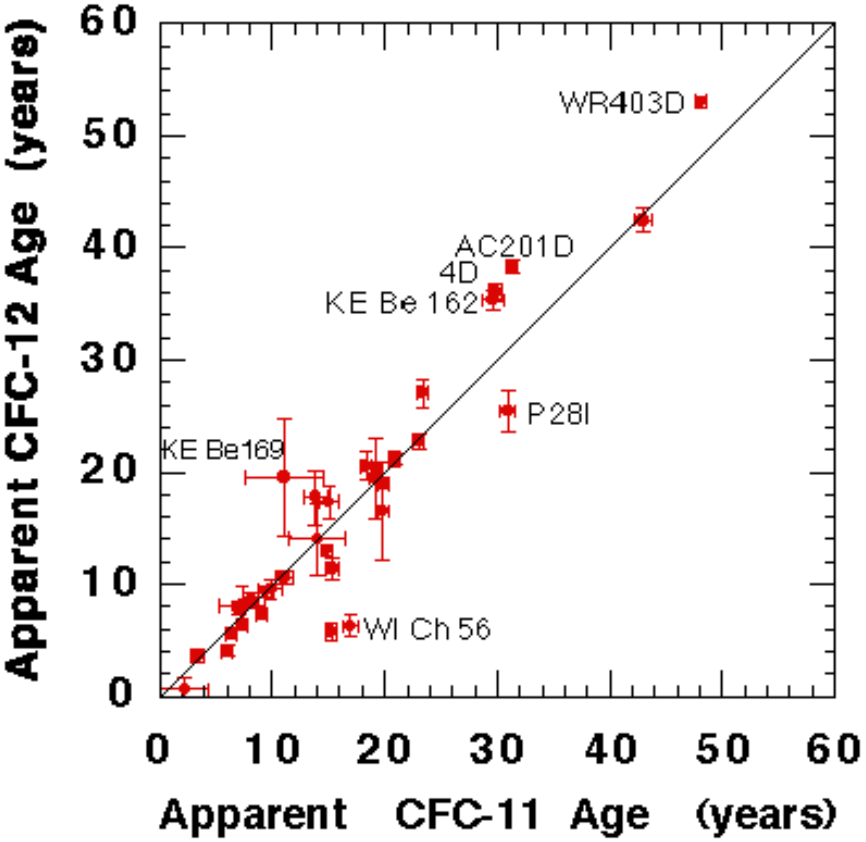

Fig. 5: *Comparison of apparent CFC-12 and CFC-11 ages. Diagonal line is a 1:1 reference line.*

