GEOCHRONOMETRIA Vol. 21, pp 79-84, 2002 – *Journal on Methods and Applications of Absolute Chronology*

A BETTER-DEVELOPED SOIL PROFILE DURING BIBLICAL TIMES IN THE WESTERN GALILEE. ^{15}N EVIDENCE IN ^{14}C - DATED GROUNDWATER

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Key words:
CARBON ISOTOPES,
NITROGEN ISOTOPES,
SOIL,
LANDSCAPE CHANGES,
CLIMATE CHANGES

Abstract: **Despite almost a hundred years of reforestation efforts, the recharge area of the Judea Group aquifer in the hills of the western Galilee still shows the signs of the severe soil erosion that transpired in previous centuries. At present the soil profile is thin and basement rock is often exposed. Historical and Biblical sources suggest that the hills in the past were more forested. Therefore, the $\delta^{15}N$ values of dissolved nitrate were measured in radiocarbon-dated groundwater to see if evidence for past soil conditions could be deduced. Nitrate mineralization processes in soils lead to enrichment in ^{15}N of the residual nitrate, which being dissolved by rain enters into the groundwater without further isotopic fractionation. Previous studies have shown that there is a trend of increasing $\delta^{15}N$ in a soil profile from plant, to litter, to the organic material in the soil. In addition, there is a tendency for higher $\delta^{15}N$ values to be observed in those samples that have been taken at greater depth in a soil profile due to progressive mineralization and subsequent nitrification of soil organic material. As long as the dissolved oxygen is not depleted, denitrification will not occur to alter the isotopic composition of the dissolved nitrate. The nitrate concentrations and $\delta^{15}N$ values, water chemistry, tritium and radiocarbon activities were measured from the phreatic outcrop recharge region, and onwards into the confined portions of the Judea Group aquifer and its continuation into the juxtaposed Kurdani and Pleistocene aquifers. The radiocarbon activity decreases with flow. Tritium values of above 2 TU are restricted to the recharge region. Using an initial ^{14}C activity of 64 pMC the radiocarbon ages of the water are found to range from recent to 7800 BP. The $\delta^{15}N$ values of the dissolved nitrate within the young water recharge area fall in the range of +3.1 to +4.8‰ (Air), having a mean of +3.9‰ (n=5). In older water the nitrate concentration increases slightly, while the $\delta^{15}N$ ranges from +4.7 to +7.2‰ (Air), having a mean of +6.4‰ (n=17). The increase in the $\delta^{15}N$ values in the older water down-dip is not due to denitrification processes; for, the waters are well oxygenated. These older waters infiltrated at the same point of origin in the phreatic portions of the aquifer (non-contaminated) as the recent water. As the earlier infiltrating water flowed down dip they retained the $\delta^{15}N$ values of the environment at that time. The $\delta^{15}N$ values present evidence that, compared to the present, the soil and plant cover was better developed in earlier times, including Biblical times.**

1. INTRODUCTION

There are two dominant processes that cause changes in the landscape. One is human activity and the other is climate change. Beginning with our forebears who traversed the Middle East about 100,00 years ago and spread into Europe and Asia (Stringer and Mckie, 1997), the Land of Israel has always been a zone in which people have wandered back and forth (**Fig. 1**). To name a few, we have the Egyptians, the Babylonians and the sons of Israel who went to Egypt and came back (Genesis 47:1; Exodus 15: 16-28). Likewise, in more recent times Napoleon and his forces, similar to other armies in the past, marched up from Egypt and back again across the Land. At other times, the Middle East corridor was accessed also from the sea – in Biblical times, e.g. by the Philistines (Amos, 9:7). In the middle Ages, waves of Crusaders came to the land of Israel, by way of the land as well as by the sea (Benvenisti, 1970). All these coming and going through the Middle East left a mark on the landscape. Trees were cut for firewood and for building. Space was cleared for agriculture. The latest and most intensive assault on the landscape was made by the Ottomans, who, during the First World War, cut the forests of the country at a rate of 10 tons/day, to feed their steam locomotives, which traversed the country from the north down to Beer Sheba (Sheffer, 1987). From the Bible, we know that during the Iron Age, at the time of our Patriarchs, the land was covered with extensive forests; although, the trees might not have been big (King Solomon had to import cedars from Lebanon in order to build the temple (I Kings 5:6)).

