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Apparent age of ground water near the southeastern margin of the Tularosa Basin, Otero County, New Mexico

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New Mexico Geological Society Guidebook, 53rd Field Conference, Geology of White Sands, 2002, p. 303-307.

APPARENT AGE OF GROUND WATER NEAR THE SOUTHEASTERN MARGIN OF THE TULAROSA BASIN, OTERO COUNTY, NEW MEXICO

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ABSTRACT.—Isotope data on hydrogen, oxygen, and carbon in ground and surface water combined with generalized directions of ground-water flow and published geochemical data were used to determine the apparent age and partial geochemical history of ground water near the southeastern margin of the Tularosa Basin. Dissolution of calcite and dolomite could account for part of the geochemical evolution of ground water, including possible dilution of ^{14}C content, as it moves away from recharge areas. Dissolution of calcium sulfate also could account for a part of ground-water evolution. Apparent ^{14}C ages, corrected for the effects of carbonate mineral dissolution, show ground water became closed with respect to ^{14}C between 10,000 and 1000 yrs ago. These apparent ages are supported by hydrogen and oxygen isotope data that are consistent with the origination of ground water as Holocene age recharge. A general correlation between greater apparent ages of ground water and total depth of sampled wells is interpreted to correspond to longer travel times along deeper ground-water flow paths. Corrected apparent ages of ground water and inferred travel times will be used to assist in calibrating a ground water flow model of the Tularosa Basin that is currently being developed.

INTRODUCTION

Concerns over increasing demand for ground water led to a currently ongoing basin-wide study of ground water flow in the Tularosa Basin. This paper presents the results of the part of the current basin-wide study that focuses on the apparent ages and geochemical evolution of ground water near the southeastern margin of the Tularosa Basin.

PURPOSE AND SCOPE

This paper presents and interprets data from hydrogen, oxygen, and carbon isotopes as well as other selected constituents in ground water near the southeastern margin of the Tularosa Basin and surface water from a spring in the upper reaches of San Andres Canyon. All samples were collected between March 11 and April 23, 1997.

STUDY AREA

The Tularosa Basin is a downfaulted, arid to semiarid area covering about 17,000 km^2 of south-central New Mexico (Fig. 1). The southeastern part of the Tularosa Basin is bounded on the east by the Sacramento Mountains. The hydrology of the Tularosa Basin was first described by Meinzer and Hare (1915). More recent hydrologic studies covering all or large parts of the Tularosa Basin include Hood (1959), McLean (1970), and Orr and Myers (1986). Hydrologic studies focused on all or part of the southeastern Tularosa Basin include Meeks (1950), Hood (1956, 1958), Ballance (1976), Garza and McLean (1977), Burns and Hart (1988), Morrison (1989), and Huff (1996).

Water level maps in Meinzer and Hare (1915), McLean (1970), and Garza and McLean (1977) indicate that ground water in the southeastern Tularosa Basin moves southward and westward away from the Sacramento Mountains. Perennial streams exist in only a few areas within the higher elevations of the Sacramento Mountains (U.S. Bureau of Reclamation and the State of New Mexico, 1976). Ground-water recharge enters the Tularosa Basin by infiltration of intermittent surface water flows associated with mountain

