

Preliminary ^{14}C study of groundwater at the fresh-saline water interface of the Mediterranean Coastal Plain Aquifer in Israel

Yoseph Yechieli: Geological Survey of Israel, 30 Malkhei Israel St. Jerusalem 95501, Israel.

Daniel Ronen: Department of Environmental Sciences and Energy Research, The Weizmann Institute of Science, Rehovot 76100, Israel.

Avner Vengosh: Hydrological Service, P.O. Box 6381, Jerusalem 91063, Israel.

ABSTRACT

^{14}C and tritium contents of saline and fresh groundwaters from the interface zone of the Coastal Plain aquifer of Israel were analysed. The low tritium values in most of the saline waters rule out penetration of present-day sea water. Preliminary ^{14}C results of saline groundwater (most of samples with values of about 50 PMC) also suggests that they are not modern sea water, although their locations are near the sea shore (100 m to 500 m). The problems involved in ^{14}C dating of penetrating sea water are discussed. Low ^{14}C content was found in several freshwater samples. The data suggest that (a) flow of fresh water from the aquifer to the sea is, in some cases, restricted and (b) the location of the fresh-saline water interface is not in equilibrium with the present level of the Mediterranean Sea.

INTRODUCTION

The intrusion of sea water into coastal aquifers is a well known process that leads to groundwater salinization to levels above drinking and irrigation water standards. It has been observed that the chemical composition of saline water at the fresh - saline water interface can be different from that of sea water (Vengosh et al., 1991). This phenomenon, attributed to be the result of subsurface storage of evaporated brines, calls into question the dynamics of the sea water - fresh water contact in coastal aquifers. More specifically it raises the question of whether: (1) there is a synchronic response between the changes in sea level and groundwater levels, and (2) the chemical composition of water at the interface zone is a result of mixing of the two presently existing saline and fresh water end members.

Kapuler and Bear (1970) suggested that the coastal plain aquifer of Israel is in a direct connection with the sea whereas Kolton (1988) has argued that in some locations the deeper sub-aquifers are not presently hydraulically connected to the sea. The elucidation of the nature of the fresh - saline water interface is of both scientific and practical interest since the nature of the fresh water - salt water contact will eventually define the pumping regime of coastal aquifers. In this paper we use tritium and ^{14}C isotopes to date saline water from the fresh - saline water interface. It is suggested that the apparent ages of the saline and fresh groundwater will assist in evaluating the residence time of saline waters in the aquifer and the dynamics of their inland penetration.

THE COASTAL PLAIN AQUIFER OF ISRAEL

The Coastal Plain Aquifer of Israel is basically a phreatic aquifer, located along the Mediterranean coast (Fig. 1). It varies in width from 7 km in the north to 20 km in the south; its thickness decreases eastwards from 200 m near the coastline to a few metres at the foothills of the Judea Mountains. The aquifer (the Kurkar Group) consists of interlayered sandstone, calcareous sandstone (arenites - kurkar), siltstone, red loam (Hamra), and marine clays of Pleistocene age, which overly impervious marine clays of Pliocene age (the Saqiye Group). In the west, up to 5 to 8 km from the coastline, interveing clay layers divide the aquifer in to four to six sub-aquifers (Fig. 2). Some of these sub-aquifers are confined (Weisbrod, 1993). In the central and eastern areas, the aquifer is composed mainly of sand and sandstone and is phreatic.