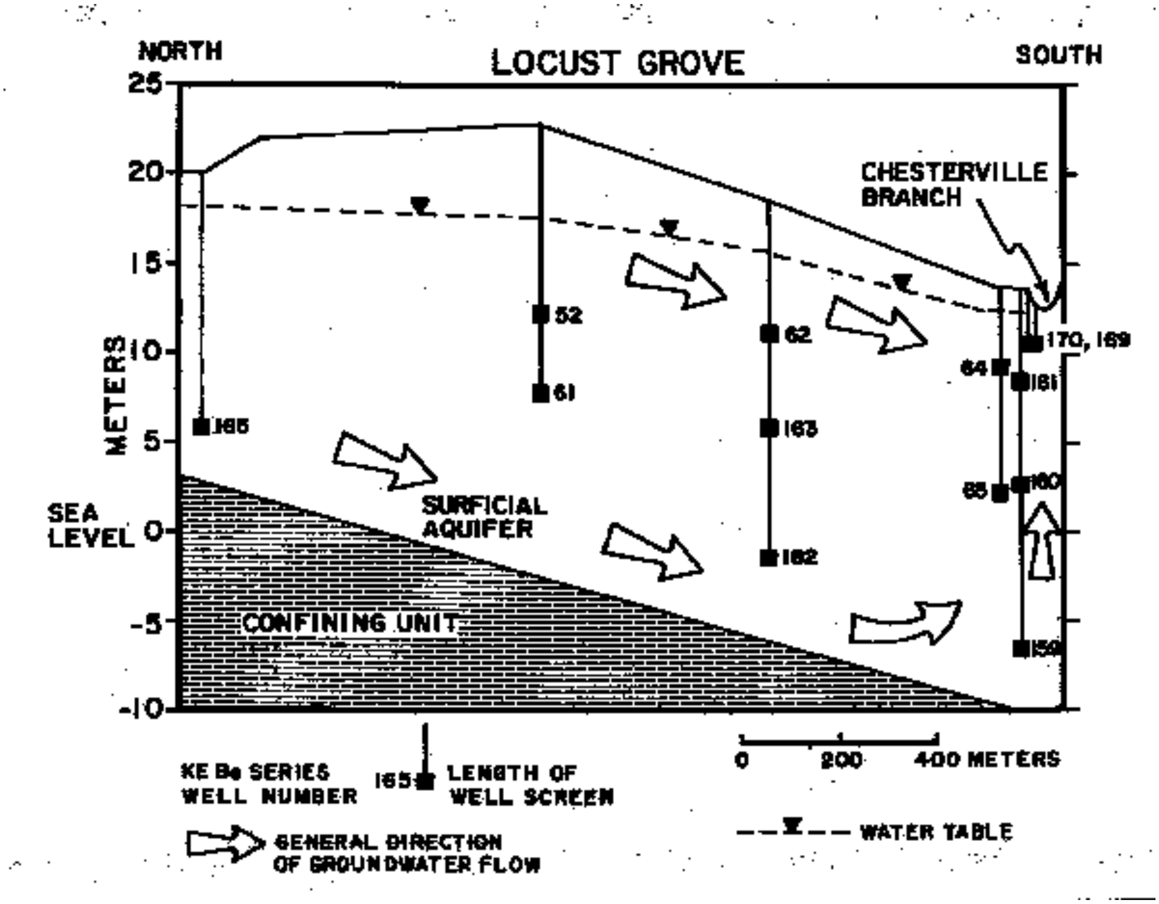

Fig. 6: *Locust Grove cross section from the local groundwater divide to local discharge at Chesterville Branch. Well KEBe 169 is beneath Chesterville Branch stream (width not drawn to scale), and well KEBe 170 is in the north bank of the stream, which is not distinguishable on the scale of this figure.*

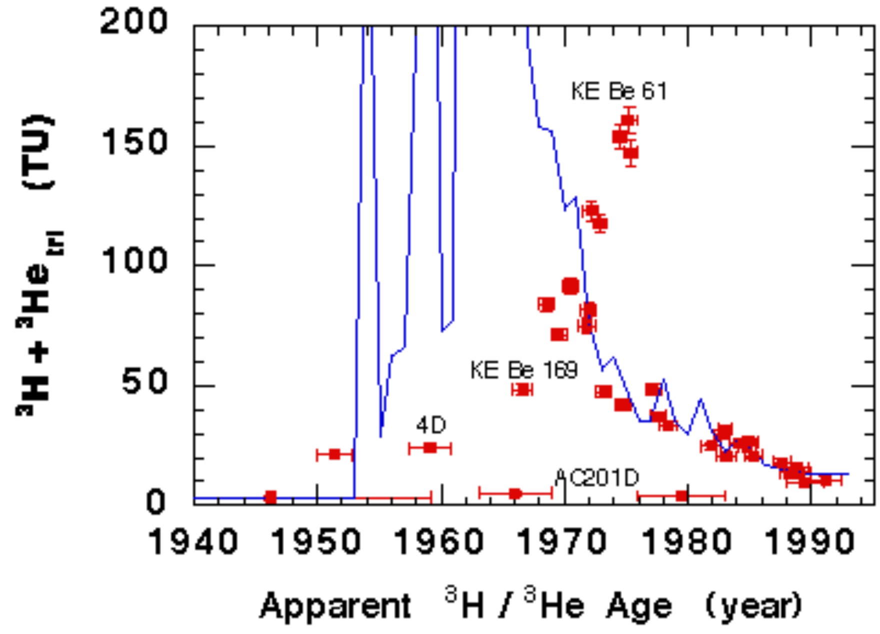

Fig. 7: *Apparent 3H/3He ages compared with 3H + 3Hetri, which reconstructs an initial tritium input function. The tritium precipitation curve (used for Fugre 2a) is plotted for reference. Individual wells discussed in the text are labeled.*