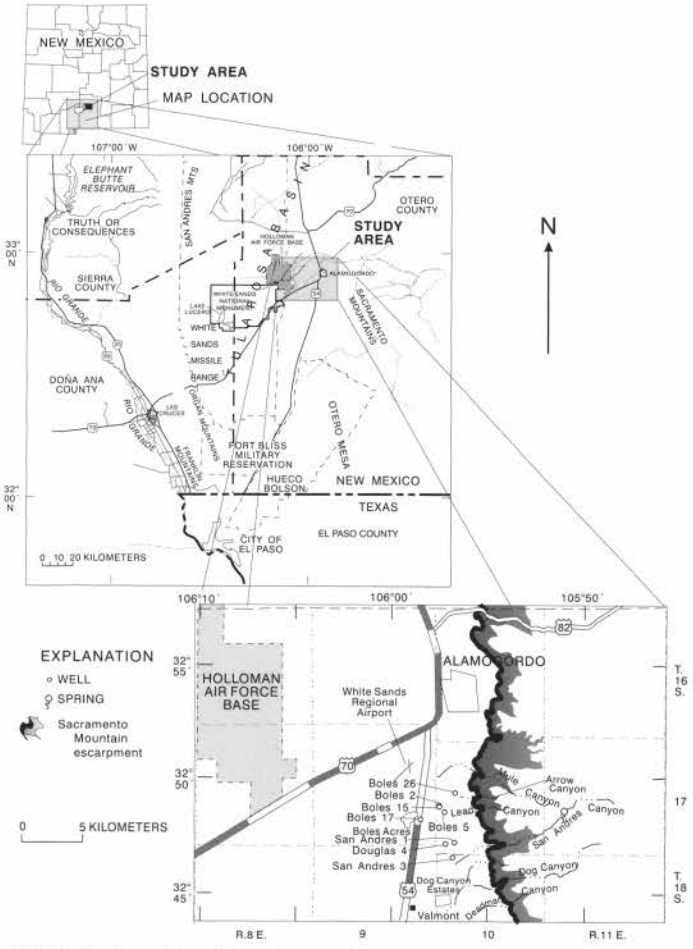

FIGURE 1. Location of sampled Holloman Air Force Base public supply wells, sampled spring in San Andres Canyon, and major canyons.

precipitation into coarse sediments near the proximal end of alluvial fans associated with canyons surrounding the basin (McLean, 1970; Burns and Hart, 1988). Recharge may also enter the alluvial fans as underflow along stream channels associated with larger drainage basins on the western escarpment of the Sacramento Mountains (Morrison, 1989). Drainage basins in the Sacramento

Mountains potentially contributing recharge to the Tularosa Basin are shown in Waltemeyer (2001). Exposed geology on the crest and large parts of the western escarpment of the Sacramento Mountains adjacent to the southeastern Tularosa Basin includes the marine San Andres Limestone and the underlying marine Yeso Formation, both of Permian age. Pray (1961) described the San Andres Limestone as massive calcium carbonate containing dolomitic intervals and the Yeso Formation as containing calcite, dolomite, gypsum, anhydrite, and other components. Both the San Andres Limestone and the Yeso Formation are in a position to contribute material to alluvial fans on the eastern side of the Tularosa Basin. Fresh ground water (dissolved-solids concentrations <1000 mg/L) occurs mostly in coalesced alluvial fan deposits along the margin of the basin. Ground-water salinity generally increases basinward, with the rest of the basin containing slightly to very saline ground water (McLean, 1970; Orr and Myers, 1986). Locations of Holloman Air Force Base (HAFB) public supply wells and a spring in the upper reaches of San Andres Canyon sampled for this study are shown in Figure 1.

APPARENT AGE OF GROUND WATER

Ground-water samples were collected from public supply wells that had been in continuous operation for 2 to 24 hrs, allowing complete purging of the well casing prior to sampling. Exposure to the atmosphere was minimized during collection of ground and surface water samples for isotopic analysis. All remaining samples were passed through a 0.45-µm filter during sample collection with the exceptions of those used for temperature, pH, and specific conductance determinations. Temperature, pH, specific conductance, and alkalinity were determined in the field immediately following sample collection using procedures described by Wood (1976). All other analytical determinations were made by U.S. Geological Survey (USGS) laboratories. Quality-control and quality-assurance procedures for USGS laboratories are given by Pritt and Raese (1995).

