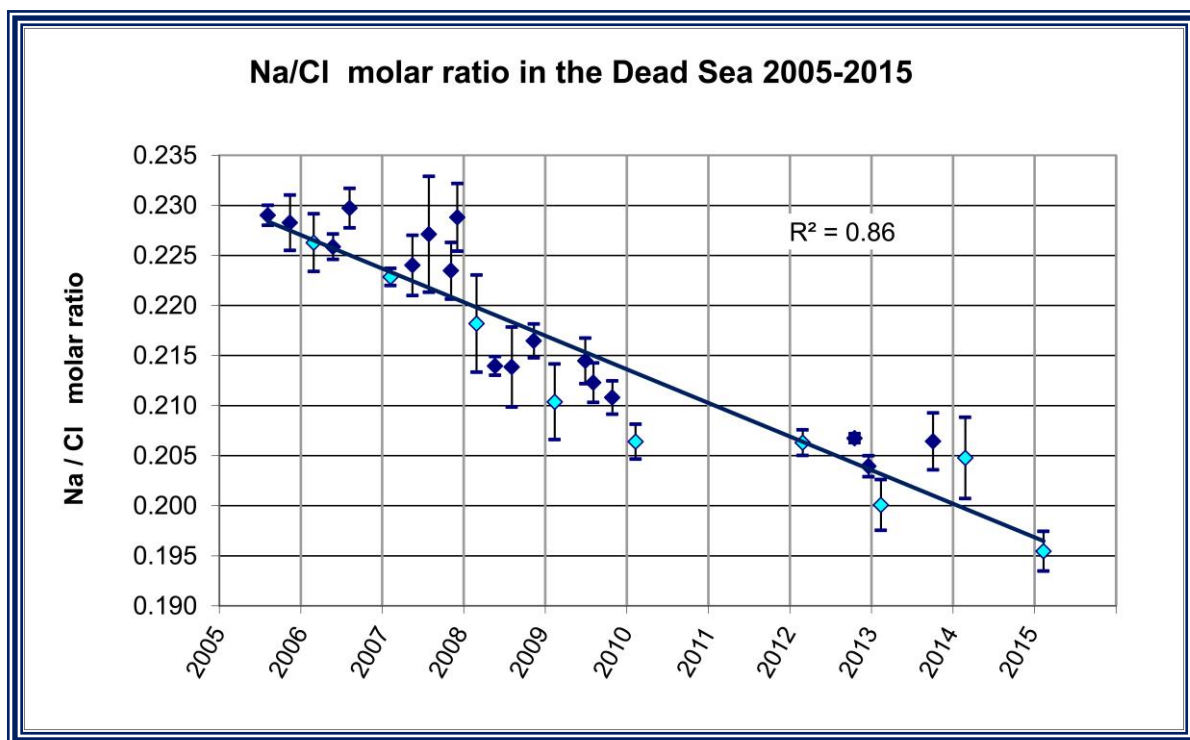




Geological Survey of Israel
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Recent Evolution of the Dead Sea Chemical Composition: 2005- 2015

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Abstract

The chemical composition of the Dead Sea has been analyzed during the years 2005-2015 on 25 depth profiles collected at a deep station (~300 m), at the lake center. Results are reported as individual summaries for each profile. In view of the decline in lake level and of the lake level-volume data of the Dead Sea, the volume of the lake decreased by a factor of 0.949 during the ten years of the survey. Accordingly, the concentration of the conservative ions should have increased inversely proportional to the volume decrease i.e. by 1.054. However, this factor, which is based on lake volume decrease derived from change in water level, does not account for an additional ~10% volume decrease due to the accumulation of halite on the lake's floor. Indeed, the enrichment factor of Mg, which is considered to be the most conservative element in the Dead Sea, is somewhat higher, at 1.066. The somewhat lower enrichment shown by Ca (by 1.057) can be partly attributed to the relatively limited aragonite and gypsum precipitation. More importantly, the increase in K concentration by only 1.048 attests that the harvesting of potash by the chemical industries operating in the southern basin of the lake indeed causes a decrease in the K content of the lake. The harvesting of the potash is also manifested by an increase in the Mg/K ratio. The Na concentration (g/L) of the lake, instead of displaying an increase because of the diminishing lake volume, has decreased during the ten years of the survey by a factor of 0.877. This decrease is due to the halite deposition on the floor of the Dead Sea and in the industrial evaporation ponds. The deposition of halite is also expressed by the molar Na/Cl ratio that has simultaneously decreased during the survey from 0.228 to 0.197. The annual change in the concentration of most major elements, except Na, is <1%. Therefore, given that the precision of the analyses of major elements in the Dead Sea is not better than 1-2%, the above mentioned long-term trends are discernable only after a period of several years whereas the annual changes which are within these precision limits are difficult to detect. Only Na presents an exception: it displays the most pronounced annual change in concentration, an annual decrease of about 1.3% in its concentration in the mixed lake, which could be identified. Based on Cl and Na mass balances and assuming spatially homogeneous deposition, the rate of halite accumulation during the years 2005-2015, was calculated to be 10.4 and 12.1cm/year, respectively. These values are in line with rates of halite precipitation calculated for earlier periods, since the 1980s.

1. Introduction

The negative water balance of the Dead Sea over the last several decades is accompanied by increasing salinity and by changes in its chemical composition. The present salinity of the brine is about 280 g/kg.

During the last few hundred years the Dead Sea (Fig. 1) has been meromictic, i.e. permanent density and thermal stratifications of its brine layers had prevailed (Stiller and Chung 1985). The upper, somewhat less saline brine layer (the epilimnion) was floating over the saltier and denser deep brine layer (the hypolimnion). The negative water budgets of the epilimnion during the second half of the last century caused the salinity to gradually increase, approaching that of the hypolimnion. Finally, a complete mixing of the brine layers (overturn) occurred in February 1979 (Steinhorn et al 1979). At that time the average salinity of the Dead Sea was claimed to be 276.2 g/kg (Steinhorn, 1985). Since then the lake level is continuing to drop at a rate of about 1 m/year (Anati and Shasha, 1989; Lensky et al. 2005), and even higher in recent years (Lensky and Dente 2017). With the exception of two very short meromictic periods, of 2 to 3 years, (Stiller et al, 1984; Anati et al 1995), since 1979 the Dead Sea became monomictic, i.e. the brine layers are undergoing complete vertical mixing once a year. The thermal stratification that develops during the warm season is destroyed in autumn as the epilimnion cools down and the brine becomes saturated with respect to halite.

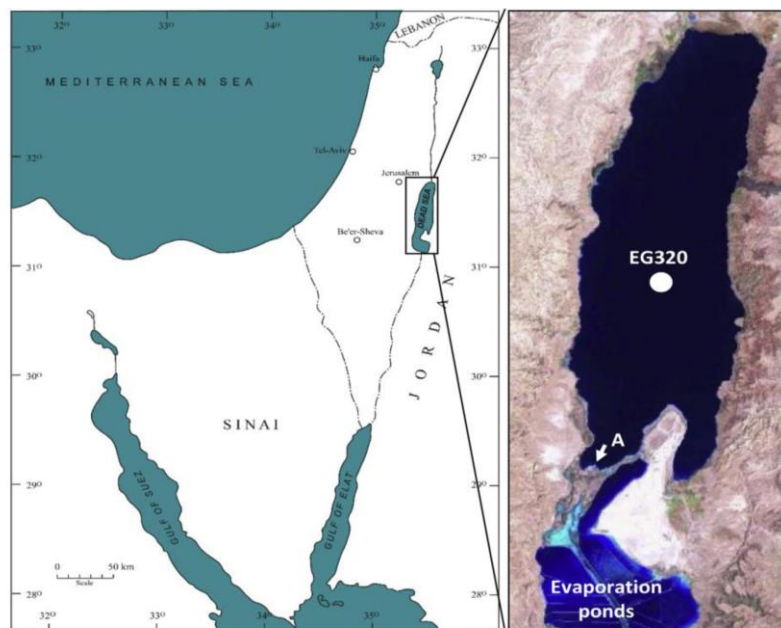


Fig 1: Dead Sea location map. EG320: site at which depth profiles were collected.

The presence of halite crystals, testifying to attainment of saturation of the lake brine, was first observed at the lake surface in February 1979 (Steinhorn 1983) and then recurred in December 1982 throughout the entire water column (Stiller et al 1997). Massive precipitation of halite and its accumulation at the lake floor is continuing ever since (Gavrieli 1997; Lensky et. al. 2005; Sirota et al, 2016; Sirota et al. 2017).

The Dead Sea is characterized by its Ca-chloride composition, whereby $\text{Na/Cl} < 1$ and $\text{Ca}/(\text{HCO}_3 + \text{SO}_4) > 1$ (Starinsky, 1974). The salinity of the Dead Sea is among the highest among the major deep salty lakes: it contains high concentrations of magnesium, sodium, calcium, and potassium chlorides, high concentrations of bromide and large amounts of heavy metals relative to seawater (Stiller and Sigg, 1990; Herut et al., 1998), whereas the concentrations of sulphate and dissolved inorganic carbon (Reznik et al (2009); Golan et al. (2017) are relatively low (< 1 g/kg). Precise chemical analysis of these hypersaline brines is quite challenging. Quantitative analyses have already been attempted at the end of the 18th century by famous chemists like Lavoisier, Gay-Lussac and many others, and continued to stir interest across the 19th and the 20th centuries (Oren 2006).

Changes in the concentration and in the chemical composition of the Dead Sea brines are caused by evaporation, winter floodings, in situ formation and deposition of aragonite, gypsum and halite, dissolution of halite from the shallow lake floor into uppermost, warm brine layers (during summer) and also by the industrial extraction of massive amounts of carnallite, and of much smaller amounts of bromide and magnesium.