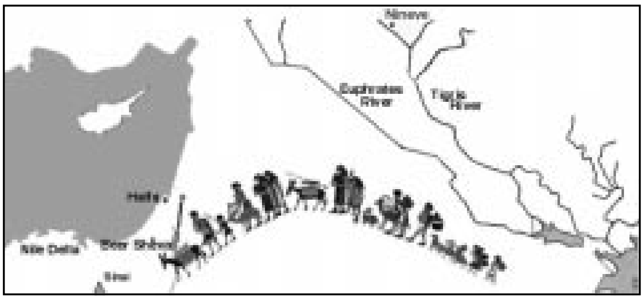

Fig. 1. The Land of Israel has served as a land corridor of the Middle East, through which people have migrated and armies have passed for millennia (Modified from Passover Hagada, Koren Publishers; Jerusalem, 1979).

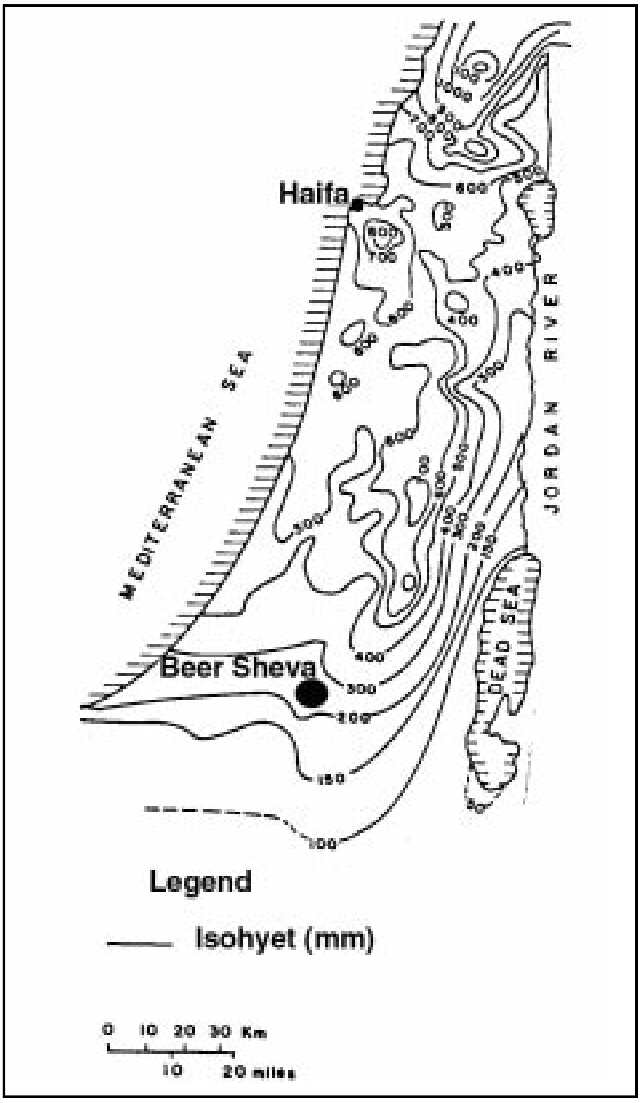

Fig. 2. Present day rainfall distribution map of Israel. There is a steep north south gradient in the precipitation. The desert boundary is located today in the vicinity of Beer Sheva. The study area extends from the hills of western Galilee to Haifa Bay, immediately north of Haifa.

Israel is not only a passage way but a transition zone between temperate and desert climate regimes. The transition line between these two regimes has been delineated by Goodfriend (1988) near the town of Beer Sheba (**Fig. 2**). Clearly a northward shift of the desert would profoundly affect the floral landscape. The possibility that the transition zone has not always been anchored near Beer Sheba must be investigated before it can be excluded as having been a cause of forest degradation to the north in the past.

