WATER TABLE DECLINE IN THE SOUTH-CENTRAL GREAT BASIN DURING THE QUATERNARY: IMPLICATIONS FOR TOXIC WASTE DISPOSAL

by

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U.S. Geological Survey Open-File Report 85-

1985

A variety of geologic evidence indicates that during the Pleistocene the water table at Ash Meadows in the Amargosa Desert, Nevada, and at Furnace Creek Wash in east-central Death Valley, California was tens to hundreds of meters above the modern water table. The evidence consists of tufas; paleo-spring orifices; calcitic veins and cylindrical calcite-lined tubes which mark the routes of paleo-ground water flow to spring orifices; and paleo-water levels inscribed on the walls of Devils Hole, a fault-controlled collapse feature adjacent to the Ash Meadows discharge area. Most of these features have been briefly described elsewhere (Winograd and Thordarson, 1975, pp. C82-C83; Dudley and Larson, 1976; Winograd and Doty, 1980; Pexton, 1984; and Winograd and others, 1985). In this study we focus on the calcitic veins as indicators of paleo-water tables because they are readily dateable using uranium-disequilibrium methods (Szabo, Carr, and Gottschall, 1981; Winograd and others, 1985).

At Ash Meadows, Nevada, the calcitic veins occur in association with, and adjacent to, a structurally-controlled 16-km long spring discharge area. The veins occur as much as 50 m higher than and as much as 14 km up-the-hydraulic gradient from the highest water level (719 m) at Ash Meadows, namely, that in Devils Hole (Winograd and Doty, 1980). Veins AM-7 and DH-1, from northern and central Ash Meadows are respectively 11 and 19 m higher than the water level in Devils Hole. Uranium-disequilibrium dating of these veins yields an age of 510,000 $\pm$ 62,000 years for the youngest laminae in vein AM-7, and 660,000 $\pm$ 75,000 for the youngest laminae in vein DH-1. These data permit calculation of the average rates of apparent water table decline; rates on the order of 0.02 - 0.03 m/10^3 yr are indicated. 1/

At Furnace Creek Wash, the apparent lowering of the water table during the Quaternary is dramatic. A calcitic vein swarm, and associated tufas occur as much as 570 m above the highest modern level of the regional water table in east-central Death Valley, namely that at Nevares Spring (286 m) 18 km to the northwest. Uranium-disequilibrium dating of vein 10B from the Furnace Creek Wash site indicates that flow in the fracture containing this vein ceased about 960,000 ± 84,000 years ago. This age, in conjunction with vein and water table altitudes, indicates an average water table lowering of 0.2 - 0.6 $m/10^3 yr$ 2/, or roughly an order of magnitude faster than the indicated lowering at Ash Meadows.

Tectonics, climate change, and erosion in response to tectonics and/or climate change are obvious potential causes for the observed water table displacements. A comparison of the cited water-table displacement rates at

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1/ These rates are minimum values, first, because we do not know how high above outcrop the sampled veins might have extended prior to erosion; and second, because the youngest laminae in our veins may only record the time of sealing of the vein, rather than the time of cessation of ground water discharge. Nevertheless, because the numerator (that is the altitude difference between vein outcrop and water level in Devils Hole) in our ratio is so much smaller than the denominator (vein age) any reasonable combination of values yields a very slow rate of decline. For example, if the altitude of vein DH-1 were 20 m higher prior to erosion (a large value considering the present relief on the Pliocene and Pleistocene rocks at Ash Meadows) and if ground-water discharge ceased 400,000 insted of 660,000 years ago, we still calculate an apparent rate of water-table decline which is less than 0.1 $m/10^3$ years.

2/ The spread in these ages reflects uncertainty about the altitude of the modern water table beneath the vein swarm. We utilized the altitude of Nevares Spring (286 m), down the hydraulic gradient from the vein site, and that of the water table in the Amargosa Desert (640 m), up the hydraulic gradient and east of the veins, to bracket the range of possible water table altitudes beneath the vein swarm. The maximum altitude of the vein swarm, and related tufas, is about 855 m.