The main industrial product of the Israeli Dead Sea Works and the Jordanian Arab Potash Company is Potash (KCl), which is being extracted from carnallite. To achieve this, Dead Sea brine is pumped into a series of evaporation ponds where first halite and then carnallite+halite precipitate. Given the relative low extraction of Br and Mg from these brines by the industries, Mg and Br are practically conservative in this system (Zilberman et al., 2017; Levy et al., 2018). Thus, the residual brines from the evaporation ponds (so-called End Brines) contain virtually the entire initial amount of these ions.

Thermo-haline stratification of the Dead Sea can be accurately followed by relatively simple and rapid measurements of depth profiles of temperature, and density at 25°C . Recently, a set of methods was developed to measure in situ the degree of saturation with respect to halite, and crystallization and dissolution evidences; the set included depth profiles of crystallization rate, along with temperature and salinity profiles (Sirota et al.

2016), and underwater lake floor photography (Sirota et al. 2017). Monthly observations over more than two years were applied by these methods along the water column and lake floor (Arnon et al. 2016, Sirota et al. 2016, Sirota et al. 2017), revealing a novel concept of the spatio-temporal dynamics of halite deposition and its relation to the dynamics of thermohaline stratification and diapycnal fluxes (Anati and Stiller 1991; Arnon et al. 2016).

Information about changes in the chemical composition of the Dead Sea is obtained only via detailed and tedious chemical analyses. The precise chemical analysis of the dense Dead Sea brines is, however, quite demanding much because of the difficulty of properly handling the halite supersaturated brine samples, from time of sampling in the field until lab analysis, during which halite precipitation often occurs (due to cooling), and due to the high dilution steps required prior to the introduction of the brine sample to the various analytical instrumentations.

While trying to improve sampling and analytical methods, it was attempted in this investigation to detect changes that occurred in the chemical composition of the Dead Sea brine during the years 2005- 2015. During this period the lake level dropped by 10.87 m, from -418.02 m to -428.89 m (Israel Hydrological Service), and the lake volume decreased by 6.8 km³, from 132.9 km³ to 126.1 km³ (interpolation between DTM data of Hall (1993)). During this period of decreasing lake volume by evaporation, the concentrations of the conservative ions should have increased. However, due to halite deposition in the lake and in the industrial evaporation ponds, and the harvesting of potash by the industries, such conservative behavior cannot be expected for Na, K and Cl concentrations. Our monitoring allowed estimating the amount of halite which has been withdrawn from the Dead Sea during this period and shows clear evidence for the removal of K from the Dead Sea.

2. Methods

Sampling and preparation of Dead Sea samples for chemical analysis include the following steps:

1. Prior to cruise

Weigh empty and dry 50ml centrifuge tubes, each with its own screwed stopcock, on analytical balances. Write onto the centrifuge tube the weight of each tube, stopcock included, with a black marker (other colors tend to fade upon contact with Dead Sea brine).

2. Brine sampling on board

On board introduce about 20 ml Dead Sea sample into a pre-weighed centrifuge tube. Close well the tube and keep it in upright position (in the centrifuge tubes holder). Write on the centrifuge tube with black marker the station no., the depth and the date of sampling.

3. Preparation for chemical analysis in the lab and calculation of concentrations

First dilution: Back in the lab, weigh the centrifuge tube containing Dead Sea sample on analytical balances. While handling the centrifuge tube, take care to keep it in upright position in order to avoid wetting the stopcock. Calculate the net weight of Dead Sea brine, by subtracting the weight of the empty centrifuge tube from the weight of the tube containing the Dead Sea sample. Then add to the centrifuge tube an amount of water equal to about half the weight of the Dead Sea sample. Close the tube with its own weighed stopcock and weigh on analytical balances. Calculate the net weight of the ‘first dilution’ by subtracting from it, the weight of the empty tube. Mix well and wait until all halite crystals – if there have been any – do dissolve. Measure the density and temperature of this first dilution. It should be about 1.15 g/cm^3 .

Second dilution (as performed since June 2009): On analytical balances weigh 250ml volumetric flasks of quality A with their stopcocks. Withdraw from the centrifuge tubes 2 ml of first dilution and transfer them into the 250ml flasks. Weigh again the 250 ml flasks with their stopcocks. Calculate the net weight of the 2 ml sample withdrawn from the ‘first dilution’. Dilute to 250ml with distilled water and mix well. Note that from August 2005 to June 2009 the second dilution was into 100 ml flasks.

Recommended further dilutions for ICP-AES analysis: to 20 ml of the ‘second dilution’ add scandium solution as required and dilute to 100ml. This dilution contains about 32 mg Na/liter and about 48 mg Mg/liter, concentrations that are within the optimal range for analysis by ICP-AES.

Recommended subsampling for Cl +Br analysis: withdraw 25 ml ‘second dilution’ from the 250 ml volumetric flask and perform directly on that volume a potentiometric titration with AgNO₃.

Analyses: The analyses of Na, K, Ca, Mg and Sr are performed by ICP-AES (Perkin Elmer, Optima 3300) while Br is analyzed with ICP-MS (Perkin Elmer, NexION 300D). Cl + Br are analyzed by potentiometric titration; the Cl concentrations are obtained after subtraction of the Br concentration from the result of the potentiometric titration. Note that the focus of this study is to document concentration changes of the major ions (see discussion); sulphate and alkalinity concentrations were not determined here as changes in their respective concentrations in the Dead Sea over the past decades were investigated by Reznik et al (2009) and Golan et al. (2017).

Calculation of concentrations: The results (R_i) of the chemical analysis for each element i , as reported by the analytical lab, are the concentrations in the second dilution in units of mg/liter. The concentration of each element (C_i) in units of mg/g brine or g/kg brine is:

$$C_i = R_i \times (D_1 / W_1) \times (D_2 / W_2)$$

where D_1 is the net weight of the first dilution in g, W_1 is the net weight of Dead Sea brine sample in g, D_2 is the volume of the second dilution in liter (0.25 liter as of June 2009), and W_2 is the net weight of the 2 ml subsample of the first dilution in g. Salinity was calculated by summarizing the concentrations of the major elements and of Sr (without alkalinity and sulphate).

3. Results

Twenty five cruises have been performed between August 2005 and February 2015. Vertical depth profiles have been sampled at the deep station Ein Gedi 300 (Fig. 1). The results from each cruise are summarized below as individual cruise reports, each including date, lake level, lake volume, and the physical and chemical data of the vertical profiles (Cruise summaries 1-25, see Appendix). Included in these summaries are also the average concentrations of major ions in the entire water column in winter, when the lake is mixed, or in the upper and deep brine layers, in the stratified lake during the rest of the year. The depth profiles of Na and of the Na/Cl molar ratio and comments describing the main features of each cruise are also given. It should be noted that the figures of all depth

profiles maintain constant ranges of Na concentrations (3 g/kg) and of Na/Cl molar ratio units (0.2). However, since over the years the Na concentration in the Dead Sea continued to dwindle, the maximum and minimum values of the scales had to be moved accordingly towards lower values.

4. Discussion

The reports of the cruises reveal that the analytical error of the chemical analyses is much larger than that of the physical measurements of the water column, i.e. its temperature and density at 25°C. This fact is reflected in the February profiles when the temperature of the water column is practically homogeneous (the standard deviation / average of the water column is between 0.05% and 0.21%), indicating that the water column is well mixed vertically and a uniform chemical profile should also be expected. However, the chemical composition is relatively noisy, with standard deviations of the average concentrations of the elements in the range of 0.5% - 2.0%. Therefore, seasonal variations in ion concentrations which usually are within this same range are difficult to be revealed in most of the individual profiles.

In winter, floods can cause some dilution of the uppermost layers (i.e. decrease in density) and dissolution of halite from the lake floor at very shallow depths as was observed by Beyth et al. (1997) after the heavy floods of winter 1991/1992. These processes should be expressed by similar decreased concentrations of the conservative ions, whereas Na will display less dilution or even slightly increased Na concentrations. The halite dissolution will also be expressed by increased Na/Cl molar ratios. Yet, during the studied period no major flooding occurred in the area and thus none of our reported cruises identify these effects.

In summer the water column becomes thermally stratified: the uppermost warm layers become less dense and float above the lower, cooler and denser layers. There are two simultaneous processes which tend to destabilize this thermal stratification: (1) the evaporation from the epilimnion which causes the concentrations of its major ions to slightly increase during summer. Such a slight increase, of about 1%, is at the analytical error range of the analyses and could therefore be observed only in a few profiles: August 2008, August 2009 and October 2013. In these profiles the concentrations of the ions in the upper 20 m were larger by about 1% than those of layers below (see the ratios between

the average ion concentrations of the upper vs. lower layers in the summaries of the respective reports) (2) the dissolution of halite which had been deposited at the lake floor that underlies the epilimnion (Sirota et al., 2017). The dissolution is enabled by the warming of the epilimnion brines ($>30^{\circ}\text{C}$) which leads to their undersaturation with respect to halite. Halite dissolution in summer due to heating of the epilimnion has been previously discussed by Gavrieli et al. (1989) and Gavrieli (1997). Halite undersaturation in the epilimnion during summer has been directly measured (Arnon et al. 2016 and Sirota et al. 2016) by comparing the density of the brine before and after the addition of halite crystals and halite dissolution has been directly observed by underwater photography (Sirota et al. 2017). But, because the expected increase in the epilimnetic Na concentration which is due to halite dissolution in summer is within the same range with the relatively large analytical error, this process has not been easily identified by dissolved Na analysis. However, despite the analytical noise, in the October 2013 profile, dissolution of halite is suggested by the increased Na concentration in the upper layer relative to that of the lower ones (Fig. 2a) and also by the higher Na/Cl molar ratio in the upper layer (Fig. 2b).