In this paper we investigate the evidence, and evaluate the causes for change in the landscape using climate proxy data, preserved in the groundwater of an important aquifer water in northern Israel, near Haifa (**Fig. 2**). The aquifer (**Fig. 3**) is bounded by the hills of the lower Galilee in the east and by the Coastal Plain, to the west (Mero, 1983). The direction of water flow is from the east, where recharge takes place, westwards. The present-day top soil is very thin and in many places the bed rock is exposed. It had been eroded by rain flushing away the bare soil of the denuded hills under the influence of the the steep gradient of the terrain,which enabled the process to be very efficient. In the cross section of the Judea Group aquifer (**Fig. 4**) it is seen that the recharge in the east is into a matrix of limestones and dolomites. Flowing down dip from the phreatic recharge area, the water becomes confined under an impermeable aquiclude. Further towards the sea there are two small aquifers (Kurdani and Pleistocene) overlain by a thick impermeable clay layer. Faulting has juxtaposed portions of the permeable beds of each aquifer against each other. Therefore, this has enabled water from the Judea Group aquifer to drain into, and recharge in turn, the carbonate Kurdani aquifer, and then the sandy Pleistocene aquifer. A small outcrop of the Kurdani aquifer supplies some water to the Pleistocene aquifer as well. Other than this small recharge, no surface water has entered these aquifers except that which has originated the in hill region where the Judea Group outcrops.

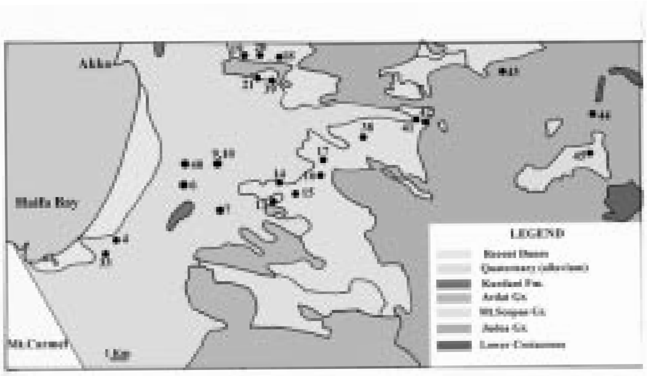

Fig. 3. Geological map of the study area showing location of the samples. The outcrop area of the Judea Group carbonate aquifer is restricted to the hills in the east. It is overlain by younger, impermeable strata westwards of the recharge. The Kurdani aquifer, which receives drainage from the Judea Group, has only two small surface exposures. The hydrologically connected Pleistocene aquifer is only encountered in the subsurface. The Pleistocene aquifer is not seen at the surface because it is covered by recent dune aquifer.

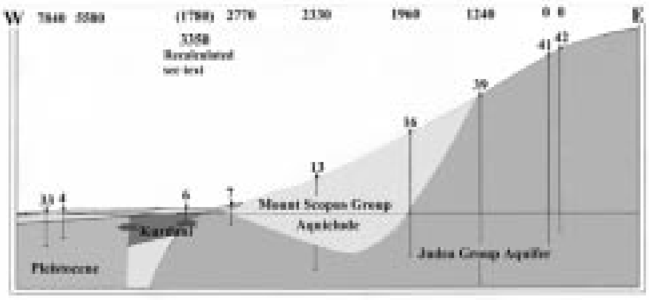

Fig. 4. *A schematic east-west hydrogeologic cross-section is presented using representative wells from the recharge and confined sections of the Judea Group aquifer. Sample 6 is projected onto the section to show the hydrologic interconnection between the Kurdani aquifer and the Judea Group, while samples 4 and 33 are projected on this east-west cross section to show interconnection between the Pleistocene aquifer and the Kurdani aquifer.*

2. METHODS

Water samples were collected from pumping wells that exploit this multi-aquiferial system, with the purpose of finding isotopic evidence for the timing and the causes of changes in the landscape above the recharge area. More specifically, evidence for the dilution or elimination of flora and its subsequent effect on the topsoil was looked for.

