

Salt Accumulation in the Loessial Sequence in the Be'er Sheva Basin, Israel

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ABSTRACT / Evidence of climatic changes is recorded in the salt content of the surface sediments in arid zones. In wetter periods airborne salts are removed downward by leaching to the groundwater, whereas in drier periods they accumulate. The period of salt accumulation in the loessial sediments of the northern Negev is about 10,000 yr. This period represents the recent aridification phase. The beginning of this stretch of time followed the last humid period in the region. Top paleo soil (calic horizon) found in the region and dated 12,000 yr B.P. is an indicator of this humid period.

Introduction

Among the more common mechanisms which contribute salts to groundwater are: (a) paleo saline waters, (b) seawater infiltration and mixing, (c) dissolution of evaporite minerals found in the geological sequence, and (d) fallout of airborne salts. Salts contribution to groundwater from this latter source is of particular importance in arid zones. At present one can estimate only the present salts contributed, which in many cases are affected by human activities. However, there is almost no information regarding atmospheric, airborne salts contribution on a wide timescale ($\sim 10^4$ yr).

The depth of penetration of the different airborne salts depends on the annual rainfall. Sparingly soluble salts—which easily reach saturation—penetrate to shallow depths and accumulate, while easily soluble salts move deeper and are leached from the sequence (Dan and Yaalon, 1982) and finally reach the groundwater reservoirs.

Along the edge of deserts where alternating periods of more and less rain occur, we expected to detect calcic horizons which were formed during wetter periods. Thus, in arid zone profiles which contain calcic horizons, the soluble salts were leached downwards during formation of this layer and the salt found today in this layer represents the salt accumulation since the last leaching period. Many of these salts are attributed to airborne origin (Ericksson, 1958).

In the present study we used a loessial sequence in the northern Negev of Israel to test the assumption

that salts presently found in the sedimentary column have been accumulating since the last leaching event. Using this data, we obtain estimates of the salts input rate into the region.

Materials and Methods

The studied profile is located 5 km northeast of Be'er Sheva, Israel. The Be'er Sheva Basin is located in the northern Negev of Israel, on the edge of the desert, with an average annual precipitation of 200 mm. Cultivation started in 1957, and the agricultural area is irrigated by local groundwater (650 mm/yr) during the summer.

The basin is covered by late Pleistocene loess deposits (Ginzburg, 1979). Average properties of the soil material (Ginzburg and Yaalon, 1963) are as follows: sand fraction, 30 percent; silt fraction, 40 percent; clay fraction, 30 percent; montmorillonite and illite, 70 percent of the clay and kaolinite, 30 percent of the clay; calcareous fraction in the loess, 20 percent; the bulk density is 1.4 g cm^{-3} .

Soil samples were collected in March 1983 (end of the rainy season) to a depth of 10.5 m along a freshly exposed vertical profile of the undisturbed zone beneath a vineyard. The soil material was sampled after removing 50 cm of the wall at 20 cm intervals. The soil was packed into preweighed glass bottles.

The water content of the soil was calculated by weighing these bottles before and after drying at 105°C . Ten g of each dried sample were extracted with 20 ml of distilled water for 24 h. Electrical conductivity (Radiometer Conductivity Bridge), Cl^- and SO_4^{2-} (Wescan Ion Chromatography), Na^+ and K^+ (Corning Flame-Photometer), and Mg^{++} (Perkin Elmer 306 Atomic Absorption Spectrophotometer) were analyzed on the clear aqueous extract.