One more process that might slightly affect the Na and the Mg profiles is the intrusion of End Brines, which are released by the chemical industries into the Dead Sea, and are entrained into the deepest layers of the lake by the end of summer and autumn. The End Brines are characterized by very low Na and by large Mg concentrations. A representative chemical composition of End Brine is given in the Cruise summary of August 3, 2009, where $\text{Na/Cl} = 0.02$ (molar ratio) and $\text{Mg/K} = 24.2$ (weight ratio). The intrusion of End Brines into the deepest layers of the Dead Sea is then suggested by somewhat lower Na/Cl molar ratios and by somewhat higher Mg/K ratios than in the rest of the water column. This has been the basis for the chemical monitoring of the End Brine mixing in the Dead Sea over the past few decades (Beyth et al., 1986; 1987; 1989; 1990; 1991; Gavrieli et al., 1993; 1996; Gavrieli et al. 1998; 2000; 2001; Gavrieli et al. 2002; 2003; Lensky et al. 2003; 2004; 2006; 2007; 2008). These studies were often able to follow the flow path of the End Brine, from the outlet of the Nahal Ha'Arava to the Dead Sea, through a gravity flow along the underwater bathymetry depression, to the deep parts of the lake. Lensky et al. (2011) have found that the End Brine mixes with epilimnetic parts and entrains large volumes of epilimnetic brines into the hypolimnion (about ten times the volume of the End Brine). By the time the End Brine reaches the deepest parts of the lake, including station EG320, it is highly diluted and is therefore difficult to detect chemically. Yet, in

According to the lake level-volume relationship (Hall, 1997), during this survey the lake volume decreased by 6.83 km³, from 132.93 km³ in August 2005 to 126.1 km³ in February 2015, i.e. change in lake volume by a factor of 0.949. Due to the declining lake volume the concentrations of the conservative ions should have concomitantly increased, inversely proportional to the lake's shrinkage, i.e. by a factor of 1.054. The observed rise in ions concentrations is shown in Table 1 and exemplified in Fig. 3. Table 1 presents the average concentration of each ion, at the beginning and at the end of this survey, while Fig.3 shows the measurable increase from August 2005 to February 2015 along the entire depth profiles of the Ca concentrations. Note that all concentrations in Table 1 are in units of g/liter at 25°C, as this unit accounts also for the changes in density.

Table 1: Dead Sea chemical compositions in August 2005 vs. February 2015 and the enrichment factor of individual ion concentrations

Concentration¹	Na	K	Ca	Mg	Cl	Br	Na/Cl	Mg/K	TDS ²
	g/liter	g/liter	g/liter	g/liter	g/liter	g/liter	molar	w/w	g/liter
on 07/08/2005	34.00	7.91	18.22	47.26	229.1	5.35	0.228	5.977	341.8
on 09/02/2015	29.83	8.29	19.26	50.38	233.3	6.39	0.197	6.122	347.4
Theoretical concentration in Feb 2015 due to volume decrease ³	35.83	8.33	19.20	49.81	241.5	5.64	0.229	5.977	360.3
Calculated average annual change (%)	-1.31	0.47	0.56	0.64	0.18	1.77			
Ion enrichment factor Feb 2015 / August 2005	0.877	1.048	1.057	1.066	1.018	1.194			1.016

¹Average concentrations in g/liter have been calculated for all the cruises by multiplying the average concentrations (g/kg) by the respective densities at 25°C (kg/liter) as given in the cruises' summaries. Then, for each element the initial and final concentrations have been estimated from the respective best fit trendlines along the entire survey

²Total Dissolved Salts. Does not include Sr, alkalinity and sulphate.

³Calculated by multiplying the August 2005 data by 1.054, to account for volume decrease.

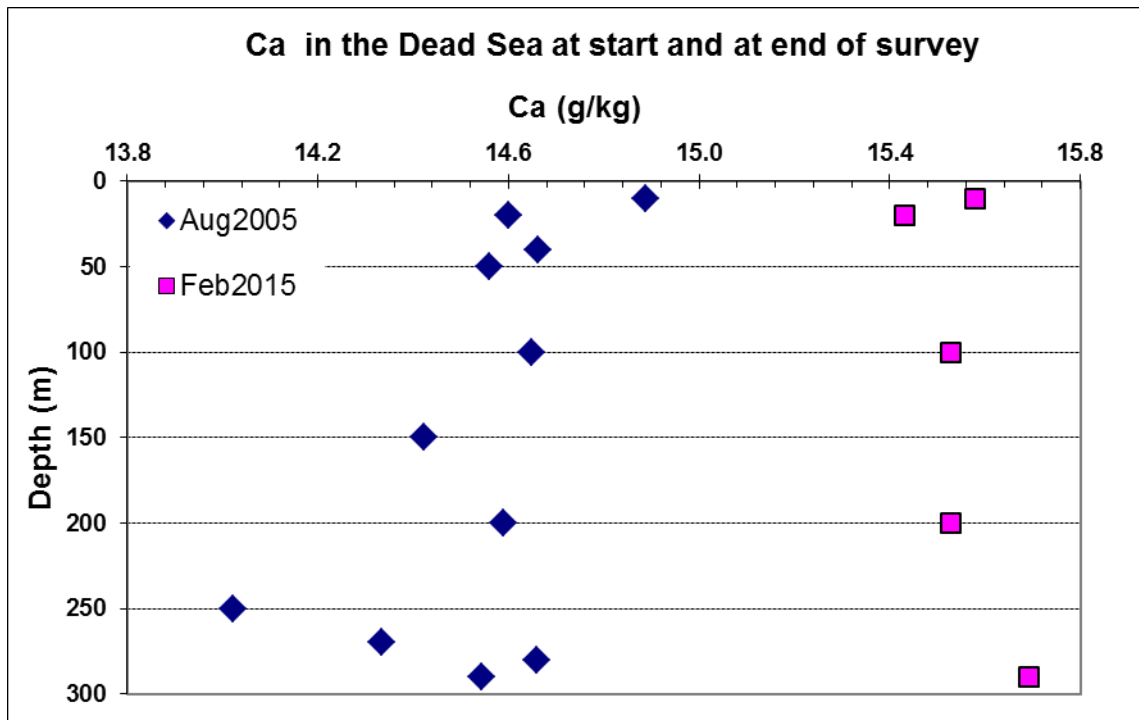


Fig 3. Ca concentrations in the water column of the Dead Sea in Aug. 2005 and Feb. 2015.

The enrichment factors of Mg and Ca during the studied period are 1.066 and 1.057, respectively (Table 1), somewhat higher than could be expected from the calculated volume change. However, it should be noted that the lake level-volume relationship does not account for the accumulation of halite at the lake floor, which effectively decreases the lake volume at a given lake level. Thus, the volume decrease, calculated from the decline in lake level and the level-volume relationship, is an underestimation by about 10%, of the true volume decrease. Consequently the concentration of conservative ions might have increased during our ten year survey by a factor somewhat larger than 1.054. Since Mg is considered to be a conservative element in the Dead Sea, its somewhat larger (1.066) than expected (1.054) enrichment ratio suggests that indeed, due to halite deposition at the lake floor during the period of the survey, the lake volume shrank somewhat more than indicated by the lake level-volume relationship. The enrichment shown by Ca, which can be expected to be similar to that of Mg is somewhat lower (by 1.057). This is partly attributed to the precipitation of aragonite and gypsum from the water body which is very limited (Goren et al., 2017; Reznik et al., 2009). It is regrettable that the ratio shown by Br (1.194; Table 1) is much higher than that shown by Mg and Ca. This is probably an artifact arising from change in the method of Br analysis (from HPLC to ICP) which took

place in the laboratory while the study was being conducted. The increase in concentration of K shown by its ratio in Table 1 (by 1.048) is somewhat lower than the enrichment ratios of Mg and of Ca. The lower enrichment factor of K is considered to be due to the harvesting of potash by the chemical industries operating in the southern basin of the lake, which prevents the K concentration to increase in proportion to the lake shrinkage. The industrial removal of K from the Dead Sea is also reflected in the Mg/K weight ratio which increases during the survey from 5.98 to 6.12 (Table 1).

It should be noted that the precision of the analyses of the major elements in the Dead Sea is not better than 0.5%-2.0%. The calculated annual increase in the concentrations of most major ions (Mg, Ca, K and Cl) is about 0.2% – 0.6% (Table 1), and is within this analytical precision limits. Hence it is difficult to detect the trend of their increasing concentrations over a time period of only one year. In contrast, the average annual decrease in Na concentration is (absolutely) much larger, -1.3% (Table 1), and is therefore easier to follow on a yearly basis. As regards the concentrations of major ions other than Na, due to the analytical uncertainties the size of their increasing trends could be clearly determined only over a period of several years.

The massive deposition of halite during the period of this survey is expressed by the large decrease in the Na concentration of the Dead Sea, and by the ratio between the final and initial Na concentrations which is only 0.877 (Table 1). As halite deposition not only removes Na from the lake waters, but also an equivalent amount of Cl, the increase in Cl concentration ratio during the studied period is only by a factor of 1.018 (Table 1).