Sampled well depths and analytical results are listed in Table 1. Values of δD and $\delta^{18}O$ are reported relative to SMOW. Values of $\delta^{13}C$ are reported relative to PDB. Values of ^{14}C are reported relative to the National Bureau of Standards 1950 oxalic acid standard. Analytical uncertainties in values of ^{3}H, δD, $\delta^{18}O$, $\delta^{13}C$, and ^{14}C in this study are approximately ±1 picoCuries per liter (piC/L), ±1 ‰, ±0.2 ‰, ±0.2 ‰, and ±0.5 %, respectively. Analytical uncertainties in the remaining analyses are in the range of 3 to 5 %.

Values of δD and $\delta^{18}O$ plot near the global meteoric water line of Craig (1961) and are largely contained within parallel meteoric water lines having deuterium excess parameters (d) of +8 and +12 (Fig. 2). Similar local meteoric water lines with slopes equal to the meteoric water line of Craig (1961) and having d values of +11 (Anderholm, 1994) and +12 (Vuataz and Goff, 1986) have been determined for precipitation in the Santa Fe area and in the Jemez Mountains of northern New Mexico, respectively.

Measured ^{14}C content (A_m) in ground water ranges from 17.39 to 44.00 percent modern carbon (pmc). Values of $\delta^{13}C$ in ground water ($\delta^{13}C_w$) fall within a relatively narrow range of –7.81 to –6.31 ‰. The activity of ^{3}H in all but one ground water sample is <1.0 piC/L. A ^{3}H activity of 2.6 piC/L in the sample from well Boles 5 indicates the possible presence of a mixture of younger water, originating as precipitation approximately 50 yrs ago or less, with older water. Therefore, all isotopic data for samples from well Boles 5 should be viewed with caution.

The initial isotopic composition of carbon in recharge water is governed by the composition of atmospheric and soil gases. Prior to atmospheric nuclear weapons testing in 1954, the ^{14}C content of the atmosphere was governed by the natural atmospheric production and radioactive decay rates of ^{14}C. The initial ^{14}C content of pre-1954 ground water prior to mineral dissolution and prior to closure with respect to ^{14}C (A_o) is equal to 100 pmc. Ideally, the difference between A_o and A_m would reflect the decrease in ^{14}C content by radioactive decay in the time elapsed since closure with respect to ^{14}C. However, A_m can be lowered by mixing with water having a lower ^{14}C content or by dissolution of, or isotopic exchange with, carbonate minerals having a lower ^{14}C content. Calculated ^{14}C apparent ages will reflect elapsed times greater than the interval between closure of recharge water with respect to ^{14}C and sample collection in either case.

TABLE 1. Values of well depth; sampling date; field measurements; concentrations of selected inorganic constituents; and isotopic measurements of oxygen, hydrogen, and carbon in water samples. [—, data not collected or value not applicable]

Sampled location	Well depth, m below land surface	Sampling date, MM-DD-YYYY	Temperature, °C	Specific conductance, µS/cm at 25 °C	pH	Cl, mg/L	SO_4, mg/L	Alkalinity, mg/L as HCO_3	$\delta^{8}0$, ‰	δD, ‰	^{3}H, pCi/L	A_m, pmc	$\delta^{13}C_w$, ‰
Spring	—	04-23-1997	—	—	—	—	—	—	-9.7	-65	—	—	—
Douglas 4	90	03-12-1997	25.0	1010	7.3	54	280	207	-9.7	-69	<1.0	20.04	-6.56
San Andres 1	113	03-12-1997	25.5	1380	7.3	65	500	198	-9.6	-68	<1.0	26.30	-7.06
San Andres 3	294	03-11-1997	26.0	1190	7.3	62	370	204	-9.7	-69	<1.0	17.39	-6.31
Boles 2	66	03-13-1997	20.5	1040	7.4	61	290	213	-9.8	-69	<1.0	44.00	-7.03
Boles 5	62	03-13-1997	22.5	1480	7.4	120	450	213	-9.5	-69	2.6	42.71	-7.81
Boles 15	113	03-14-1997	21.0	1150	7.4	79	320	208	-9.7	-66	<1.0	35.21	-6.99
Boles 17	62	03-17-1997	20.5	872	7.3	38	220	221	-9.8	-67	<1.0	40.18	-7.09
Boles 26	155	03-17-1997	22.0	809	7.3	29	200	215	-9.9	-67	<1.0	—	—