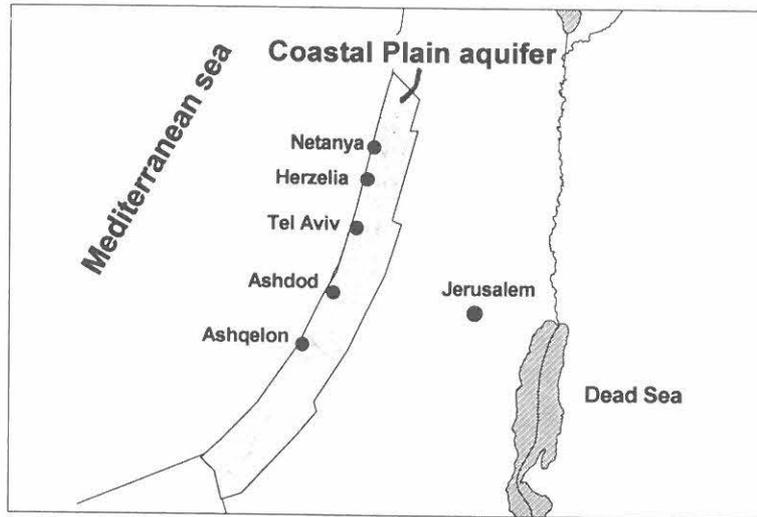


Fig. 1. Location map of the Coastal Plain Aquifer.

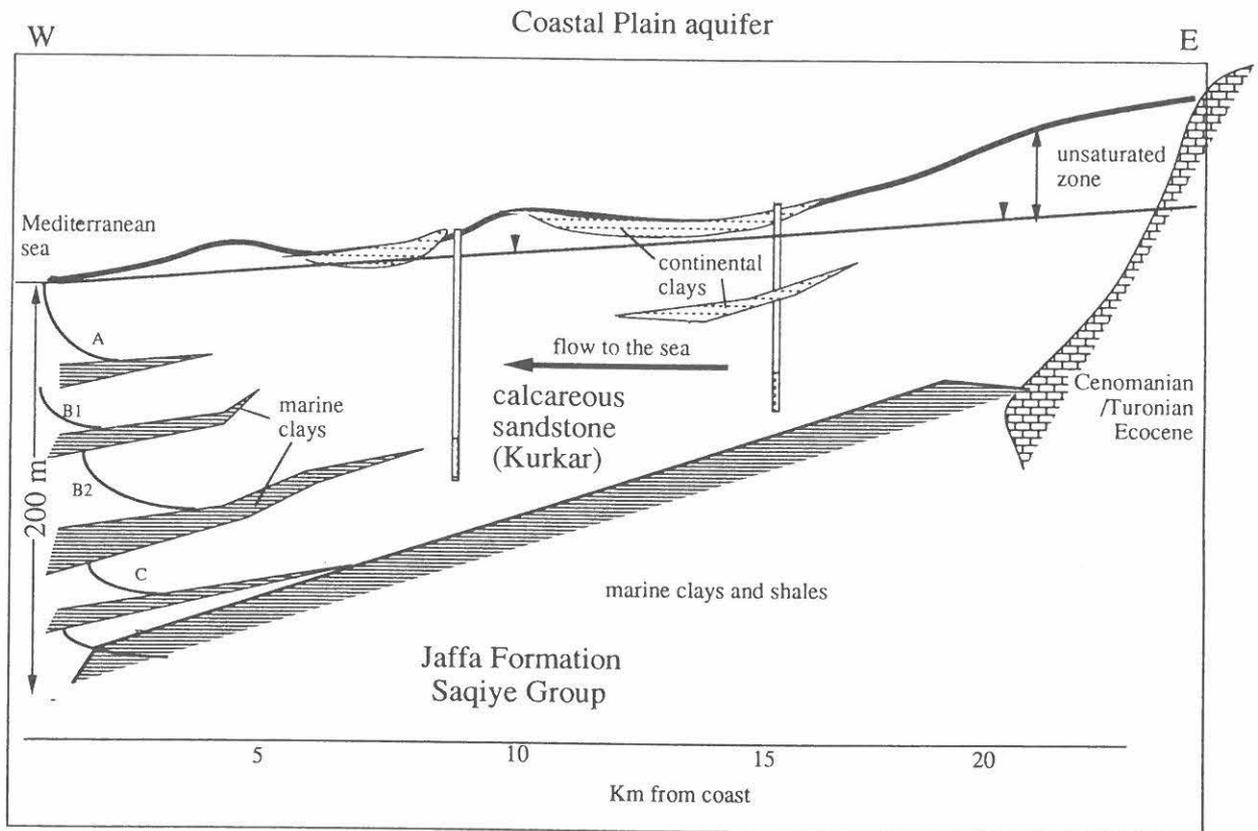


Fig. 2. Schematic hydrogeological cross section of the Coastal Plain Aquifer.