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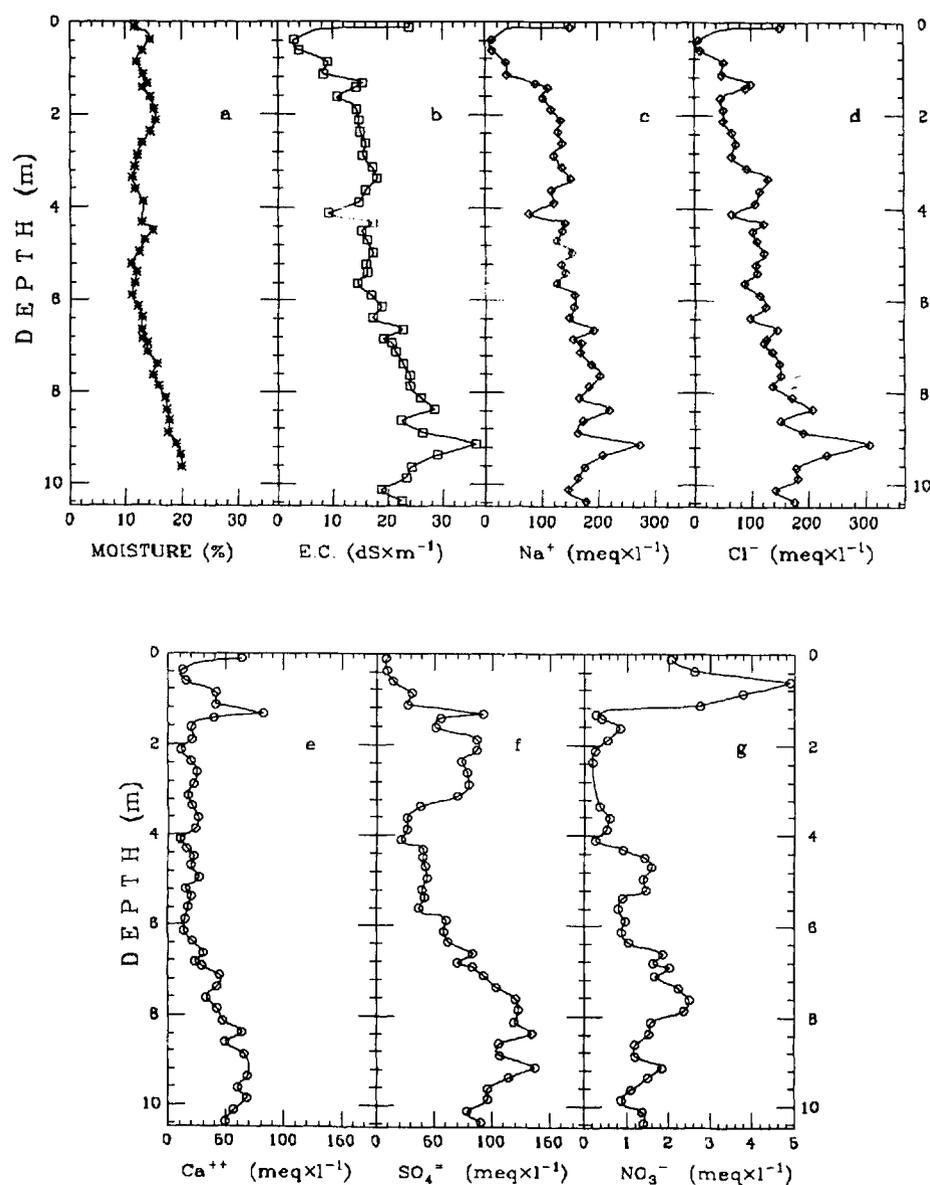


Figure 1. Water content (a), electrical conductivity (b), sodium (c), chloride (d), calcium (e), sulfate (f), and nitrate (g) concentrations in the sediment solution.

Results

Moisture content was found to increase from 12 percent weight in the upper part to 20 percent weight in the lower part of the loess profile (Fig. 1a). Total salt content increased with depth from 5 to 35 dS/m. Cl^- and Na^+ have similar concentrations in the sediment solution and both increase tenfold with depth. Cl^- and Na^+ concentrations are far from saturation with respect to halite. SO_4^{2-} concentration increases with depth by a factor of 6; exceptionally high concentrations are found between 1 and 3 m depth. Two phases of sulfate exist in the sediment: dissolved in the sediment-solution and soluble solid mineral (gypsum). During extraction procedures, one inevitably adds to the aqueous phase of the sediments a certain amount

of water which is larger than the naturally existing amount. This addition dilutes the sediment solution, causing undersaturation (Prather and others, 1978) which is followed by dissolution of solid gypsum present in the sediments (Keren and O'Connor, 1982). Therefore, when back-calculation of sulfate concentrations is carried out, the resulting sediment solution is artificially supersaturated under the original natural conditions. Results presented in Figure 1f show that all samples with the exception of those close to the surface have SO_4^{2-} concentrations above 15 mM/l (gypsum saturation level), indicating that solid gypsum was present in the profile sediments. Sulfate concentrations throughout the profile represent the combination of both SO_4^{2-} phases mentioned above.

Nitrate content was maximal at the depth of 60 cm

Table 1. Water content, chemical composition and two elemental ratios in the Omer loessial profile.