The gradual decrease in the Na concentration of the Dead Sea from August 2005 to February 2015 is shown in Fig.4. The data points represent the average concentration of the deep waters (hypolimnion) during the stratified seasons (spring, summer and autumn) and of the entire water column when the lake is vertically well mixed (February-winter). The standard deviations of these averaged concentrations are in the range of 0.3% to 1.7%, with 2 outliers at 2.3% and 3%. Since these averaged concentrations are expected to represent uniform, well mixed water layers, their standard deviations seem rather large. Fig. 4 reveals two features:

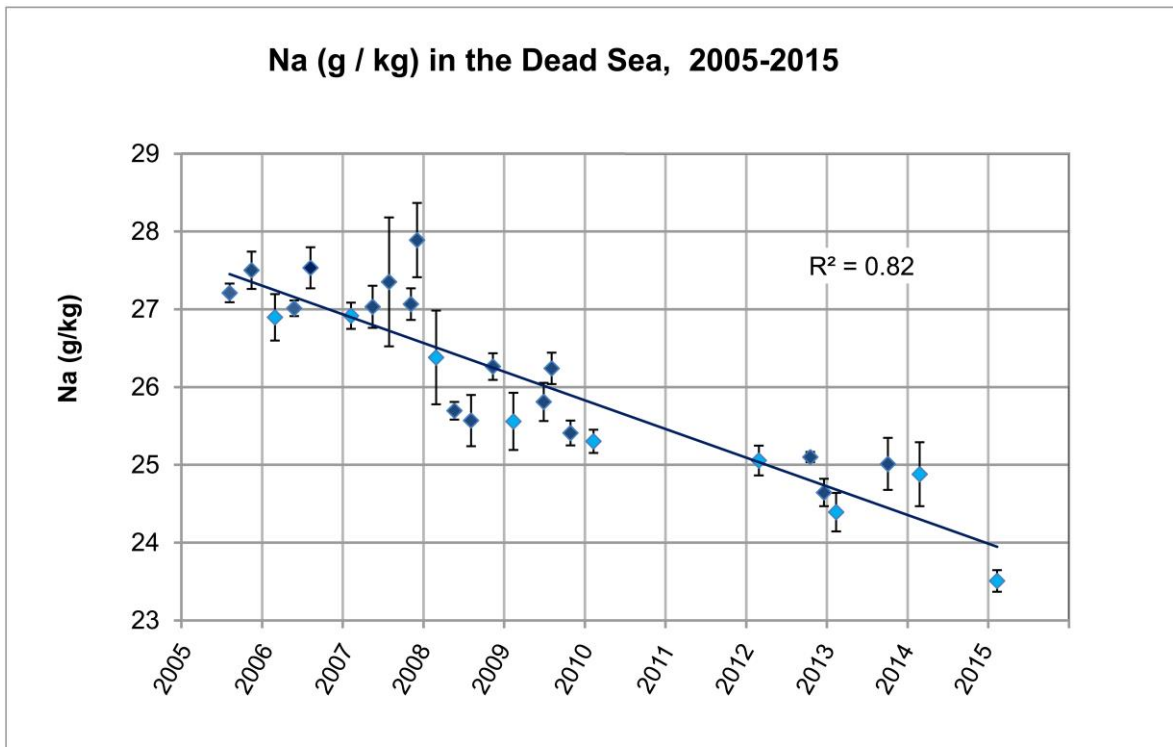


Fig. 4: Average Na concentration of the deep layer during stratified seasons (darker data points) and of the entire water column (light blue symbols) in February of each year, when the lake is fully mixed. The standard deviations are large and represent lack of precision of the analysis rather than actual data variation.

1. With only one exception, the average Na concentration of the mixed water column in February is lower than that of February of the previous year. This feature marks the gradual withdrawal of NaCl from the Dead Sea.
2. The Na concentration of the deep waters increases slightly during late summer and autumn in some of the observed years. This apparent increase is, however, wiped out during winter by halite deposition, as shown by the somewhat lower average Na concentration in the following February. The lower concentrations in February, compared to the preceding months, emphasize the fact that much of the halite deposition occurs in late autumn / winter during the cooling of the upper layer and then continues from the entire, mixed and cool, water column (Gavrieli 1997; Stiller et al .1997; Arnon et al. 2016, Sirota et al. 2016, Sirota et al., 2017) during the overturn and thereafter, as long as the cooling persists.
3. As with the Na concentration, the Na/Cl molar ratio also steadily decreases during the period of this survey, from 0.228 to 0.197 (Fig. 5), during the time interval from 2005 to 2015, respectively, thus offering an additional evidence for halite

removal from the Dead Sea. The overall decrease in the Na concentration of the Dead Sea (Fig. 4, see data points and trendline), provides an opportunity to estimate the total amount of halite that has been deposited on the lake floor and in the evaporation ponds during the ten years of this survey. If there was no halite deposition, the expected concentration of Na in February 2015, due to the diminished lake volume should have been 35.8 g/liter (the Na initial concentration as shown in Table 1 multiplied by 1.054), whereas the trendline concentration in February 2015 is only 29.8 g Na/liter (Fig. 4). It seems therefore that in February 2015, 6.0 g Na/liter are missing from a volume of 126.1 km³, which are equivalent to 757*10⁶ ton Na or 1924*10⁶ ton of NaCl. In other words, between the years 2005 and 2015 about 192* 10⁶ ton NaCl had been removed annually from the Dead Sea brine; this estimate includes the NaCl deposition in the evaporation ponds of the industries.

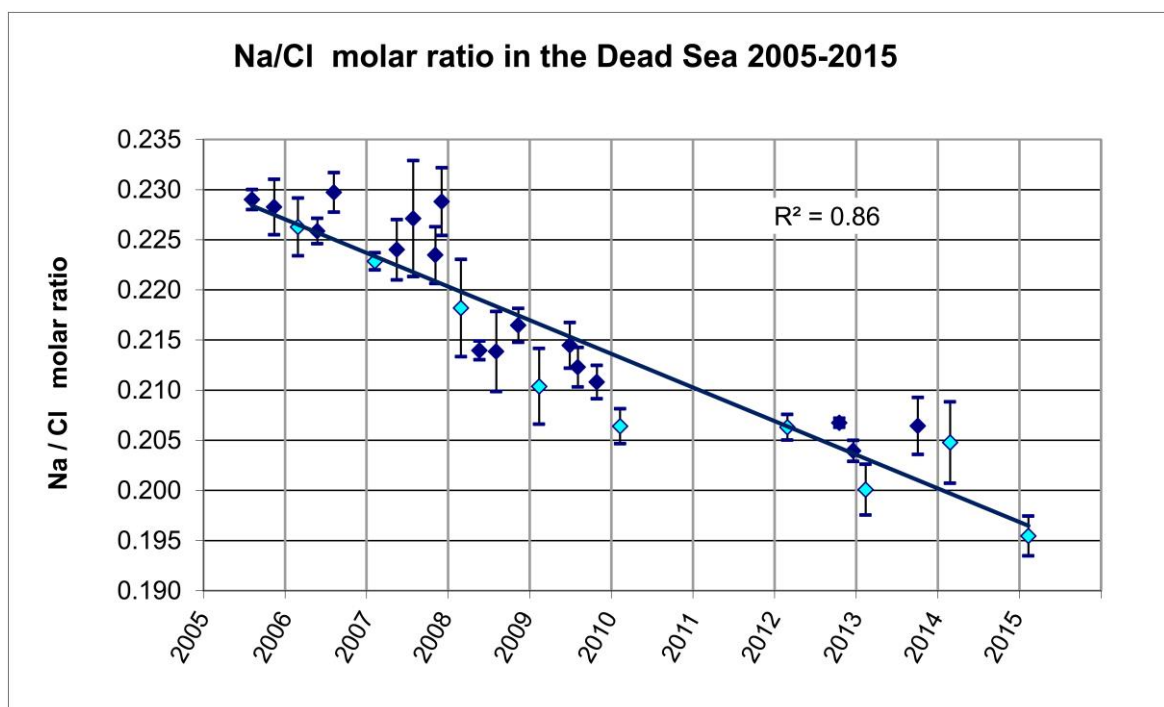


Fig. 5: Average Na/Cl ratio of the deep layer (darker symbols) and of the entire water column in February of each year (light blue symbols). The standard deviations are large in many cases and represent lack of precision of the analysis rather than actual data variation.

The amount of NaCl deposited in the industrial evaporation ponds can be estimated via the production rate of potash by the Dead Sea Works (DSW) and by the Arab Potash Company (APC): during 2005 -2015 the production was about 3.5 and 2.3 million ton / year, respectively (Zbranek 2013, site resources.worldbank.org, 2013). From chemical analyses of End Brine and Dead Sea (see Cruise Summaries August 2009a,b) it can be calculated that about 7 ton NaCl must be deposited for each ton KCl to be produced. Given a total potash production of $5.8 \cdot 10^6$ ton /year it follows that $40.6 \cdot 10^6$ ton NaCl/year precipitate on the floors of the industrial evaporation ponds. Thus, between 2005 and 2015 about 150 million ton NaCl were deposited annually ($192 \cdot 40.6 = 151.4$) on the floor of the Dead Sea. Assuming a density of 2.0 g/cm^3 for the halite deposits (Stiller et al., 2016) and assuming homogenous distribution of the halite precipitation on a Dead Sea area of about 625 km^2 , it follows that the annual average deposition rate is **12.1cm/year**. It should however be noted that halite is not evenly accumulated on the lake's floor, but deposits preferentially at the hypolimnetic lake floor, where it is thickened at the expense of the dissolution of halite accumulated on the epilimnetic lake floor (Sirota et al., 2017).

A similar estimate of halite deposition rate can be performed via the Cl data. If there was no halite deposition, the expected concentration of Cl in February 2015 should have increased to 241.5 g/liter (the initial concentration -Table 1- multiplied by 1.054), whereas the trendline concentration in February 2015 is only 233.3g/liter, meaning that 8.2 g Cl/liter are missing. Calculations as described above lead to an estimate of 170 million tons of halite that are annually withdrawn from the lake, of which about 130 million tons are deposited within the lake , yielding a halite deposition rate derived from the Cl data, of **10.4 cm/year**. These deposition rates of halite, 12.1 and 10.4 cm/year, are comparable to previous estimates of Gavrieli (1997) for the years 1976-1991 and of Lensky et al (2005) for the years 1996-2001 which were 11.2 cm/year and 10 cm/year, respectively.