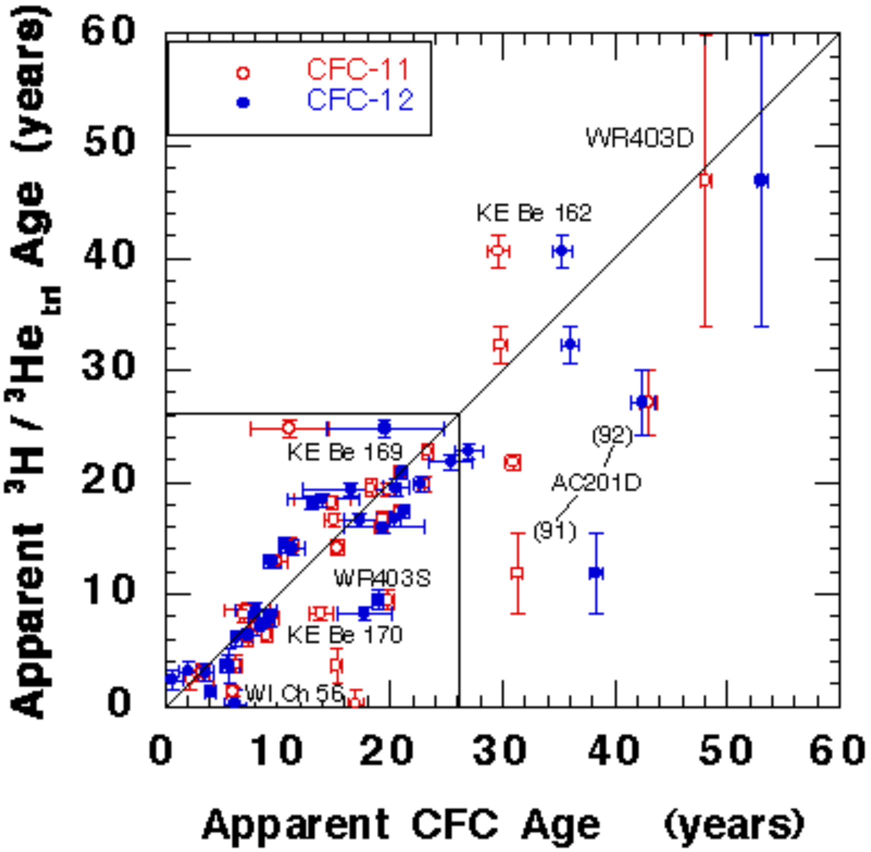

Fig. 8: *Apparent 3H/3He age compared to apparent CFC-11 and CFC-12 ages. Wells discussed in the text are labeled. Diagonal line is a 1:1 reference line. The vertical and horizontal reference lines are 26-year age lines representing the bomb peak and a 2 year lag for flow through the unsaturated zone.*