Depth (cm)	Water ^a (mm)	Water ^b (mm)	Cl ⁻ (10 ³ eq/ha)	SO ₄ ⁼ (10 ³ eq/ha)	Na ⁺ (10 ³ eq/ha)	Ca ⁺⁺ (10 ³ eq/ha)	Na/Cl (eq/cq)	Ca/SO ₄ (eq/eq)
25	41	16	61.71	3.33	60.91	25.70	0.98	7.71
50	50	20	3.26	4.56	5.08	6.15	1.55	1.34
75	45	18	4.50	6.58	5.08	6.75	1.12	1.02
100	42	17	21.57	13.08	15.21	17.85	0.70	1.32
120	36	14	17.83	9.97	14.21	15.20	0.79	1.52
140	39	16	39.01	36.04	34.52	31.80	0.88	0.88
160	36	15	32.93	20.31	40.78	14.80	1.23	0.72
180	40	17	18.64	20.62	40.82	8.00	2.18	0.38
200	42	18	21.57	36.37	48.82	8.95	2.26	0.24
225	54	23	27.69	46.85	71.21	6.15	2.57	0.13
250	50	22	33.40	36.77	63.60	10.10	1.90	0.27
275	45	20	32.70	35.16	60.91	11.20	1.86	0.31
300	42	18	27.43	33.64	50.82	9.55	1.85	0.28
325	41	18	37.35	28.79	54.82	6.95	1.46	0.24
350	39	17	50.50	14.83	58.26	8.10	1.15	0.54
375	41	18	47.49	10.64	47.91	10.40	1.00	0.97
400	45	20	48.67	12.02	54.60	10.40	1.12	0.86
420	36	16	24.28	7.89	28.39	8.80	1.16	0.48
440	36	17	44.42	14.85	50.91	6.00	1.14	0.40
460	41	19	42.67	16.79	55.95	9.10	1.31	0.64
480	37	17	40.64	16.85	46.56	7.40	1.14	0.46
500	34	16	42.36	15.43	52.69	8.25	1.24	0.59
525	38	18	40.81	15.00	50.73	5.80	1.24	0.38
550	41	20	45.01	17.52	58.21	8.15	1.29	0.46
575	40	19	35.18	14.97	50.69	6.95	1.44	0.46
600	38	19	44.64	23.47	60.82	5.75	1.36	0.24
620	34	17	42.35	19.64	52.87	4.65	1.24	0.23
640	36	18	34.70	22.04	52.60	7.40	1.51	0.33
660	36	18	53.09	30.33	69.00	11.10	1.29	0.36
680	37	19	46.59	25.66	56.87	8.80	1.22	0.34
700	38	19	46.78	32.22	64.82	11.10	1.38	0.34
725	49	25	66.64	45.29	81.26	22.00	1.21	0.48
750	54	28	80.28	56.41	101.43	23.10	1.26	0.40
775	51	27	77.69	61.75	103.91	17.26	1.33	0.27
800	55	29	76.31	67.85	101.21	23.70	1.32	0.34
825	59	32	100.56	70.39	88.17	27.75	0.97	0.39
850	60	32	125.21	80.66	131.82	38.75	1.05	0.48
875	62	34	94.08	66.04	106.52	31.05	1.13	0.47
900	61	33	116.31	65.16	28.65	40.50	0.84	0.62
925	66	36	204.39	90.62	179.91	0.00	0.88	0.00
950	69	38	159.15	78.20	142.00	47.35	0.89	0.60
975	70	39	125.29	67.20	121.78	42.00	0.97	0.62

^aTotal water amount.

^bImmobile water amount.

(root zone), reflecting fertilization. Unexpected high concentrations of nitrate, up to 2 meq/l in the soil solution, exist throughout the profile.

Cations concentrations represent equilibration between extracted solution and exchangeable cations, which means that the ratio between the amount of soil and the volume of the extracting phase has a strong effect on cation composition. This effect is possibly due to the fact that gypsum serves as an inexhaustible source of Ca⁺⁺. Ca⁺⁺ and Mg⁺⁺ concentrations also increase with depth.

In order to assess the amount of salt in each layer of the profile, Cl⁻, SO₄⁼, and Ca⁺⁺ contents were calculated in each horizon (Table 1). Ignoring the upper 1 m of soil, which is disturbed by plant root activity, it can be seen that Cl⁻ concentration in each soil layer down to 7 m is almost constant. Below this depth Cl⁻ content is more than doubled.