Summary

According to the lake level- volume relationship, during the ten years between 2005 and 2015 the volume of the Dead Sea shrank by 6.83 km^3 , which signifies a loss in volume by a factor of 0.949. Because the lake level- volume relationship does not account for the accumulation of halite at the lake floor, it should be kept in mind that this volume decrease factor is an underestimate of the true volume decrease by about 10%. In a fully closed system the decreasing volume should be accompanied by a complimentary increase by 1.054 ($=1/0.949$) in the concentrations of the conservative ions. Indeed, even with the uncertainties in the chemical analyses of the brine, the results do show such an increase. Mg, the most conservative element in the Dead Sea system, rose by a factor of 1.066, whereas the concentrations of Ca and K rose by factors of 1.057 and 1.046, respectively. The lower factor for Ca might be partly due to gypsum and aragonite precipitation from the brine whereas the lower factor of K is likely due to its harvesting from the Dead Sea brine by the chemical industries, the Dead Sea Works (DSW) and the Arab Potash Company (APC).

During the studied period massive halite precipitation from the brine took place, which is reflected by the *decrease* in the Na concentration of the lake by a factor of 0.877 and by a decrease in the Na/Cl molar ratio from 0.228 to 0.197. Halite precipitation also buffered the increase in Cl concentration which rose only by a factor of 1.018. The record of the gradual decrease in lake's Na concentration reveals that most of the halite deposition occurs in late autumn / winter during the cooling of the upper layer and then continues at overturn and thereafter from the entire, mixed water column as long as cooling persists. The chemical analyses and mass balances of Cl and of Na for the studied period show, respectively, that some 170 -192 million tons of halite precipitated annually from the Dead Sea brine. Of this amount, some 130- 150 million tons/year precipitated within the lake; assuming an even accumulation over the entire lake floor, yields an annual average rate of halite deposition of 10.4-12.1 cm/yr. The rest, some 40 million ton halite/yr, precipitated in the evaporation ponds of the DSW and APC.

The analytical precision of the major elements in the Dead Sea (about 0.5% -2%) enabled to detect the above-mentioned decadal changes in their concentrations. Seasonal variations, and annual concentration changes, which are usually within these precision limits, are more difficult to detect. Therefore, the summer increase in the ions

concentrations of the warmer epilimnion layers caused by evaporation and the increase in the Na concentration of these warmer layers due to halite dissolution from the epilimnetic lake floor, could be observed only in few profiles: those of August 2008, August 2009 and October 2013. Likewise, the intrusion of End Brines from the chemical industries into the deepest layers of the Dead Sea could be perceived by small changes in their Mg/K and Na/Cl ratios only in the August 2009 and October 2013 profiles.

It is our hope that the analytical precision of the major ions will be further improved so that likewise the annual change in the Na concentration of the lake that has been reported in this survey, annual concentration changes will be discernable also for all other elements. Such improvement will also allow to observe in any individual summer/autumn profile, the seasonal rise in epilimnetic ions' concentrations as well as small chemical composition changes in the deepest layers.

5. Acknowledgement

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Appendix

Cruise summaries 1-25

Cruise Summary :

August 7, 2005

Station En-Gedi-320

Lake level 418.02 m bmsl

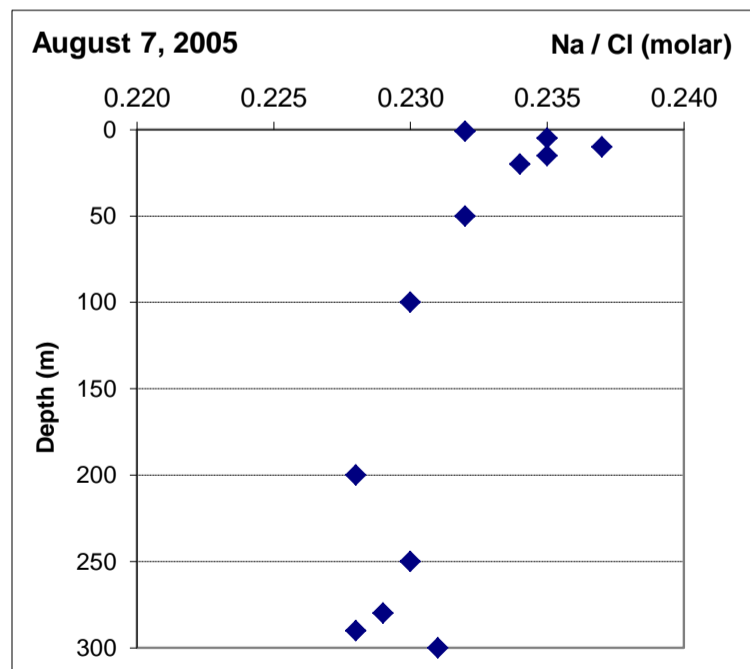
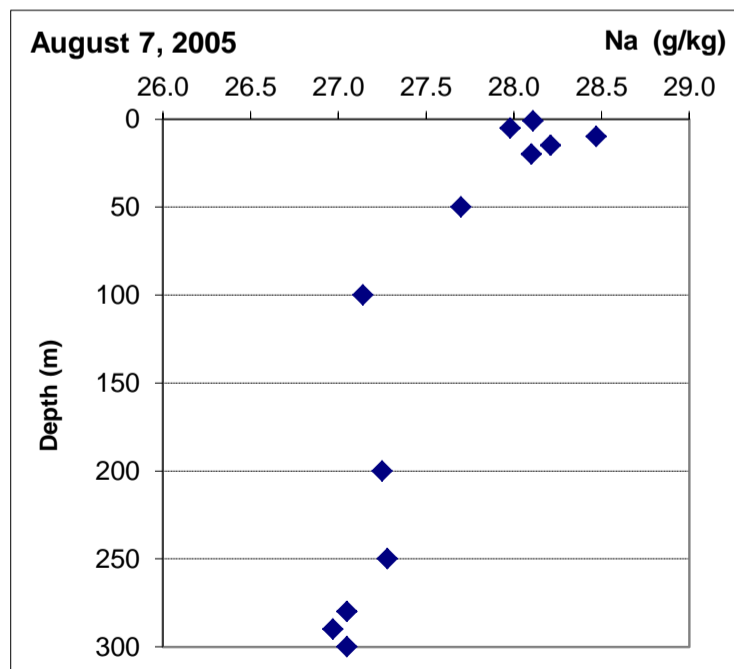
Lake volume 132.93 km³

Sampled in glass bottles. Kept in warm bath . Samples from 1m to 50m filtered because of NaCl crystals. Samples from 100m to 300m have not been filtered. Weight of NaCl crystals was added to Na and Cl concentrations 5ml were weighed, diluted to 100ml and submitted to chemical analysis.

GSI no.	Depth (m)	Temp in situ °C	Density at 25°C g/cm ³	Na g/Kg	K g/Kg	Ca g/Kg	Mg g/Kg	Sr g/Kg	Cl g/Kg	Br g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w	
1109	1	33.9	1.24081	28.1	6.4	14.9	37.9	0.279	187.1	4.51	279.6	0.232	5.93	
1110	5	33.9	1.24081	28.0	6.29	14.7	37.4	0.278	183.2	4.50	274.8	0.235	5.95	
1111	10	33.62	1.24076	28.5	6.48	15.1	38.3	0.283	185.3	4.51	278.9	0.237	5.92	
1112	15	33.45	1.24077	28.2	6.33	14.8	37.7	0.280	185.3	4.44	277.5	0.235	5.96	
1106	20	33.42	1.24076	28.1	6.33	15.0	37.8	0.279	185.1	4.43	277.4	0.234	5.98	
1108	50	22.72	1.23813	27.7	6.34	14.9	37.8	0.276	184.4	4.49	276.4	0.232	5.97	
1104	100	22.68	1.23815	27.1	6.33	14.9	37.6	0.276	182.2	4.45	273.3	0.23	5.94	
1105	200	22.82	1.23822	27.3	6.23	14.8	37.2	0.277	183.9	4.45	274.5	0.228	5.97	
1100	250	23.02	1.23835	27.3	6.36	15.0	37.9	0.277	182.5	4.43	274.2	0.23	5.96	
1101	280	23.06	1.23840	27.1	6.35	15.0	37.9	0.276	181.7	4.44	273.1	0.229	5.97	
1102	290	23.29	1.23855	27.0	6.24	14.7	37.2	0.278	182.6	4.46	272.9	0.228	5.96	
1103	300	23.29	1.23855	27.1	6.32	15.0	38.0	0.277	180.6	4.45	272.1	0.231	6.02	
avg 1-20m		33.66	1.24078	28.17	6.37	14.89	37.84	0.280	185.2	4.48	277.6	0.235	5.94	
std. dev.		0.23	2.59E-05	0.25	0.07	0.14	0.3	0.002	1.27	0.04	1.73	0.002	0.02	
%		0.7	0.002	0.9	1.1	0.9	0.8	0.7	0.7	0.9	0.6	0.9	0.4	
avg. 50-300m		22.98	1.23834	27.21	6.31	14.90	37.67	0.277	182.6	4.45	273.8	0.230	5.97	
std. dev.		0.23	0.00016	0.12	0.06	0.12	0.37	0.001	1.11	0.01	0.88	0.001	0.02	
std.dev/avg (%)		1.0	0.0	0.4	1.0	0.8	1.0	0.4	0.6	0.2	0.3	0.4	0.4	
avg.1-20m / avg. 50 300m				1.036	1.009	0.999	1.005	1.011	1.014	1.006	1.014	1.021	0.996	

Comments

- 1 Na and Cl are larger in the upper 20m than in the rest of the brine column
- 2 In the other elements, the concentrations ratios between the upper and lower layers show no clear trend, suggesting that the effect of evaporation is not yet readily detectable by chemical analysis
- 3 Due to the larger Na and Cl concentrations, the upper layer is more saline than the lower one
- 4 The larger Na and Cl in the upper layer suggest halite dissolution from the underlying lake floor by its warm (33°C) brine
- 5 The larger Na/Cl molar ratio in the upper 20m supports the halite dissolution concept



Cruise Summary :