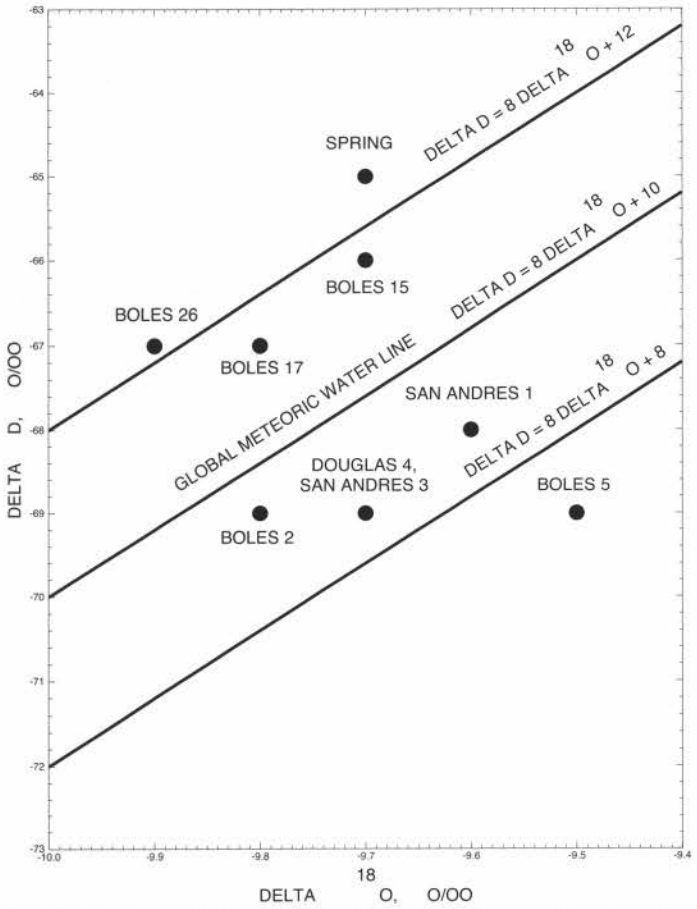

FIGURE 2. Plot of δD as a function of $\delta^{18}O$ in ground and surface water.

It is possible that water samples from HAFB wells are composed of a mixture of younger fresh water from recharge areas in the Sacramento Mountains and older more saline basinward water drawn into the heavily pumped public supply wells. However, values of A_m in Table 1 show no meaningful correlation with specific conductance. This suggests that mixing with basinward water has not substantially affected A_m.

The saturation index (SI) is given by the equation:

$$SI = \log (IAP/K_T)$$

where IAP is the ion activity product of a mineral-water reaction, and K_T is the thermodynamic equilibrium constant of the mineral-water reaction at the sample temperature.

Calculations of saturation indices using PHREEQC (Parkhurst, 1995) on data from selected HAFB public supply wells (Huff, 1996) show that ground water is saturated to slightly oversaturated with calcite and dolomite (Table 2). Also, values of $\delta^{13}C_w$ are intermediate between the –17 to –25 ‰ reported for soil gases (Rightmire and Hanshaw, 1973) and the 0+2 ‰ typical of marine carbonates (Back et al., 1983). Together, these data suggest dissolution of calcite and dolomite into recharge water. In addition, concentrations of dissolved sulfate (Table 1) suggest dissolution of calcium sulfate into recharge water. Calcite, dolomite, and calcium sulfate are abundant in lithologies that are likely to contribute material to alluvial fans on the western escarpment of the Sacramento Mountains, providing the opportunity for dissolution of these phases into recharge water.