In the water, two isotopic proxies were studied to differentiate between the two possible scenarios outlined above. One proxy is the ratio of the stable isotopes of carbon. The composition of this isotopic ratio in aquifer water is a result of the combination of inputs of carbon from two end members: organic matter on the surface and the matrix through which recharge water passes into the aquifer (Mook *et al.*, 1974). The source of organic matter on the surface are plants that have grown there. In a temperate climate these are predominantly C_3 plants, with $\delta^{13}C$ values within the approximate range of –20 and –32‰ (Clark and Fritz, 1997). When a temperate climate gives way to desert conditions there is a corresponding change in the flora. The land cover changes from C_3 to predominantly C_4 plants. The latter are characterized by $\delta^{13}C$ values between –11 and –17‰ (Vogel *et al.*, 1986). As the other end member is a carbonate rock matrix, having a $\delta^{13}C$ of ~ 0‰ (Magaritz *et al.*,1983), then $\delta^{13}C$ of the dissolved bicarbonate in the water will be approximately half of the average soil gas value. Thus, if the aquifer water were to exhibit a marked enrichment in ^{13}C, this would be supportive of a climatic control; whereby, the erosion would have resulted from a northward excursion of the desert boundary from its present position.

The second proxy is the nitrogen isotope ^{15}N. The nitrogen in water is also derived from organic matter in the topsoil. The decomposition of this organic matter generates ammonium which can be partly volatilised as ammonia gas (at high pH), and the remaining organic matter is oxidized to nitrites and nitrates by bacterial nitrification. When a light gas like ammonia is formed, it becomes relatively depleted in ^{15}N. The remaining nitrate becomes enriched in ^{15}N. The extent of the enrichment in ^{15}N depends on the intensity and duration of nitrification in the top soil: when it is thick, more time is available for production of ammonia and the ^{15}N of nitrates becomes more enriched. Previous studies have shown a trend of increasing $\delta^{15}N$ in a soil profile from plant, to litter, to the organic soil material. Moreover, there is a tendency for higher $\delta^{15}N$ values in samples that have been taken at greater depth in a soil profile, due to progressive mineralization and subsequent nitrification of soil organic material (Lajtha and Michener, 1994). By contrast, when the topsoil is thin, the time of ammonia production is short and the $\delta^{15}N$ of the nitrate should be lower. Once in the aquifer the isotopic signature of the dissolved nitrate will not change unless either additional nitrate is added along the water flow path, or if bacterial denitrification (which occurs only under unaerobic conditions) of the dissolved nitrate takes place. In the aquifer under consideration both these effects can be excluded for: (1) no additional inputs of nitrate, even if such sources were to have existed, could penetrate through the impermeable confining aquicludes, and (2) the water of the Judea Group aquifer is well oxygenated (8-9 mg/l in the recharge reigon and 4-7 mg/l in the confined region (Rogojin, 2000)). Thus, anaerobic conditions never prevailed to allow for the alteration of the isotopic signature of the dissolved nitrate by denitrification processes. Therefore, we feel confident that the $\delta^{15}N$ values of the groundwater at each sampling site reliably reflect the isotopic signature of the dissolved nitrate at the time of recharge. To use these proxies in a historical context, we dated the aquifer water with ^{14}C and with tritium.

3. EXPERIMENT

The sampling was carried out in 1994-1996. Samples for nitrogen analyses were collected in 1 liter plastic bottles. The analyses were carried out at the Center for Scientific and Industrial Research in Pretoria, South Africa, using a SIRA 24 mass-spectrometer. The $\delta^{15}N$ values are reported relative to atmospheric air, with a precision of 0.15‰. Radiocarbon analyses required 50-liter samples. The tritium and radiocarbon analyses were measured at the Radiocarbon Dating Laboratory at the Weizmann Institute of Science in Rehovot, Israel. The tritium was enriched by electrolysis, converted to ethane and detected in proportional counters. Tritium concentrations are reported in tritium units (1 TU = 1 atom tritium per 10^{18} atoms of hydrogen). The associated standard deviation is reported at the 1σ level of confidence. The precision was better than 0.3 TU. Radiocarbon measurements were carried out on the CO_2 that was precipitated as $BaCO_3$ from 50 liters of water. It was converted to ethane and ^{14}C was detected in proportional counters. The results are expressed in percent with respect to "modern carbon" (pMC), with the associated statistical counting error at the 1σ level of confidence. The precision was better than 0.6 pMC. $\delta^{13}C$ was measured using an Atlas MAT 250 mass spectrometer with a precision of 0.1‰.