November 13-14, 2005

Station EG-320

Lake level 418.43m bmsl

Lake volume 132.665 km³

On board sampling into pre-weighed (in the lab) glass bottles. Dilution in the lab with deionized water (DIW) (about 2 DS to 1 DIW)

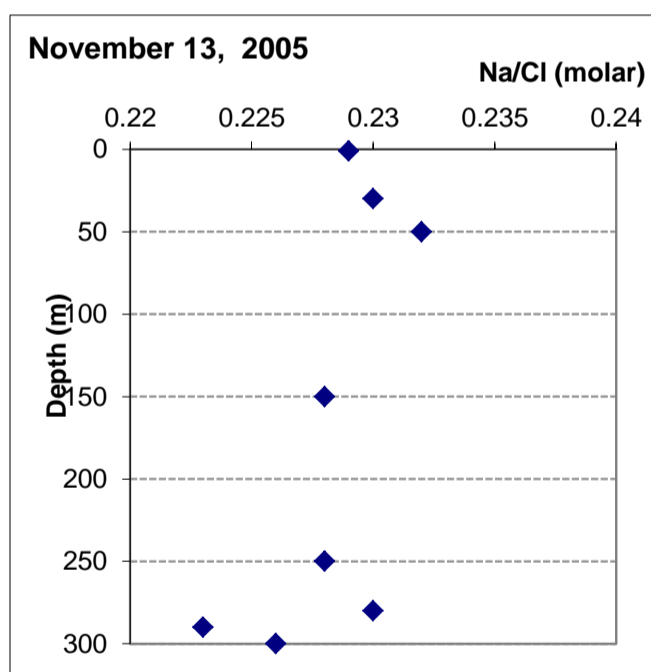
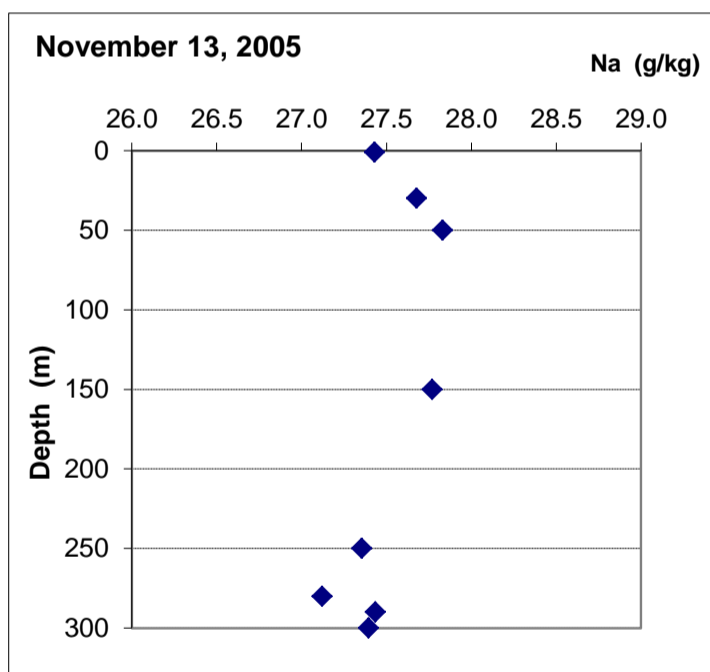
Samples collected in duplicates (DS1115a,b - DS1122a,b). The averages of each pair are given below
Salinity does not include Alkalinity and Sulphate

GSI no.	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na g/kg	K g/kg	Ca g/kg	Mg g/kg	Sr mg/kg	Cl g/kg	Br g/kg	Salinity g/kg	Na/Cl molar	Mg/K w/w
DS1119	1	24.12	1.23884	27.43	6.47	14.80	38.85	276	184.6	4.47	276.9	0.229	6.01
DS1120	30	24.00	1.23878	27.68	6.35	14.86	38.01	277	185.1	4.40	276.7	0.230	5.98
DS1121	50	24.01	1.23879	27.83	6.46	14.88	38.89	275	185.2	4.45	278.0	0.232	6.02
DS1122	150	24.09	1.23882	27.77	6.48	15.01	39.31	278	187.4	4.57	280.8	0.228	6.07
DS1115	250	24.13	1.23882	27.35	6.47	14.58	38.23	274	184.6	4.39	275.9	0.228	5.91
DS1116	280	24.14	1.23885	27.12	6.33	14.63	38.01	274	182.1	4.46	272.9	0.230	6.01
DS1117	290	24.48	1.23900	27.44	6.40	15.03	39.33	278	189.6	4.48	282.6	0.223	6.15
DS1118	300	24.67	1.23908	27.40	6.43	15.26	39.33	278	186.8	4.48	280.0	0.226	6.12

avg. 1-300m	24.21	1.23887	27.50	6.42	14.88	38.75	276	185.7	4.46	277.9	0.228	6.03
std.dev.	0.24	0.00011	0.24	0.06	0.22	0.58	1.75	2.25	0.05	3.06	0.003	0.08
std.dev./avg (%)	1.0	0.01	0.9	0.9	1.5	1.5	0.6	1.2	1.2	1.1	1.2	1.3

Comments

- 1 Duplicates for Na and Cl were reasonable, mostly within less than 1.0%
- 2 Overturn has apparently occurred in the upper 280m, the lake is not yet well mixed.
- 3 Na is lower by ~ 1g/kg in upper 50m than in Aug 2005, probably due to Halite precipitation caused by cooling
- 4 Salinity fluctuations with depth are larger than analytical error.
- 5 Na/Cl ratio is lowest at 300m, possibly evidence for end brine intrusion



Cruise Summary :
Station En--Gedi 320

February 28, 2006
Lake level 418.67 m bmsl

Lake volume 132.51 km³

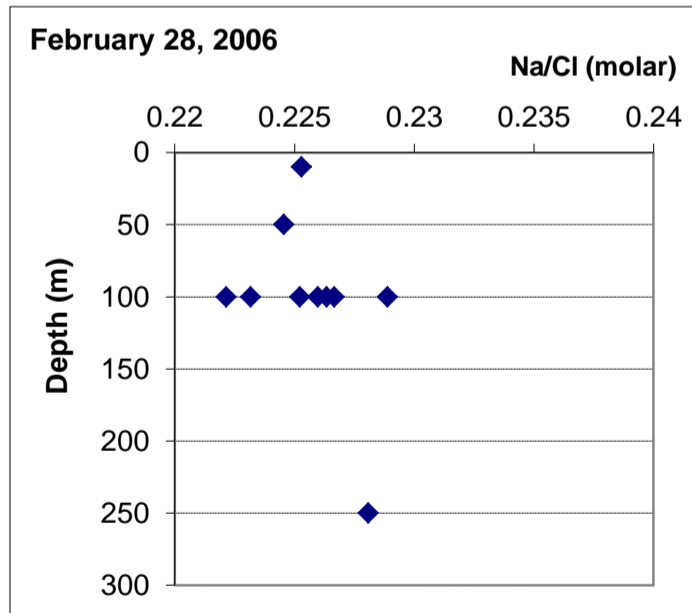
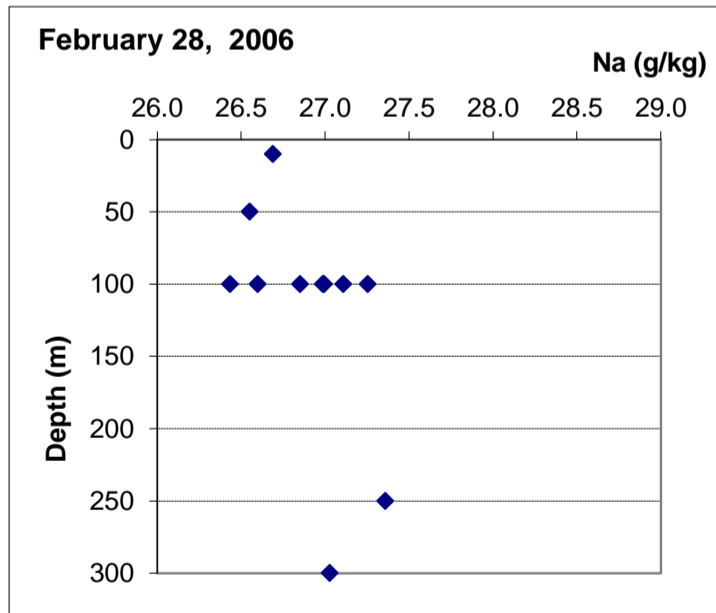
Dead Sea samples diluted about 2:1 with deionized water. From this dilution 5ml were weighed and further diluted to 100 ml.
 Salinity does not include Alkalinity and Sulphate

GSI no.	Sample no.	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na g/kg	K g/kg	Ca g/kg	Mg g/kg	Sr g/kg	Cl g/kg	Br g/kg	Salinity g/kg	Na/Cl molar	Mg/K w/w
1134	12	10	22.90	1.23870	26.69	6.34	14.97	37.54	0.262	182.6	4.49	272.9	0.225	5.93
1133	11	50	22.91	1.23869	26.55	6.33	14.96	37.65	0.262	182.2	4.49	272.5	0.225	5.94
1130	9	100	22.93	1.23869	26.60	6.36	14.92	37.54	0.261	183.7	4.52	273.9	0.223	5.90
	8	100	22.93	1.23869	26.44	6.26	14.91	37.34	0.261	183.4	4.51	273.1	0.222	5.96
	7	100	22.93	1.23869	26.85	6.36	15.07	37.75	0.261	183.2	4.56	274.0	0.226	5.94
	6	100	22.93	1.23869	27.25	6.48	15.17	38.31	0.265	183.5	4.53	275.5	0.229	5.91
	5	100	22.93	1.23869	26.99	6.43	15.17	37.78	0.262	183.8	4.58	275.0	0.226	5.88
	4	100	22.93	1.23869	27.00	6.35	14.95	37.58	0.262	184.7	4.50	275.4	0.225	5.92
	3	100	22.93	1.23869	27.11	6.38	15.10	37.70	0.261	184.3	4.47	275.4	0.227	5.91
1126	1	250	22.97	1.23869	27.36	6.45	14.97	37.94	0.263	184.9	4.47	276.3	0.228	5.88
1128	2	300	22.98	1.23869	27.03	6.34	14.97	37.56	0.259	179.0	4.42	269.6	0.233	5.92
Avg. of 100m samples			22.93	1.23869	26.89	6.37	15.04	37.71	0.262	183.8	4.52	274.6	0.225	5.92
Std Dev at 100m			0.00	0.00000	0.29	0.07	0.11	0.30	0.001	0.5	0.04	0.93	0.002	0.03
%					1.07	1.05	0.76	0.81	0.57	0.30	0.81	0.34	1.00	0.44
Avg. 10-300m			22.94	1.23869	26.85	6.37	14.97	37.66	0.26	183.44	4.50	274.04	0.227	5.91
Std. Dev.			0.04	4.5E-06	0.30	0.06	0.10	0.26	0.002	1.2	0.0	1.8	0.003	0.02
std.dev./avg (%)			0.15	0.00	1.11	0.95	0.64	0.68	0.59	0.88	1.00	0.65	1.27	0.42