TABLE 2. Saturation indices of selected minerals calculated using PHREEQC (Parkhurst, 1995) based on analyses of samples from selected HAFB public supply wells (Huff, 1996). [—, data needed for calculation not contained in Huff (1996)]

Sampled location	Calcite saturation index	Dolomite saturation index	Gypsum saturation index	Anhydrite saturation index
Douglas 4	0.09	0.15	-1.18	-1.41
San Andres 1	0.27	0.45	-0.84	-1.06
San Andres 3	0.53	1.08	-1.13	-1.35
Boles 2	0.17	0.24	-1.29	-1.52

Springs associated with the uppermost low permeability interval of the Yeso Formation are commonly visible on the eastern side of the Sacramento Mountains. Flow in these springs is derived from infiltration through fractures in the San Andres Limestone and the upper part of the Yeso Formation (Pray, 1961). The spring sampled in San Andres Canyon may be a similar phenomenon. Determination of the stratigraphic position of the sampled spring relative to the San Andres Limestone or the Yeso Formation was hampered by inadequate geologic exposure. Water passing through fractures in the San Andres Limestone or the Yeso Formation would have the opportunity to dissolved calcite, dolomite, and calcium sulfate. Such water may enter the proximal end of alluvial fans as surface flow or underflow already having dissolved carbonate and sulfate minerals. The effect of possible subaerial exposure on the isotopic composition of recharge water is unknown.

A number of approaches have been proposed to correct A_o for the dilution of ^{14}C content on dissolution of, or isotopic exchange with, carbonate minerals. Details of these approaches are discussed by Fontes and Garnier (1979), Fontes (1992), and Plummer et al. (1994). The complexity of these correction approaches ranges from consideration of the effects of congruent carbonate dissolution only (Ingerson and Pearson, 1964), to carbonate dissolution coupled with isotope exchange (Fontes and Garnier, 1979; Eichinger, 1983), to mass balance modeling approaches (Tamers, 1967; 1975; Tamers and Scharpenseel, 1970; Plummer et al., 1990). The goal of all these approaches is to give an estimate of ^{14}C content that is corrected for chemical interactions that decrease the value of A_o, with the exception of radioactive decay. The approaches described above to calculating corrected values of A_o vary in assumptions, and some are formulated for specific conditions. However, a number of these approaches converge on a corrected value of A_o that is equal to about 53 pmc (see tabulation in Plummer et al., 1994). Studies exemplified by Back et al. (1983) and Plummer et al. (1990) use geochemical modeling to quantify further the effect of chemical reactions, such as the incongruent dissolution of dolomite along a ground-water flow path on the ^{14}C content of ground water. These modeling approaches require information on geochemical evolution along a ground-water flow path, making a modeling approach unsuitable for the current study.

The apparent age of ground water represents the apparent elapsed time since ground water became closed with respect to ^{14}C contained in pre-1954 atmospheric and soil gases. Apparent ages are calculated using values of A_m, assuming a ^{14}C half-life of 5715 yrs (IUPAC, 1992), and using the equation:

$$\text{apparent age in yrs} = 5715 \log (A_o/A_m)/\log(2).$$

Two sets of apparent ages for ground-water samples are listed in Table 3. The first set are uncorrected apparent ages calculated assuming $A_o = 100$ pmc, and the second set are corrected apparent ages calculated assuming $A_o = 53$ pmc.

Uncorrected apparent ages range from approximately 14,420 to 6769 yrs since closure with respect to ^{14}C (Table 3). The uncorrected apparent ages are consistent with recharge in latest Pleistocene to mid-Holocene time. With the exception of the sample from well Douglas 4, there is a general correlation between uncorrected apparent age and the depth of the sampled well. This correlation is interpreted to represent longer travel times along deeper ground water flow paths. Localized upward flow of deeper, and presumably older, water into well Douglas 4 in response to pumping could account for its relatively high uncorrected apparent age.