SAMPLING SITES AND ANALYTICAL METHODS

All existing wells up to a distance of 1 km from the shore line were surveyed. Groundwater from different sub-aquifers were sampled for chemical and isotopic analysis. Water samples were collected with a 700 cc sampler which enable acquisition of groundwater from predetermined depths.

The results of the preliminary survey were then used for establishing specific study areas. Since the ^{14}C analysis was conducted in the conventional way, which requires a large quantity of water (about 100 liters), two types of wells were found to be suitable for this project: (a) pumping wells in the Tel Aviv area, and (b) observation wells, in which it was possible to immerse a pump. All wells were purged before sampling; the volume of water removed was about 3 times the volume of the water in the well pipe. The research wells were located in the Ashqelon-Ashdod area and in the Herzelia-Netanya area (Fig. 1).

The ^{14}C concentration in groundwater was measured by means of proportional counters on ethane produced from extracted CO_2 which was released from the sample after acidifying with HCl. The ^{14}C concentrations are expressed as PMC (Percent Modern Carbon). For tritium analysis, the water samples were first enriched by electrolysis and then mixed with scintillation liquid and measured in an LKB 1220 Quantulus scintillation counter. The purpose of the enrichment was to reduce the counting errors to 0.3–0.5 T.U. Tritium concentrations are expressed in Tritium Units (1 T.U. corresponds to a tritium/hydrogen atom ration of 10^{-18}).

$\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ were determined using a Varian M250 mass spectrometer. For oxygen results are reported relative to the SMOW standard with a precision of $\pm 0.1\text{‰}$ and for $\delta^{13}\text{C}$ results are given as the per mil deviation from the PDB standard with a precision of $\pm 0.1\text{‰}$. Chemical analyses of major ions were conducted according to standard procedures in both the Hydrological Service and the Geological Survey of Israel with a precision of $\pm 5\%$.

RESULTS AND DISCUSSION

The results of this work indicate large chemical variability in the different sub-aquifers. This variability is in many cases the result of mixture between fresh groundwater and sea water as indicated by the good correlation between $\delta^{18}\text{O}$ values and Cl concentrations (Fig. 3). The deviation from a simple mixing process (Fig. 4) may be the result of chemical interaction with the aquifer rock matrix, in particular base exchange reactions (Mercado, 1985), and/or by mixing with other saline water bodies present in the aquifer (Vengosh et al., 1991).

Tritium concentrations in most saline groundwaters were low (< 3 T.U.) indicating that they are not the result of penetration of recent sea water. The variable tritium content in the different sub-aquifers reflects the difference in the rate of groundwater recharge (Fig. 5).