*Cl at 300m excluded

Comments

- 1 The results are weird. Density at 25°C is homogenous, 1.23869, implying a well mixed lake and homogenous salinity. But the spread of the salinities is large. Moreover, salinity is overall lower than in November 2005. Did so much halite precipitate meanwhile?
- 2 It is disappointing that multiple sampling at 100m displays large standard deviation
- 3 Na/Cl ratio is definitely lower than in Nov 2005, suggesting heavy halite precipitation from the upper layer



Cruise Summary :

May 26, 2006

Station En Gedi 320

Lake level 418.68 m bmsl

Lake vlume 132.50 km³

Depth duplicates, for 250 m no duplicate.

Sampling in pre-weighed glass bottles. Samples diluted by weight with deionized water, (dilution ratio: 2DS: 1 water) 6, 7 or 9 ml of first dilution were weighed in 100 ml volumetric flasks and diluted to 100ml and weighed again

Salinity does not include Alkalinity and Sulphate which have not been measured

The data below are averages of the duplicates

Averages of duplicates and corrected by weights of the 100ml volumes

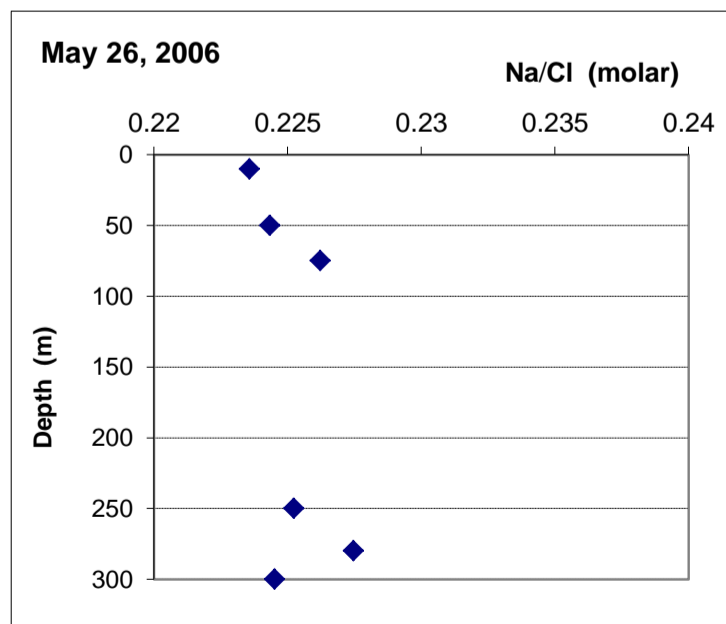
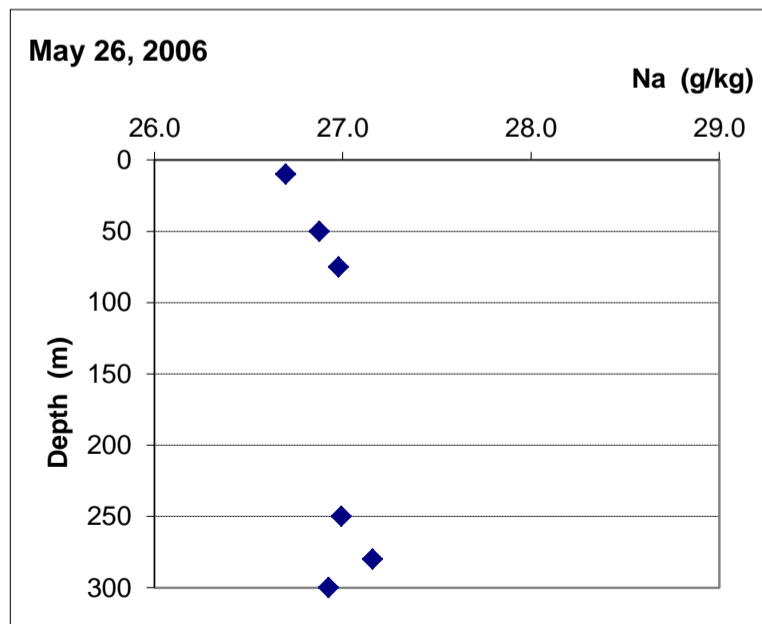
Depth (m)	Temp. in situ °C	Density at 25°C g/cm ³	Na g/kg	K DSg/kg	Ca DS g/kg	Mg g/kg	Sr g/kg	Cl g/kg	Br g/kg	Salinity g/kg	Na/Cl DS molar	Mg/K w/w
10	28.03	1.23732	26.70	6.38	14.55	38.8	0.281	184.1	4.49	275.3	0.224	6.08
50	23.11	1.23855	26.87	6.42	14.97	39.5	0.279	184.6	4.58	277.3	0.224	6.15
75	23.05	1.23858	26.98	6.48	14.90	39.4	0.283	183.8	4.54	276.4	0.226	6.09
250	22.97	1.23863	26.99	6.40	14.95	39.6	0.281	184.7	4.54	277.4	0.225	6.18
280	22.98	1.23863	27.16	6.43	14.85	39.4	0.282	184.0	4.56	276.7	0.227	6.13
300	23	1.23863	26.92	6.50	14.70	39.6	0.279	184.8	4.41	277.3	0.225	6.10

avg 50-300m	23.02	1.23860	26.99	6.45	14.87	39.5	0.281	184.4	4.52	277.0	0.226	6.13
std.dev.	0.06	0.00004	0.11	0.04	0.11	0.09	0.00	0.46	0.07	0.42	0.001	0.04
std.dev./avg (%)	0.3	0.0	0.4	0.6	0.7	0.2	0.7	0.2	1.4	0.2	0.6	0.6

ratio: 10m/avg 50-300m			0.989	0.990	0.979	0.982	1.001	0.998	0.993	0.994	0.991	
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Comments

- 1 Lower concentration of Na, and all other elements, in the upper 10m than in the deeper layers below 10m (see ratios:10m/average 50-300m)
- 2 Lower Na/Cl in upper 10m. These features, lower concentrations and lower Na/Cl in upper 10m, suggest dilution by floods and some NaCl precipitation that might have occurred either previous to the floods or due to the colder flood waters
- 3 Density at 25 °C is lower at 10m than in the rest of the water column and also suggests slight dilution by floods



Cruise Summary :

February 7, 2007

Station En Gedi 320

Lake level 419.77 m bmsl

Lake volume 131.82 km³

Sampling in 100ml pre-weighed glass bottles.

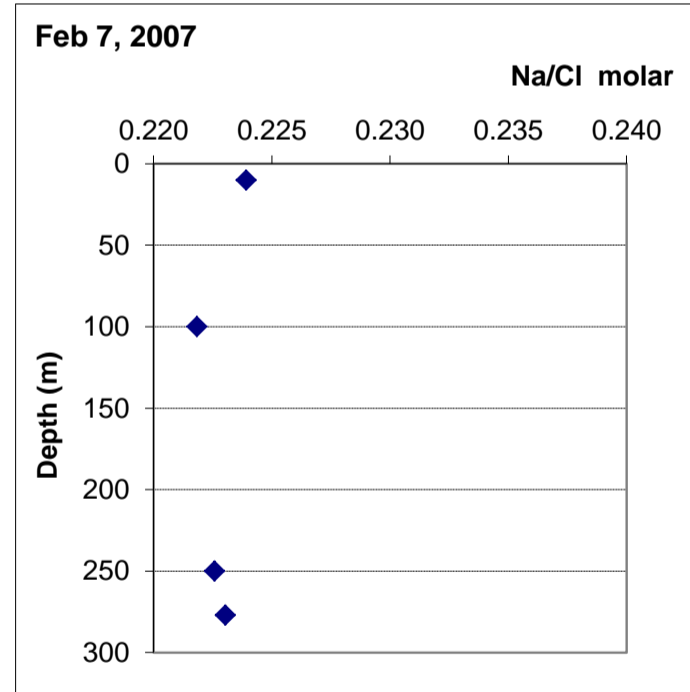
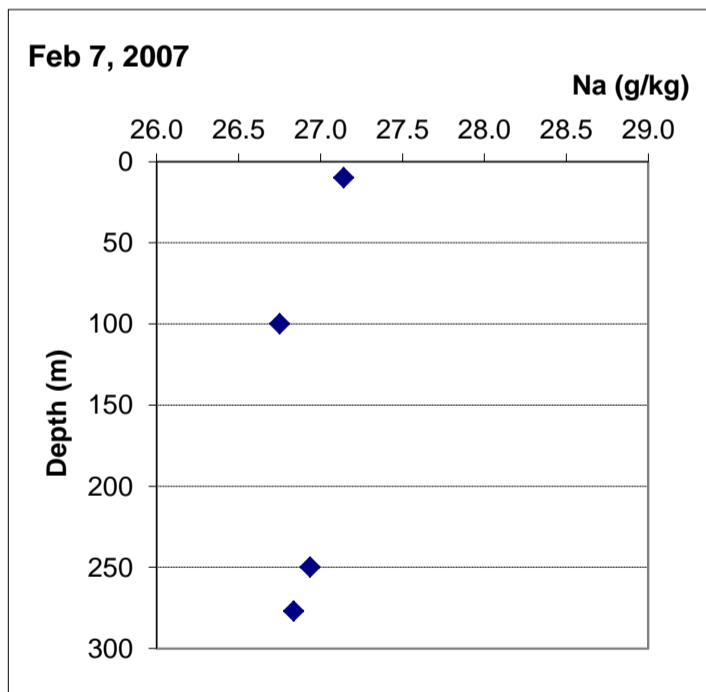
First dilution with water (2:1) . Second dilution: 5 or 6 ml mixture are weighed and diluted to 100ml