The Na/Cl ratio of most samples is greater than 1; at a depth of 2 m it reaches a value of 2.7. Below 2 m the ratio gradually decreases until it is lower than 1 at depths greater than 8 m (Table 1). The Ca⁺⁺/SO₄⁼

ratio is 0.4, with slight variation for most samples below 2 m. Samples close to the surface show the highest ratio (>1).

Anions and water accumulation in the profile can be calculated from the above data. The total water stored in the studied profile is about 2 m. A plot of accumulated chemical species against accumulated water produces a curve which is divided into three segments with different slopes; while Cl^- and Na^+ show a decrease in rate of accumulation from the lower to the upper segments (Fig. 2), Ca^{++} and SO_4^- show a minimal accumulation rate in the central segment (Fig. 2).

Discussion and Conclusions

Origin and Accumulation of Salts in the Studied Profile

The amount of salt in the profile can be used to determine the history of the local supply of salts in the studied region (Allison and others, 1985). Anions are not supplied to the profile due to weathering of minerals in the loess sediments and are not affected by exchange reactions; therefore, they are used for these calculations.

Salts may be contributed from two possible sources: accumulation with the sediments during profile formation or accumulation of dry and wet fallout salts under the prevailing arid conditions.

Loess deposits in the region have been accumulating throughout the last 100,000 yr (Issar and others, 1984). Within the loess profile, several calcic horizons were recognized (Magaritz, 1986), representing wet periods in which conditions suitable for soil formation existed. Under these conditions one would expect that the salts which accumulated in the loess during drier periods would be washed down to the aquifer. Dan and Yaalon (1982) discuss the relationships between the degree of salt leaching and mean long-term precipitation. They show that salt accumulated in soil only in regions with annual rainfall below 350 mm/yr. On the other hand, calcic horizons are commonly found in areas with rainfall between 300 and 500 mm/yr. The uppermost calcic horizon in this region was formed about 12,000 yr ago. This calcic horizon represents the time interval when topsoil formation occurred throughout the coastal plain of Israel (Magaritz and others, 1981) and the northern Negev (Magaritz, 1986). Two samples from the calcic horizon found in the studied profile yield ^{14}C -ages of 23,400 and 23,600 ± 300 yr. They represent the second calcic horizon found in other loessial sequences in the region (Magaritz, 1986). The fact that the last (12,000 yr B.P.)

calcic horizon was not found in the studied sequence, as compared to other nearby sections, led to the conclusion that during its formation the salts from the studied profile had already been leached.

Cultivation of the investigated field started in 1957. Gvirtzman and Magaritz (1986) showed that after 26 yr of irrigation (up to the sampling date) the sediment solution was still in a transitional state. Under natural conditions (before 1957) there was no downward water flow, and the 200 mm of annual rainwater evaporated completely from the exposed surface during the dry summers. A significant change followed an additional 600–700 mm of summer irrigation. Rain and irrigation water are low in solute concentration and the original saline water was displaced by the fresh penetrating water. Gvirtzman and Magaritz (1986) postulated that the leaching efficiency is low, on the basis of the following: (1) the small amount of percolating water—about 8 percent of the applied amount; (2) the relatively low water flow velocity—66 cm/yr; and (3) unsaturated flow conditions. They suggested that dispersion of clay minerals caused a formation of saline immobile water surrounded by fresh mobile water. They estimated that the percentage of the total water which is immobile (original solution) was about 40 percent at the surface and 55 percent at 8.5 m depth. Thus, the amount of the immobile water in the 8.5 m sediment sequence is 900 mm (Table 1, third column).

Salts in the Negev region are in origin either marine (chloridic) or aridic (sulfatic) (Nativ and others, 1983; Yaalon, 1964). The main factor determining the marine source contribution to the salt load is the distance from the sea (Eriksson, 1959; Loewengart, 1964).

Nativ and others (1983) reported a decrease of the fallout rate from 900 to 800 to 700 $\text{kg Cl}^-/\text{km}^2 \text{ yr}$ with respective distances from the sea of 56, 66, and 74 km. An amount of 900 $\text{kg}/\text{km}^2 \text{ yr}$ (9 $\text{kg}/\text{ha yr}$) is used for calculating chloride accumulation since the studied profile is situated 54 km from the sea. Assuming this rate is constant, the total accumulated Cl^- in the profile represents 9,300 yr of accumulation. It should be pointed out that this period (9,300 yr) closely follows the last evidence of leaching of salt from the sedimentary sequence (Magaritz, 1986).