4. RESULTS

Table 1 summarizes the data used in our interpretation. No NO_2 was detected. The $\delta^{15}N$ values of the dissolved nitrate within the recharge area fall in the narrow range of +3.1 to +4.2‰. They gradually change to higher values along the flow path, reaching +6 to + 7‰. The nitrate values range from 12 to as high as 38 mg/L nitrate but there is no consistent change in the nitrate concentrations with flow. The tritium values vary with geographical position. There are measurable amounts of tritium in the phreatic recharge, and none in the confined sections of the aquifer. The radiocarbon concentration varies from 64-70 pMC in the phreatic region where tritium is encountered, to 46 pMC in the well furthest the down-dip (the Afeq-B well). The $\delta^{13}C$ values vary from -14.0 to -18.6‰ (PDB). In the Kurdani aquifer the $\delta^{13}C$ values vary from -12.3 to -15.2‰ (PDB), while the radiocarbon activity is in the range of 50-55 pMC. The nitrate values are similar to those most frequently encountered in the Judea Group water being in the range of approximately 12 to 23 mg/l, with a corresponding range in $\delta^{15}N$ values +5.6 to +7.0 ‰. The radiocarbon activity of the water of the Pleistocene aquifer is much lower, 24.8 and 32.6 pMC; otherwise, it has a similar range nitrogen of isotopic values.

To convert the measured radiocarbon activity of the water to an absolute age it is necessary to determine its initial activity. According to the model of Ingerson and Pearson (1964), the range of the initial activity of (pre-thermonuclear) radiocarbon in the water is 64-66 pMC. Kroitoru e*t al*. (1989), using mass-balance considerations, calculated the initial radiocarbon activity for recharge water in the Judea Group aquifer to be 62±3 pMC. We therefore use 64 pMC to calculate the ages of the water in the aquifer (**Table 1**). Clearly, values above 64 pMC have a component of thermonuclear radiocarbon and are regarded modern. The oldest water in the main aquifer is about 2800 years old. This defines the flow rate of this aquifer to 5 m/yr, which is comparable with the rate of flow of other carbonate aquifers in Israel (e.g. Kronfeld *et al*., 1992). The waters in the Kurdani and Pleistocene aquifers are significantly older, the oldest being about 7800 BP. Yet, they exhibit $\delta^{13}C$ and $\delta^{15}N$ values that are similar to those from the confined portions of the main aquifer. The hydraulic gradient near the coast is very small, and this can explain the big difference in water ages over small distance.

Table 1. *Radiometric age data and nitrogen isotopic data in the multi-aquiferal system of the Western Galilee*