Ash Meadows (0.02 - 0.03 $m/10^3$ yr) and Furnace Creek Wash (0.2 - 0.6 $m/10^3$ yr) with average rates of vertical crustal offsets in these regions seemingly supports tectonism as the prime cause for the displacements we have observed. Data presented by Pexton (1984) on the age and displacement of a dated ash-fall tuff at Ash Meadows indicates relative vertical crustal offset on the order of <0.01 $m/10^3$ yr. In east-central Death Valley, a rate of 0.3 $m/10^3$ yr has been calculated by Carr (1984) for the Black Mountains ultilizing the data of Fleck (1970).

Climatic change cannot be discounted as an important auxiliary cause for the documented water table displacements. Axelrod (1979) using paleo-botanical evidence argued for increasing aridity in the Sonoran Desert and adjacent areas during the Tertiary. He (1979, pp. 36-37) attributed this increasing aridity, in part, to uplift of the Peninsular Ranges and the Mexican Plateau. Major uplift of the Sierra Nevada and Transverse Ranges during the Pliocene and Quaternary should similarly have markedly and progressively reduced the precipitation reaching the Great Basin during this time. Smith and others (1983, p. 23) suggested that 3 m.y. ago, when the Sierra Nevada was about 950 m lower, about 50 percent more moisture might have crossed the Sierra and moved into the Great Basin. Isotopic evidence for increasing aridity in the southern Great Basin throughout the Quaternary has recently been presented by Winograd and others (1985). And, Pexton (1984, pp. 43 - 46, 57), on the basis of studies of sediment depositional environments believes that the Ash Meadows area became progressively more arid during the Quaternary. Thus, to whatever degree the cited rates of water table lowering reflect increasing aridity, they overestimate displacement due to tectonism.

The role of erosion in the apparent lowering of water table is not known. We assume that in east-central Death Valley, where the rate of vertical crustal offset is large, tectonism dominated over both erosion and climate as a factor in water table change during the Quaternary. This may not, however, be correct for the Ash Meadows region where the rate of vertical crustal offset is an order of magnitude smaller (see above); here, the erosional history of the bordering Amargosa Desert -- a history influenced by climate change and possibly also by tectonism in Death Valley -- may have played an important role in the water-table changes we see at and northeast of Ash Meadows.

Above, we have summarized evidence for an apparent lowering of the water table during the Quaternary at Ash Meadows and Furnace Creek Wash. We do not know to what degree this displacement reflects: a) local tectonic uplift unaccompanied by a change in water-table altitude; b) an actual lowering of water-table in response to the tectonic downdropping of a region adjacent to our dated veins, to increasing aridity, or to erosion; or c) some combination of a) and b). However, a synthesis of regional hydrogeologic, tectonic, and paleoclimatologic information with our observations indicates that a progressive and absolute lowering of the regional water table (more correctly the potentiometric surface) is likely to have occurred throughout the south-central Great Basin during the Quaternary. This inference is based on the following three considerations:

a) The several-thousand meter topographic relief in Death Valley is apparently largely of Pliocene and Pleistocene age (Hunt and Mabey, 1966; U.S. Geological Survey, 1984) and the movement of the floor of Death Valley has probably been downward relative to both sea level and to bordering areas (Hunt and Mabey, 1966, p. A153).

b) Gravity-driven interbasin flow of ground water through Paleozoic carbonate rock and Tertiary welded-tuff aquifers is widespread in the region today (Winograd and Thordarson, 1975; Blankennagel and Weir, 1973) and is directed toward Ash Meadows and Death Valley. Such interbasin flow of ground water toward Death Valley in all likelihood also occurred during the Quaternary in response to the progressive lowering of ground-water discharge outlets there. As a result of a) and b) Death Valley gradually evolved, during the Quaternary, into the modern hydrologic sump for ground waters of the south-central Great Basin.

c) The progressive increase in aridity of the region, due to uplift of the Sierra Nevada and Transverse Ranges, would presumably have resulted in a progressive reduction in ground-water recharge.