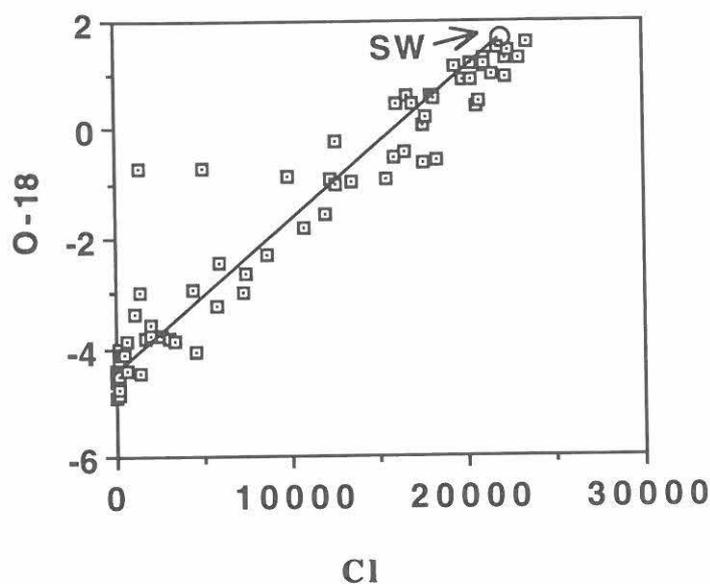


Fig. 3. Cl concentrations versus $\delta^{18}\text{O}$ in groundwater from observation wells in the interface zone of the coastal plain aquifer. Also shown is the mixing line between fresh water and sea water.

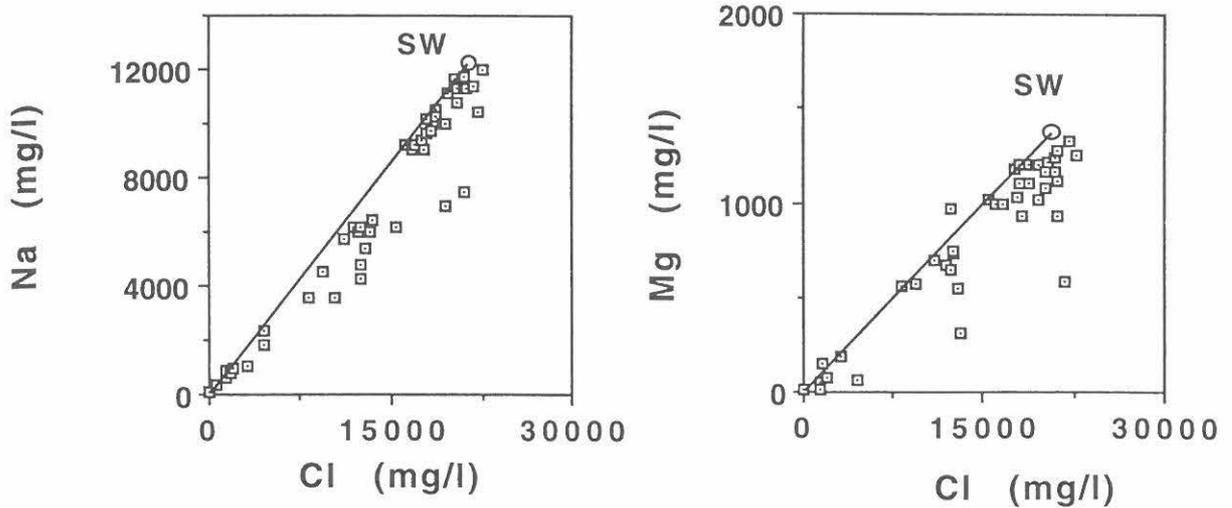


Fig. 4. Na and Mg versus Cl concentrations in groundwater from observation wells in the coastal plain aquifer. Also shown is the mixing line between fresh water and sea water.