Sample Code #	**Wells**	**Aquifer***	**Tritium** [TU]	**$\delta^{13}C$** [‰, PDB]	**^{14}C** [pMC]	**Age** [BP]	**NO_3** [mg/l]	**$\delta^{15}N$** [‰ Air]
				Young samples from recharge region				
41	Meged Kramim-1	J.G.	2.9±0.2	-15.1	64.0±0.6	Recent	14.6	3.7
42	Meged Kramim-2	J.G.	2.6±0.2	-14.6	70.1±0.4	Recent	15.5	4.0
43	Meged Kramim-3	J.G.	1.7±0.2	-14.9	66.1±0.5	Recent	12.4	3.1
44	Hazon-3	J.G.	5.6±0.2	-15.4	83.1±0.4	Recent	22.6	4.8
45	Hazon-4	J.G.	1.5±0.2	-15.5	76.4±0.4	Recent	20.4	4.2
				Samples from confined section of the aquifer				
38	Miar	J.G.	0.5±0.3	-15.7	59.8±1.0	561±140	19.0	6.5
20	Akko-2	J.G.	1.9±0.2	-18.6	56.9±0.5	972± 73	23.5	6.8
40	Lokhamey HaGetto-Dror	K	2.0±0.2	-15.2	55.3±0.4	1208±60	22.6	6.9
39#	Ahihud	J.G.	0±0.2	-12.9	55.1±0.6	1238±90	12.4	4.7
6	Afeq-C	K	0±0.2	-14.3	51.6±0.3	1780±49	12.0	5.6
16	Damun-5	J.G.	0.4±0.2	-14.0	50.5±0.4	1959±65	19.0	6.8
9	Kefar Masaryk-3	K	0.4±0.2	-12.3	50.0±0.7	2041±116	23.6	6.9
18	Akko-4	J.G.	1.1±0.2	-16.7	49.8±0.4	2074±66	14.6	5.1
13	Damun-3	J.G.	1.1±0.3	-14.5	48.3±0.4	2327±69	38.5	7.0
7	Afeq-B	J.G.	0±0.2	-14.6	45.8±0.4	2766±73	17.3	6.6
4	Qiryat Khaim-24	P	0.2±0.2	-14.2	32.6±0.4	5577±102	10.2	6.1
33	Qiryat Khaim-22	P	0±0.2	-12.7	24.8±0.2	7838±67	11.5	7.2
				Samples in confined section of the aquifer with measured $\delta^{15}N$ but lacking concomitant radiocarbon ages				
21	Birwa-3	J.G.	n.d.	n.d.	n.d.	-	13.7	5.9
19	Akko-3	J.G.	n.d.	n.d.	n.d.	-	16.4	7.0
15	Damun-4	J.G.	n.d.	n.d.	n.d.	-	25.7	6.8
14	Damun-1	J.G.	n.d.	n.d.	n.d.	-	31.9	6.4
10	Kefar Masaryk-2	K	n.d.	n.d.	n.d.	-	18.6	7.0

J.G. = Judea Group, K = Kurdani, P = Pleistocene,
# = a difference was noted, for this sample, between the nitrate concentration measured before the isotopic analysis and the yield of N that was produced in the laboratory- possibly indicating that the isotopic analysis is suspect.

5. DISCUSSION

The ^{13}C in the aquifer is quite depleted (**Table 1**) and this suggests that the organic end-member of carbon in the water, which came from the organic matter of the topsoil, have always been C_3 plants. For a contribution from C_4 plants we would expect values of $\delta^{13}C$ around –7‰ and this is clearly not the case. We can thus conclude that the change in the land cover was not due to the shift of the desert line from Beer Sheba to the Lower Galilee.

Fig. 5. shows the $\delta^{15}N$ data for water in the aquifer, as a function of the age of the water, calculated from radiocarbon**.** The broad picture is a practically stable value of $\delta^{15}N$ in the +6 to +7‰ range. This is in the range of $\delta^{15}N$ found in the literature for soil organic matter (Gormly and Spalding, 1979; Heaton, 1984; Komor and Anderson, 1993). There are 5 additional measurements (**Table 1**) for the confined portion of the aquifer that also fall within this range; but, as we have no dates for them they are not presented in **Fig. 5**. Though the aquifer contains one continuous water body, there is a sharp break in the nitrate isotopic compositons that delineates the older from the younger water groups, in which the $\delta^{15}N$ of the dissolved nitrate decreases to as low as +3.5‰. This change is taken not as an isotopic evolution process that occurred within the aquifer. No isotopic fractionation can be attributed to bacterial denitrification within the downdip segment of the aquifer to raise the $\delta^{15}N$; for denitrification requires anoxic conditions and the waters are well oxygenated. Indeed, no lowering of the nitrate concentration is noted. Thus, the measured $\delta^{15}N$ values have not been altered within the aquifer. Therefore, these values reflect the degree of isotopic fractionation of nitrogen within the soil before the nitrate entered the aquifer. Thus it appears that the groundwater preserves and records the changes in the nitrogen isotopes of the dissolved nitrate, which in turn is related to – and thus records – the thickness of the soil and the extent of the overlying plant cover of the last few centuries, when the region was ruled by the Ottoman empire. This process, that led to erosion, could have begun with uncontrolled grazing by goats, in conjunction with the cutting of trees to avoid taxation and culminated with the massive destruction of forests for use in the Ottoman steam locomotives, at the beginning of the 20th century. Whatever, the precise sequence of events, by the end of the Ottoman rule, the landscape of the Galillee was largely denuded of trees and soil. This necessitated largescale reforestation projects that are still ongoing. The nitrogen isotopic data supports the biblical description.