Evidence for carbonate mineral dissolution into ground water suggests that these uncorrected apparent ages may be effected by dilution of ^{14}C content. Figure 2 shows no major differences in δD or $\delta^{18}O$ values among samples representing deeper ground water, shallower ground water, or spring water. Also, all samples lie near meteoric water lines having d values ranging from about +8 to +12. Although not always observed, shifts toward isotopically lighter values of δD and $\delta^{18}O$ in ground water may occur if recharge originated from precipitation in a presumably cooler and wetter Pleistocene climate (Fontes, 1980). Additionally, the value of d for meteoric water lines describing ground water originating from Pleistocene precipitation may differ significantly from that of modern ground water (Merlivat and Jouzel, 1979; Coplen, 1993).

Neither of these patterns of change in stable isotopes of hydrogen or oxygen is apparent in collected samples. The lack of evidence of a Pleistocene component in ground water and the evidence for dissolution of carbonate minerals into recharge water suggests that uncorrected apparent ages may be overestimates. Current research in the Albuquerque Basin of New Mexico suggests that exposure to modern soil gases in thick unsaturated zones may reset the ^{14}C content of recharge water to values near 100 pmc following near-surface carbonate dissolution (Scott Anderholm, USGS, personal commun., 2002). The effect such processes may have on ^{14}C content of ground water in this study are unknown.

TABLE 3. Uncorrected and corrected ^{14}C apparent ages for selected ground-water samples. [—, apparent age not calculated]

Sampled location	Uncorrected ^{14}C apparent age assuming $A_o = 100$ pmc, yrs	Corrected ^{14}C apparent age assuming $A_o = 53$ pmc, yrs
Douglas 4	13,250	8019
San Andres 1	11,010	5777
San Andres 3	14,420	9188
Boles 2	6769	1534
Boles 5	—	—
Boles 15	8606	3372
Boles 17	7518	2283

Corrected apparent ages range from approximately 9188 to 1534 yrs since closure with respect to ^{14}C (Table 3). The pattern of apparent age distribution with sampled well depth is the same in corrected apparent ages as in uncorrected apparent ages. Apparent ages corrected for the effects of carbonate dissolution may represent the more accurate estimates of apparent age of ground water. These corrected apparent ages suggest that ground water near the southeastern margin of the Tularosa Basin became closed with respect to ^{14}C between 10,000 and 1000 yrs ago, reflecting Holocene age recharge.

The computer program MODPATH (Pollock, 1994) allows calculation of travel times along simulated ground-water flow paths. Corrected apparent ages of ground water and inferred travel times will be used in conjunction with MODPATH to assist in calibration of a ground water flow model of the Tularosa Basin that is currently being developed.

CONCLUSIONS

Ground water near the southeastern margin of the Tularosa Basin originates as precipitation at the crest or on the western escarpment of the Sacramento Mountains and subsequently moves into coarse material at the proximal end of alluvial fans. The geochemical evolution of ground water as it moves from recharge areas into the basin could be partially accounted for by dissolution of calcite, dolomite, and calcium sulfate.

The ^{14}C apparent ages of ground water could have been effected by dilution of ^{14}C content caused by dissolution of carbonate minerals. Data from stable isotopes of hydrogen and oxygen, along with corrected ^{14}C apparent ages, indicate that ground water became closed with respect to ^{14}C between 10,000 and 1000 yrs ago, consistent with Holocene age recharge. A general correlation between greater apparent ages of ground water and total depth of the well sampled is interpreted to correspond to longer travel times along deeper ground-water flow paths. Corrected apparent ages of ground water and inferred travel times will be used to assist in calibration of a ground water flow model of the Tularosa Basin that is currently being developed.

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The "backbone of New Mexico" along the lumbar region of the San Andres Mountains. The range is 85 miles long and between 6 to 17 miles wide. The tallest peaks are: San Andres Peak (8,239 ft), Salinas Peak (8,958) and Greer Peak/Silver Top Mountain (8,005 feet). All elevations presented in elevation from seal level. Photograph by Virgil Lueth.