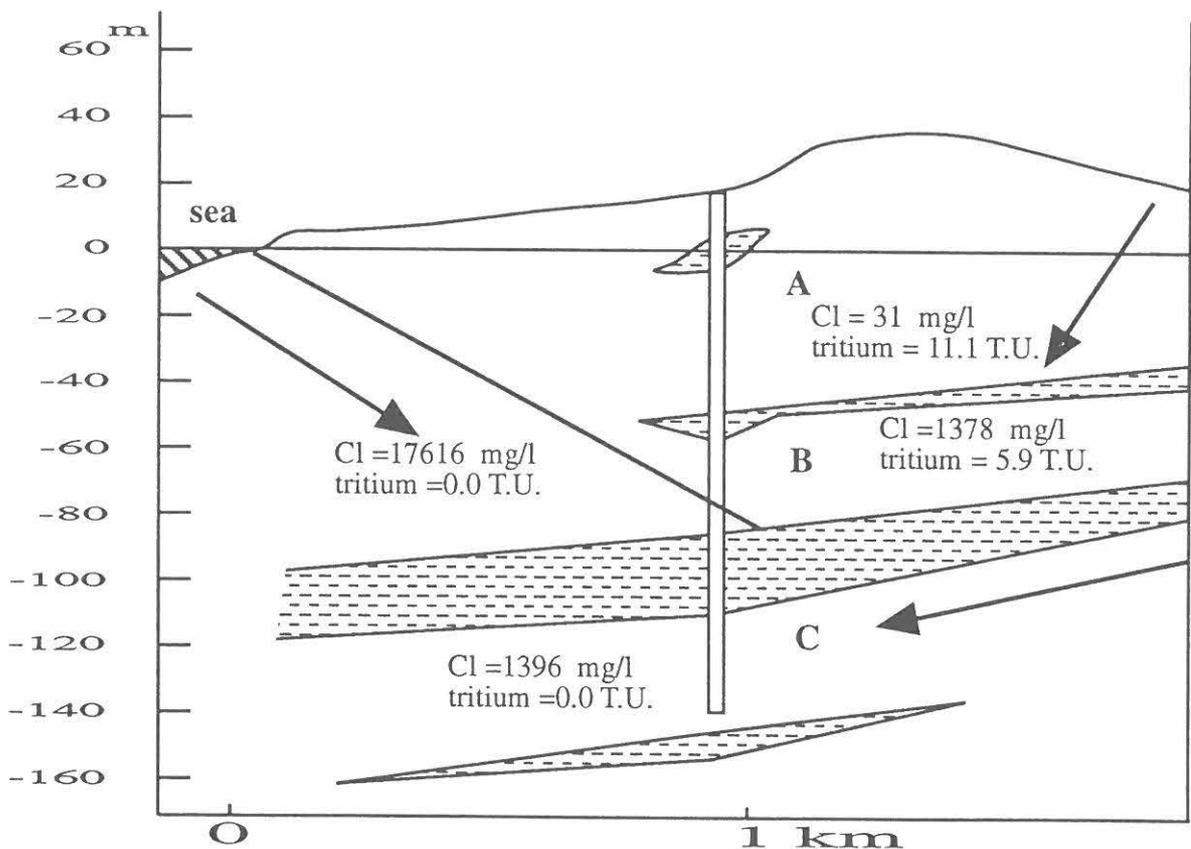


Fig. 5. Schematic cross section of the coastal plain aquifer 5 km south of Ashqelon. The arrows denote the direction of flow of the different water bodies. Note the differences in Cl and tritium concentrations between the adjacent sub-aquifers (denoted by A, B and C).