One cannot be sure if the rate of accumulation was constant throughout the period. The constancy of the rate of accumulation can be tested by the relationship between the accumulated salt and accumulated water. In relation to the accumulating water (Fig. 2a) the rate of accumulation of Cl^- should decrease from the lower part of the profile upward. The change in rate

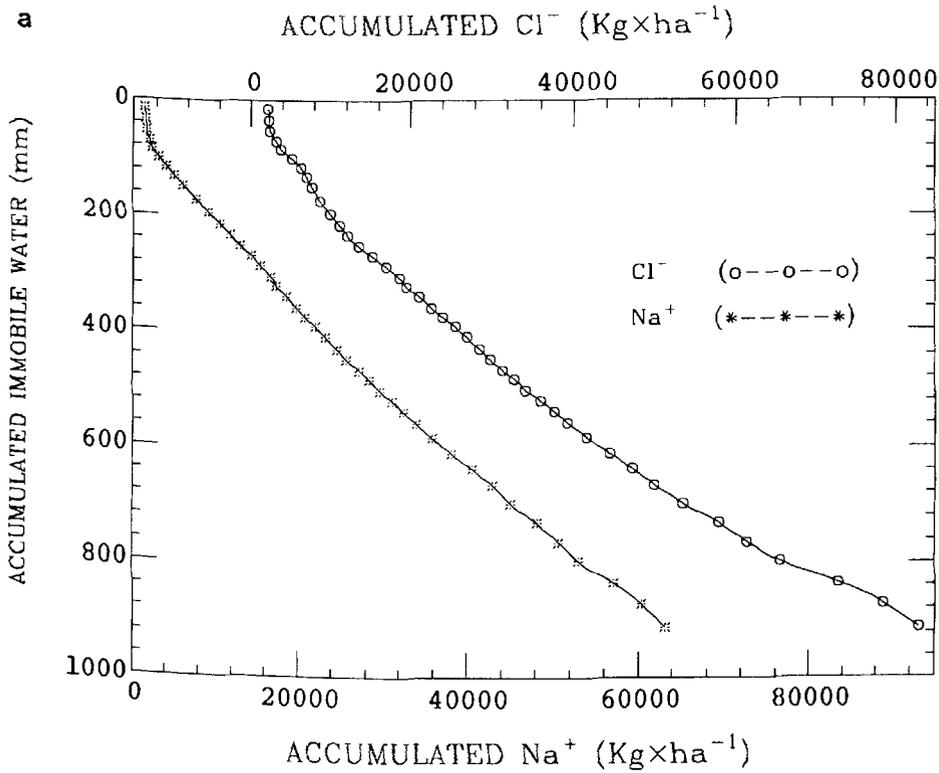


Figure 2a. Accumulated sodium (*) and accumulated chloride (o) in the Omer loessial profile plotted vs. the accumulated immobile water phase.