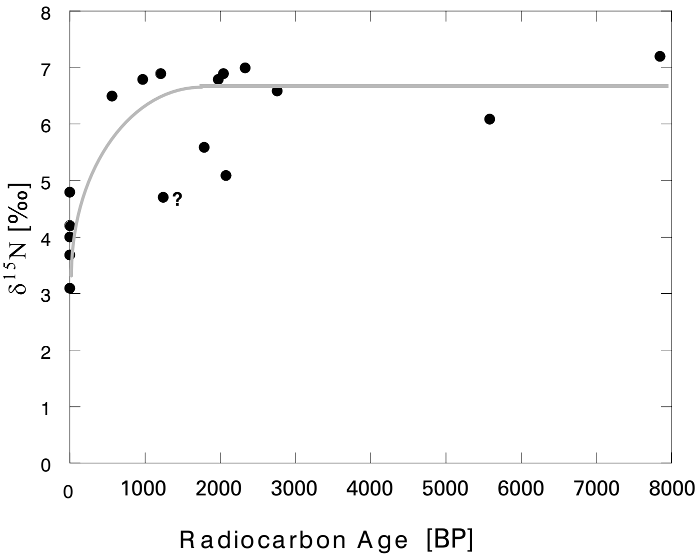

__Fig. 5.__ The nitrogen isotopic composition of the groundwater nitrate is plotted as a function of age. All of the groundwater samples can be considered to have entered the aquifer in the recharge area in the east before flowing to the point at which they have been subsequently sampled in this study. The sample #39 is denoted with a question mark; for, the isotopic analysis may not be reliable (as discussed in Table 1).

There are 3 data points in **Fig. 5** with $\delta^{15}N$ that fall below the average for the older water. One of them (No. 6) (**Fig. 4**) is also an outlier in the age gradient of the aquifer. However, this well is very close to the small outcrop of the Kurdani aquifer, which has a very thin soil cover (**Fig. 3**). Therefore the water in this well could be a mixture of the main aquifer water with young water, characterized by higher ^{14}C activity combined with lower $\delta^{15}N$. If we take $\delta^{15}N = +3.5$‰ for the young water and $\delta^{15}N = +7.0$‰ for the main aquifer, we find that this sample from the Kurdani aquifer is composed of 40% young water and 60% water from the main aquifer. Assuming that the ^{14}C content of the young water is 64 pMC, we find the ^{14}C content of the water from the main aquifer to be 43.3 pMC with a corresponding age of 3130 BP. This age is quite consistent with the gradient of ages along the direction of flow in the main aquifer.

The other two points are well behaved hydrologically and therefore they could be either an artifact or perturbation of the grand trend, or they could represent actual historical events. As historical events, they seem to suggest reversible changes in the land cover: thinner topsoil, or less organic matter in the top soil. The historical timing of these data points are Hellenistic, and some 300 years after the Arab conquest of the land, just before the Crusaders. Until we have some more data, the interpretation must remain speculative. It is clear, however, that a highly eroded soil profile produces much less isotopic fractionation of ^{15}N than a well developed soil profile, like the one that covered the land when lions roamed the forests of Judea (I Kings 13:24).

6. CONCLUSION

Our analysis shows that of the two potential culprits responsible for the changes in the land cover of northern Israel only one is to blame, namely, the changes brought about by human hands. There is no evidence that the desert line migrated this far north from its present position during the last 8000 years. We think that it is of interest to note that an aquifer can be an archive for the history of environmental processes.

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