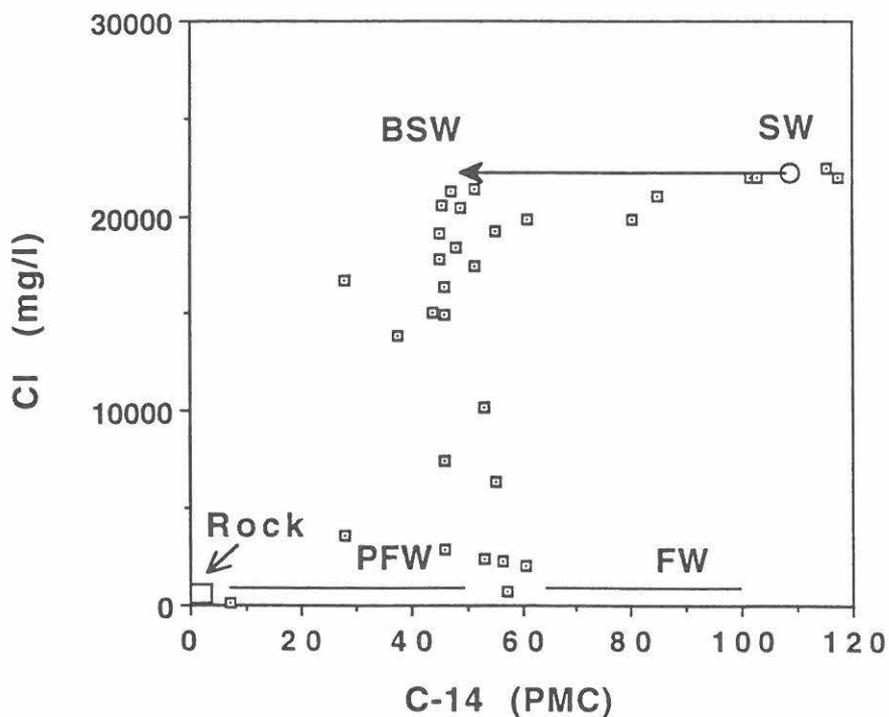
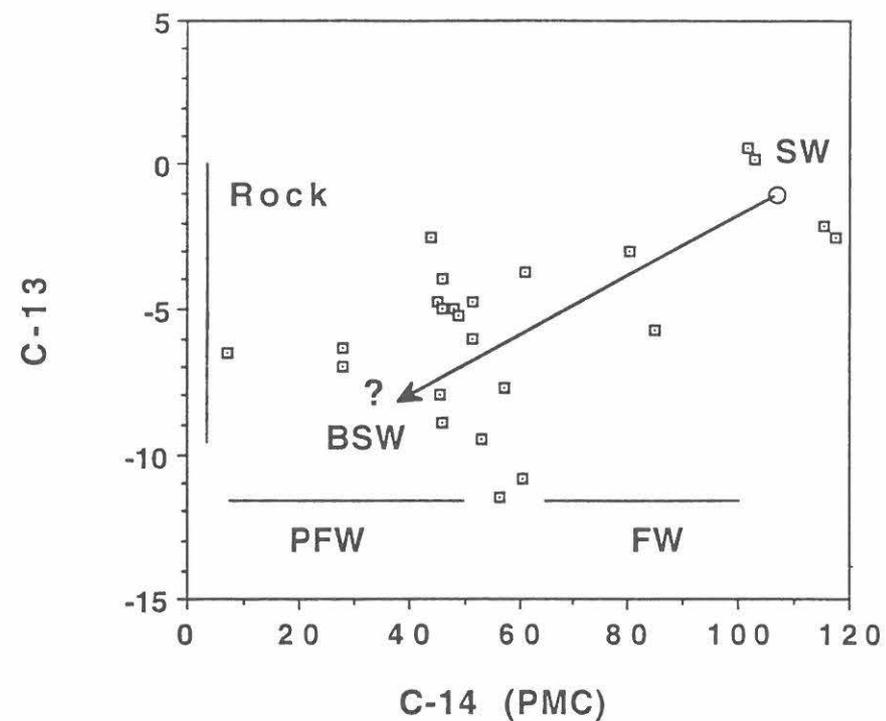


Fig. 6. ^{14}C concentration versus Cl concentration and $\delta^{13}\text{C}$ in groundwater from all studied wells (including pumping and observation wells). Also shown are the possible end-members that determine the final composition of groundwater: SW - sea water; BSW - sea water in the sediment at the bottom of the sea; FW - present fresh water; PFW - paleo fresh water ($^{14}\text{C} = 7-45$ PMC); Rock - typical values of calcareous sandstone (Magaritz, 1973).