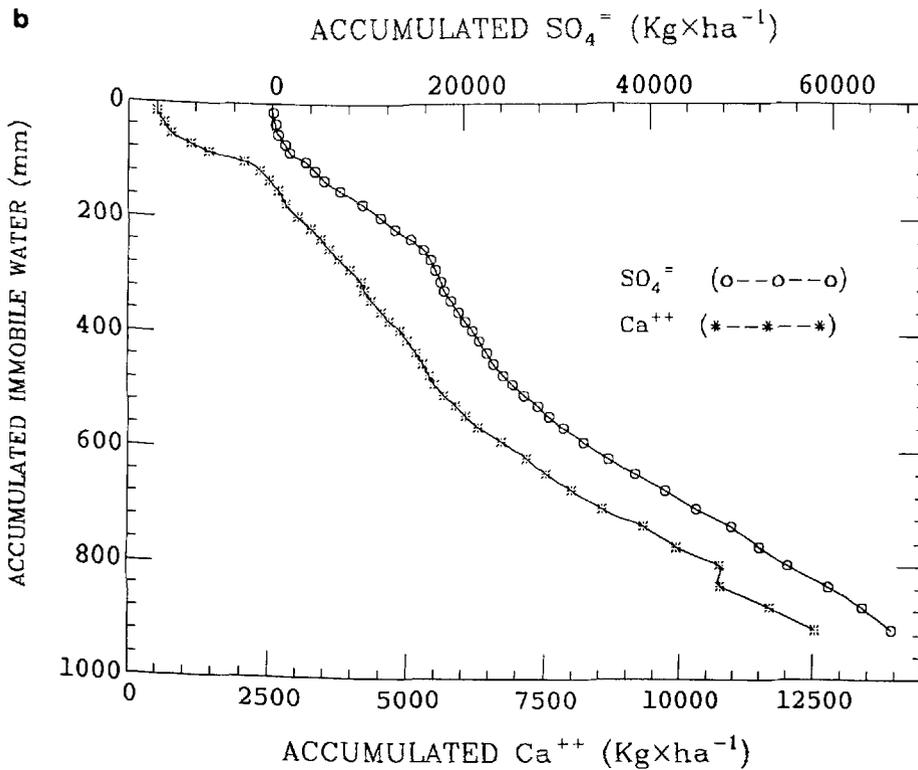


Figure 2b. Accumulated calcium (*) and accumulated sulfate (o) in the Omer loessial profile plotted vs. the accumulated immobile water phase.

of Cl^- accumulation (relative to accumulated water) which occurred at 5500 and 1500 yr B.P. can be explained in two ways:

1. A change in the amount of precipitation, which caused the different slopes of the segments (Fig. 2a). After evaporation, the water fraction is smallest in the lower segments and increases through the higher segments.
2. A change in salt input due to the fact that only 10,000 yr ago, the seashore was farther away from its present location, due to the low sea-level stand (Morner, 1971).

In that case the opposite trend should be expected, namely, an increase of Cl^- accumulation with the decrease of distance to the seashore. It can therefore be concluded that the annual residual water content in the lower segment was smaller than in the upper segments. This phenomenon is expressed in the mobile-immobile water model (Gvirtzman and Magaritz, 1986), which suggests that the fraction of mobile water in the profile decreases with depth. This is followed by a greater dilution of the immobile water fraction in the upper part, causing widening of the layers.

SO_4^{2-} accumulation was checked to verify the above assumptions. According to Nativ and others (1983) the present-time $\text{SO}_4^{2-}/\text{Cl}^-$ ratio of the arid/marine components equals 0.8, which is the same ratio as that between total accumulated Cl^- and total accumulated SO_4^{2-} in the studied profile (Figs. 2a, b).

The minimal rate of SO_4^{2-} accumulation occurred (Fig. 2b) in the central part of the profile (calculated age 1700 to 4300 yr B.P.). Although the last change in the rate of accumulation occurred at periods similar to those for the Cl^- (Fig. 2a), the decrease in SO_4^{2-} accumulation is sharper and cannot be explained by a change in the annual residual water content (as above). One possible explanation is the decrease of the desert-blown dust in the Negev, suggesting slightly wetter periods. This is in agreement with evidence that during the period from 4300 to 1700 yr B.P. the region of the northern Negev was extensively populated. This period represents the time of Abraham to the Nabatean period.

The excess of Na^+ in the profile over Na^+ originating from a marine source, throughout the profile, is 17,000 kg/ha. Assuming 20 percent clay content (of which half is montmorillonite), the entire potential for Na^+ exchange is three orders of magnitude (23×10^6 kg/ha) greater than the above difference. If Na^+ was released from the montmorillonite, another cation must have been removed from the solution. Ca^{++} is the most suitable cation to replace the Na^+ .

One can also calculate the input of Ca^{++} to the re-

gion assuming that the arid continental component is the major source brought as gypsum grains (Issar and Bruins, 1983). The amount of Ca^{++} which should be present in the profile according to the accumulated amount of SO_4^{2-} is:

$$66,765 \text{ [kg/ha]} \times 20/48 = 27,818 \text{ [kg/ha]}$$

The total amount of Ca^{++} actually found in the extracted soil solution is 12,525 kg/ha leading to a deficit of 15,291 kg/ha. This value is surprisingly equivalent to the excess of 17,000 kg/ha of Na^+ calculated above. These quantities are equal after correcting for their equivalent weights, 20 and 23 for Ca^{++} and Na^+ , respectively. Therefore, due to exchange reactions, it is suggested that the amount of cations like Ca^{++} and Na^+ is insufficient to determine their period of accumulation. These may be due either to reactions taking place under natural conditions or to an artifact of the extraction procedure.

The $\text{SO}_4^{2-}/\text{Cl}^-$ ratio in the entire salt content of the loess profile is similar to present-day fallout ratio (0.8). The accumulation period according to Cl^- is 9,300 yr, which is in agreement with the Paleoclimatic model of the Negev region (Magaritz, 1986).

From the salts input values obtained in this study it is seen that the regional amount of airborne salts input represents the Holocene period. This input rate may be applied to estimate the total amount of salts introduced into the groundwater in Israel.

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