We are aware that the regional carbonate-rock and welded-tuff aquifers are hydraulically compartmentalized by faulting (Winograd and Thordarson, 1975, pp. C63 - C71) and that, consequently, the postulated lowering of ground-water base level in Death Valley during the Quaternary may not have propagated uniformly throughout the region, specifically northeast of the major hydraulic barrier at Ash Meadows (Winograd and Thordarson, 1975, pp. C78 - C83). Nevertheless, we believe that the combination of increasing aridity and local erosion in the Amargosa Desert during the Quaternary should, in any event, have resulted in a progressive lowering of the water table at and northeast of Ash Meadows. Yet another mechanism for water table lowering at and northeast of Ash Meadows which involves neither erosion nor climate change, but rather extensional fracturing, is outlined by Winograd and Doty (1980). They point out (p. 74 - 75) that the major springs at Ash Meadows oasis differ in altitude by as much as

35 m and are as much as 50 m lower than the water level in Devils Hole. Thus, periodic initiation of discharge from new spring orifices (or an increase in existing discharge) in the lower portions of this oasis due to faulting would have resulted in new and lower base-levels for ground water discharge. Implicit in their hypothesis is the belief that the faulting would be of extensional nature opening new (or widening old) avenues of discharge from the buried Paleozoic carbonate rock aquifer which underlies eastern Ash Meadows and which feeds all the modern springs (Winograd and Thordarson, 1975). In support of their hypothesis we note that most of the calcitic veins in Pliocene and younger rocks at Ash Meadows strike N.40° ± 10° E, that is, nearly at right angles to Carr's (1974) estimate of the direction of active extension in the region, namely N.50°W. - S.50° E. This mechanism may also have periodically lowered the water table in east-central Death Valley where the difference in altitude between the highest (Nevares Spring) and lowest major springs (Texas and Travertine springs) discharging from the regional carbonate aquifer is about 170 m (Winograd and Thordarson, 1975, pp. C95 - C97).

The suggested progressive lowering of the regional water table throughout the Quaternary does not preclude superimposed and relatively rapid cyclical fluctuations in water level in response to the glacial and interglacial climates of the Pleistocene. Indeed, preliminary data from Devils Hole indicate that the water table may have fluctuated as much as 10 m in the past 30,000 years (A.C. Riggs, B.J. Szabo, and I.J. Winograd, work in progress). This, in turn, indicates that vein AM-7 (see above), which is only 11 m above the modern water table, would by itself, be of limited utility for determination of the postulated water table decline since the middle Pleistocene. Intensive studies of paleo-water level fluctuations are underway in Devils Hole where excellent records of both Quaternary paleohydrology and paleoclimatology are preserved. We hope that these studies will permit us to distinguish between short (10^4 to 10^5 year) and long (10^5 to 10^6 year) term water-table fluctuations at Ash Meadows where the difference between the highest paleo-water level and the highest modern water table is only 50 m.

The cited evidence for an apparent lowering of the water table at Ash Meadows and Furnace Creek Wash and the inference of an absolute lowering of water table over a broader region during the Quaternary are both highly pertinent to an evaluation of the utility of the thick (200-600 m) unsaturated zones of the region for isolating solidified radioactive and toxic wastes from the hydrosphere for tens to hundreds of millenia (Winograd, 1981). Wastes buried a few tens to perhaps 150 m above the modern water table -- that is above possible water-level rises due to cyclical climatic changes (Winograd and Doty, 1980 and Czarnecki, 1985) 3/ -- are unlikely to be inundated by a rising water table in the forseeable geologic future.

The present study adds additional support for the principal conclusion of Winograd and Doty (1980); namely, that deep water tables, thick (up to several hundred meter) unsaturated zones, and ground-water flow paths tens of kilometers in length, characterized the south-central Great B asin during the Pleistocene and presumably will so characterize it during future pluvial climates.

3/ In general, the analyses of Winograd and Doty (1980) and Czarnecki (1985) assumed worst-case conditions, that is, they maximized water table rises expectable during the pluvial climates of the Pleistocene.

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