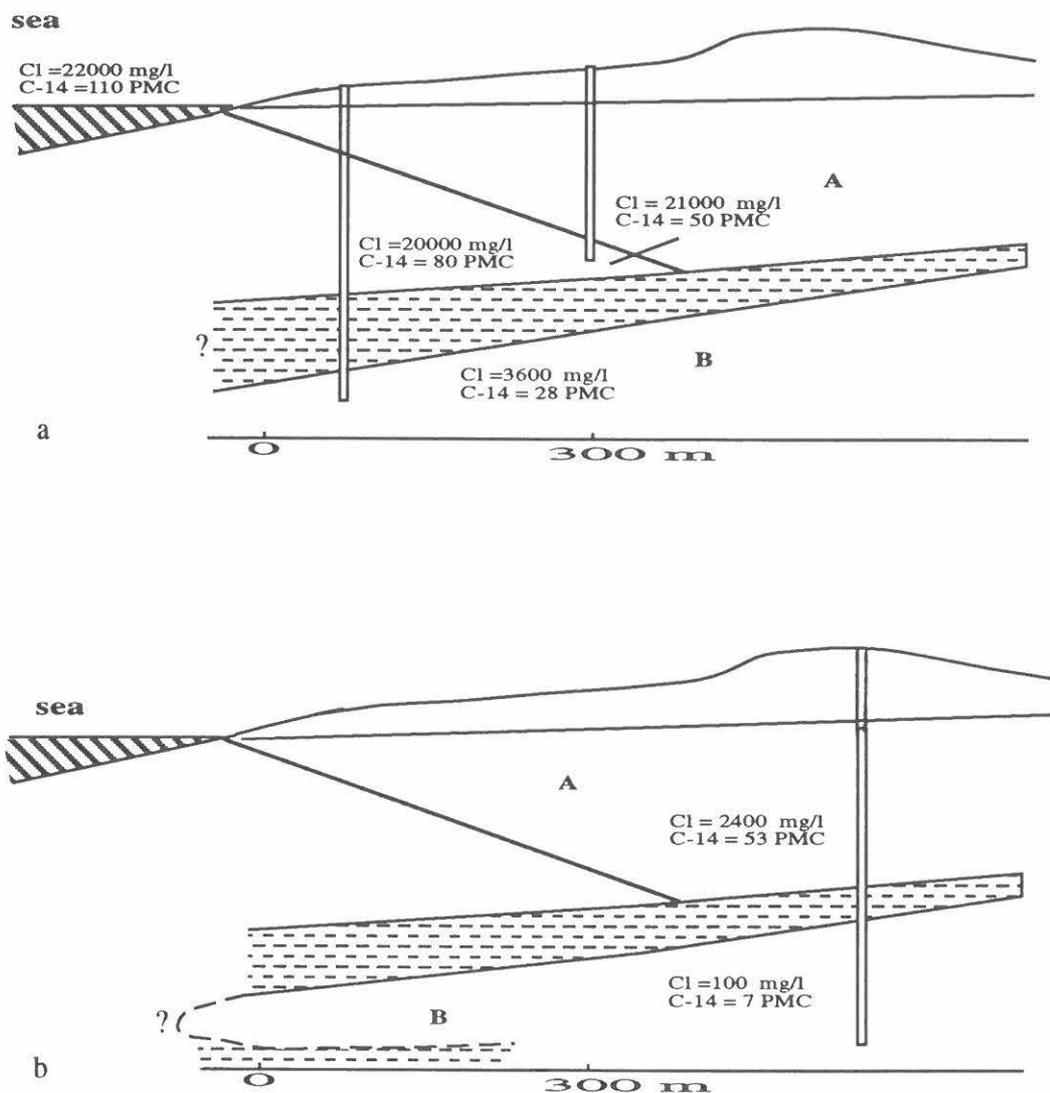


Fig. 7. Schematic cross sections of the coastal plain aquifer in Herzelia (a) and Netanya (b). Note the differences in Cl and ^{14}C concentrations in the different sub-aquifers.