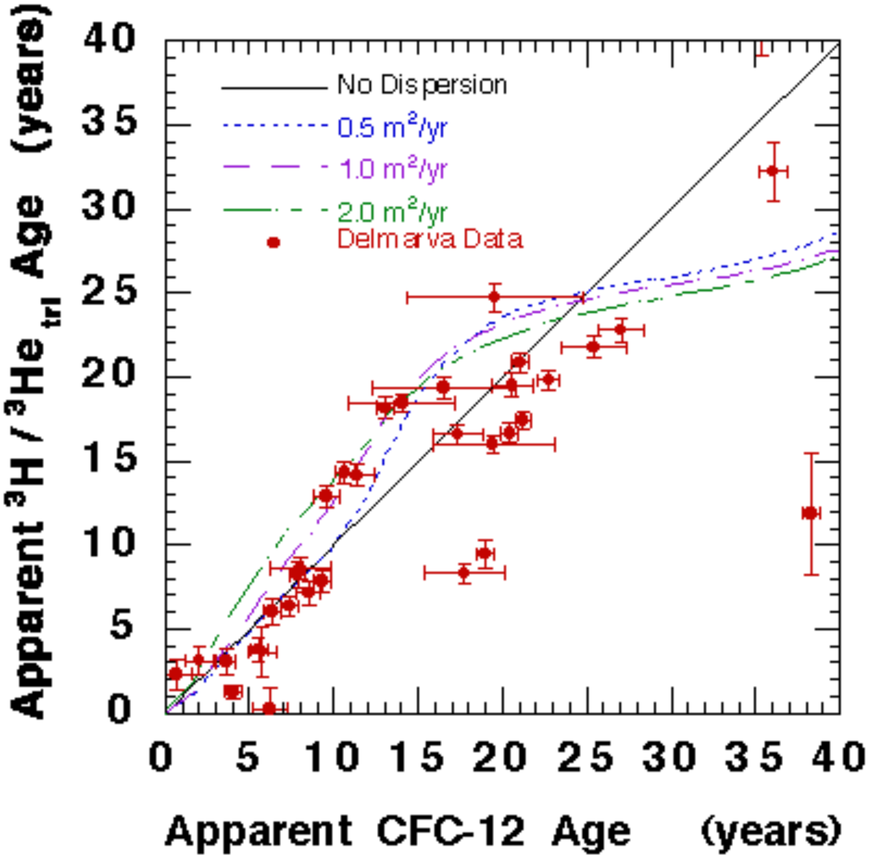

Fig. 11: *Vogel model, adapted after Schlosser et al., [1989], dispersion effect on 3H/3He and CFC-12. Average linear velocity of 1 m/yr is plotted with different dispersions and with a 1:1 reference line. Tracer data for the Delmarva Peninsula are included.*

Conclusions

The comparison of 3H/3He, CFC-11, CFC-12, and 85Kr age dating techniques in shallow groundwater shows close agreement between results obtained by the individual methods. This agreement can be attributed to aerobic conditions, permeable sand, nearly complete gas confinement, and low dispersion found on the Delmarva Peninsula. Most apparent tracer ages measured in the shallow unconfined aquifers of the Delmarva Peninsula agree to within 2 years for water ages below about 30 years. All tracer methods provide age information suitable for flow velocity calculations, recharge rate estimates, and model validation. Use of multiple tracers is desirable for age dating because (1) 3H/3He dating is sometimes unusable for waters older than the bomb peak; (2) CFCs are perhaps the easiest of the three tracers to sample and analyze, but CFCs may be influenced by sorption, degradation, or contamination, and reliable estimates of recharge temperature are necessary; (3) 85Kr is an inert conservative tracer, but field sampling for 85Kr is difficult (as much as 6 hours is required for collecting 120 L of water and extracting the gas), compared to 3H/3He and CFC methods, which require only several minutes for sample collection; and (4) dispersion affects each tracer differently. Multitracer sampling at specific sites within an aquifer can provide a cross-check of the behavior of the other transient tracers.

References

Busenberg, E., E. P. Weeks, L. N. Plummer, and R. C. Bartholomay, Age dating ground water by use of chlorofluorocarbons (CCl3F and CCl2F2) and distribution of chlorofluorocarbons in the unsaturated zone, Snake River Plain Aquifer, Idaho National Engineering Laboratory, Idaho, in U.S. Geol. Surv. Water Resour. Invest., 93-4054, 47pp., 1993.

Elkins, J. W., T. M. Thompson, T. H. Swanson, J. H. Butler, B. D. Hall, S. O. Cummings, D. A. Fisher, and A. G. Raffo, Decrease in the growth rates of atmospheric chlorofluorocarbons 11 and 12, Nature, 364, 780-783, 1993.

Michel, R. L., Tritium deposition over the continental United States, 1953-1983, in Atmospheric Deposition, pp. 109-115, International Association of Hydrological Sciences, Oxfordshire, England, 1989.

Dunkle, S. A., L. N. Plummer, E. Busenberg, P. J. Phillips, J. M. Denver, P. A. Hamilton, R. L. Michel, and T. B. Coplen, Chlorofluorocarbons (CCl3F and CCl2F2) as dating tools and hydrologic tracers in shallow groundwater of the Delmarva Peninsula, Atlantic Coastal Plain, United States, Water Resour. Res., 29(12), 3837-3860, 1993.

Rozanski, K., Krypton-85 in the atmosphere 1950-1977, a data review, Environ. Int., 2, 139-143, 1979.

Sittkus, A. and H. Stockburger, Krypton als Indikator des Kernbrennstoffverbrauchs, Naturwissenschaften, 63, 266-272, 1976.

Schlosser, P., M. Stute, C. Sonntag, and K.O. Mu"nnich, Tritiogenic 3He in shallow groundwater. Earth Planet. Sci. Lett., 94, 245-256, 1989.

Smethie, W. M., Jr., D. K. Solomon, S. L. Schiff, and G. G. Mathieu, Tracing groundwater flow in the Borden Aquifer using krypton-85, J. Hydrol., 130, 279-297, 1992.

Weiss, W., A. Sittkus, H. Stockburger, and H. Sartorius, Large-scale atmospheric mixing derived from meridional profiles of krypton 85, J. Geophys. Res., 88(C13), 8574-8578, 1983.