The ^{14}C in saline groundwaters was generally < 50 PMC (much lower than the concentration in modern sea water, 100–115 PMC) giving an age of thousands of years. This age should be considered a preliminary estimate for the following reasons: (1) the initial ^{14}C content of interstitial water in the sediment at the bottom of the sea is difficult to establish since the ^{14}C content of the solid carbonate matrix and the organic matter is unknown and it is reasonable to assume that it decreases with depth, (2) the amount of organic carbon in the sediments, their variation with depth and their ^{13}C values are not known (Fig. 6), and therefore, the ^{14}C of interstitial water resulting from the interaction with "dead" rocks (containing no ^{14}C) cannot be corrected according to the $\delta^{13}\text{C}$ values as is normally done for fresh groundwater, (3) the ^{14}C of the fresh water end member may be highly variable, and (4) according to available data (Magaritz, 1973) the ^{13}C of the calcareous sandstone in the aquifer is not uniform, varying from 0 to -10‰ .

Within a same sub-aquifer and along a horizontal stream line an interesting case was detected in the Netanya area where two water bodies having similar Cl content and an age difference of 4000 years

were found at a distance of 250 m one from the other (Fig. 7). The inland penetration of the 4000 year old water body may reflect penetration of the sea water - fresh water interface as a result of the increase in sea water level during the Holocene. An additional factor that could enhance the inland penetration of the interface is over pumping in the east during the last 50 years. Where such a sequence is detected in the field the ^{14}C value of the near shore-line well may be considered to reflect the initial ^{14}C content of sea water after percolation and interaction with the aquifer matrix. In such a case the age variability can be calculated with better confidence.

Low ^{14}C (7 to 28 PMC) was detected for some fresh water at a distance of about 500 m from the shore line. A similar value was also obtained by Weisbrod (1993) in another area of the coastal aquifer. The presence of an old fresh water body in a location where saline water is expected, and also the presence of saline water in overlying sub-aquifers in the area indicate that (a) there is a restricted flow of fresh groundwater in to the sea as suggested by Kolton (1988); (b) the location of the fresh - saline water interface is not in equilibrium with the present sea level but rather with some historic levels, as suggested for other coastal aquifers (Essaid, 1990; Leahy and Meisler, 1988).

ACKNOWLEDGEMENT

We wish to thank I. Carmi and J. Mintz for their great help in performing the analysis of tritium and C-14 and in discussing the results. R. Selinkov is thanked for stable isotopes analysis and H. Hemo is thanked for his help in the field.

REFERENCES

- ESSAID, H.I., 1990: A multilayered sharp interface model of coupled freshwater and saltwater flow in coastal systems: Model development and application. *Water Resources Research*, 26 (7): 1431-1454.
- KAPULER, Y. & BEAR, J., 1970: A numerical solution of the movement of the fresh-saline water interface in a multi-layered coastal aquifer. Tahal report 01/74/70.
- KOLTON, Y., 1988: Examination of the connection between groundwater and sea water in the Pleistocene aquifer in the continental shelf of the Mediterranean sea coast in Central Israel. Tahal report 01/88/31.
- LEAHY, P. & MEISLER, H., 1988: Effect of eustatic sea level changes on the position of saltwater-freshwater transition zone in the coastal plain aquifer system of New Jersey. *EOS* 69 (16): 356.
- MAGARITZ, M., 1973: Isotopic composition of oxygen and carbon in carbonatic rocks from Israel. Ph.D. thesis, Weizmann Institute of Science, Rehovot.
- MERCADO, A., 1985: The use of hydrogeochemical patterns in carbonate sand and sandstone aquifers to identify intrusion and flushing old saline water. *Groundwater* 23:635-644.
- VENGOSH, A., SRARINSKY, A., MELLOUL, A., FINK, M. & ERLICH, S., 1991: Salinization of the coastal aquifer water by Ca-chloride solutions at the interface zone, along the Coastal Plain of Israel. Hydrological Service report Hydro/20/1991.
- WEISBROD, N., 1993: Hydraulic connections in the groundwater system of the Kurkar Group, Coastal Plain, Israel. M.Sc. thesis, Hebrew University, Rehovot.