Salinity does not include Alkalinity and Sulphate which have not been measured

GSI no.	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na g/kg	K g/kg	Ca g/kg	Mg g/kg	Sr g/kg	Cl g/kg	Br g/kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
1205	10	22.80	1.23878	27.14	6.59	14.58	38.6	0.275	186.8	3.94	278.0	0.224	5.86
1208	100	22.81	1.23877	26.75	6.71	14.62	38.8	0.277	185.9	4.02	277.0	0.222	5.78
1200	250	22.85	1.23876	26.94	6.70	14.77	39.0	0.280	186.5	3.90	278.1	0.223	5.82
1201	277	22.86	1.23880	26.84	6.69	14.72	39.0	0.279	185.5	4.13	277.1	0.223	5.83
average		22.83	1.23878	26.92	6.67	14.67	38.85	0.28	186.2	4.00	277.6	0.223	5.82
std. dev		0.03	0.00002	0.17	0.06	0.09	0.19	0.002	0.62	0.10	0.57	0.001	0.03
std.dev./avg (%)		0.13	0.00	0.62	0.84	0.59	0.50	0.75	0.33	2.51	0.21	0.39	0.59

Comments

- 1 Profile is not detailed enough, too few data points.
- 2 Homogeneous profile, % std dev. of the average concentration of elements is less than 1%, except Br 2.5%
- 3 Average Na, 26.92 g/kg, is about the same as in February 2006, 26.85g/kg, but if Lake Level dropped meantime by 1.1m it means that Na is probably missing, due to NaCl precipitation
Estimated NaCl precipitation: about 24 million ton NaCl from Feb 2006 to Feb 2007 (a layer of 1.9 cm over the entire lake floor)



Cruise Summary :

May 16, 2007

Station En Gedi 320

Lake level 419.88 m bmsl

Lake volume 131.75 km³

Sampling in 100ml pre-weighed glass bottles.

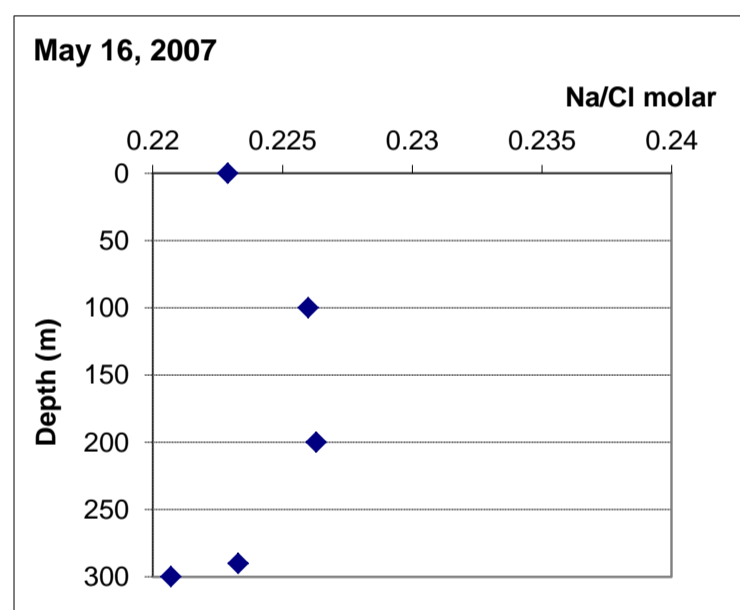
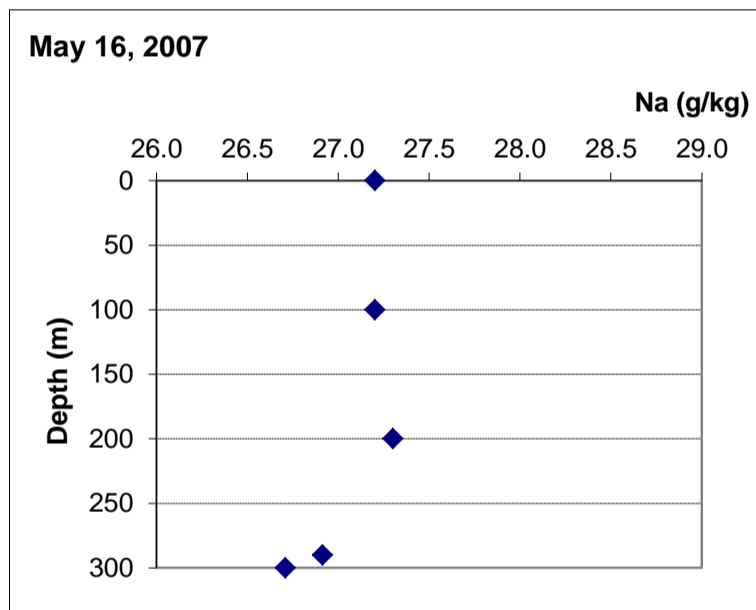
First dilution with water (2:1) . For second dilution 5 or 6 ml of first dilution are weighed and diluted to 100ml

Salinity includes SO4 concentration. Alkalinity has not been measured

GSI no	Lab no.	Depth m	Temp in situ	density 25°C	Na g/kg	K g/kg	Ca g/kg	Mg g/kg	Sr g/kg	Cl g/kg	Br g/kg	SO4-- g/kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
1217	MY-0	0	28.71	1.23960	27.20	6.48	14.90	38.9	0.285	188.1	3.89	0.285	280.0	0.223	6.00
1215	MY-100	100	22.73	1.23892	27.20	6.22	14.77	38.9	0.285	185.5	4.04	0.285	277.2	0.226	6.25
1210	MY-200	200	22.73	1.23892	27.30	6.55	14.72	38.4	0.286	185.9	4.03	0.286	277.5	0.226	5.86
1212	MY-290	290	22.76	1.23891	26.91	6.52	14.62	38.5	0.282	185.8	3.96	0.282	276.9	0.223	5.90
1213	MY-300	300	22.77	1.23892	26.71	6.48	15.08	38.3	0.302	186.5	4.09	0.302	277.8	0.221	5.90
avg. 100-300m			22.75	1.23892	27.03	6.44	14.80	38.50	0.29	185.9	4.03	0.289	277.3	0.224	5.98
std.dev.			0.02	0.00001	0.27	0.15	0.20	0.25	0.01	0.43	0.06	0.01	0.40	0.003	0.18
std.dev./avg (%)			0.09	0.00040	1.00	2.38	1.33	0.66	3.12	0.23	1.37	3.12	0.14	1.17	3.05

Comments

- 1 At **0m** higher Cl concentration and higher salinity, supported by higher density, are evidence for evaporation
- 2 Few data points. However, the **Na/Cl ratio** suggests that there is (or has been) halite precipitation in the 0m layer
- 3 There might be some EB intrusion at 300m, suggested by somewhat lower Na, somewhat higher Cl and lower Na/Cl/



Cruise Summary :

July 29, 2007

Station En Gedi 320

Lake level 420.17 m bmsl

Lake Volume 131.56 km³

Sampling in 100ml pre-weighed glass bottles.

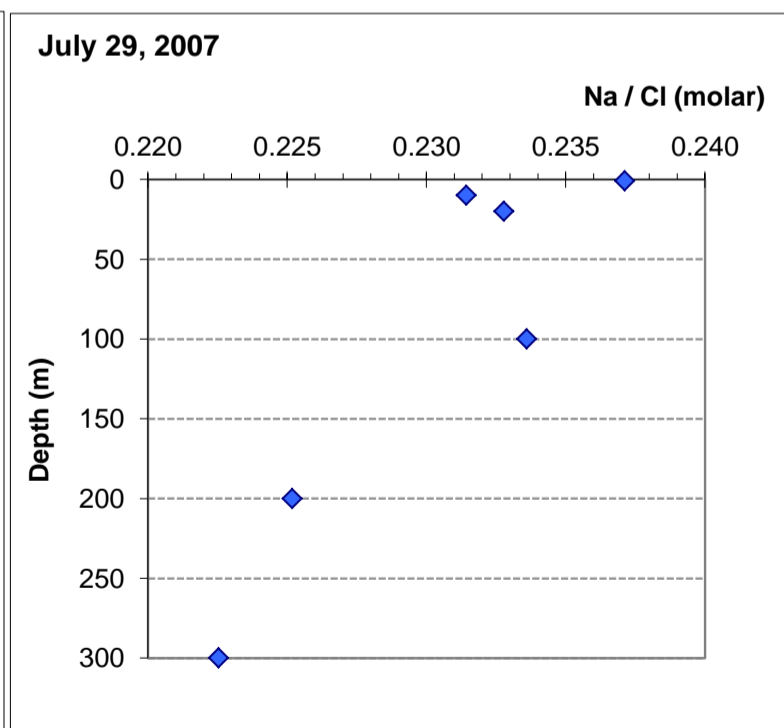
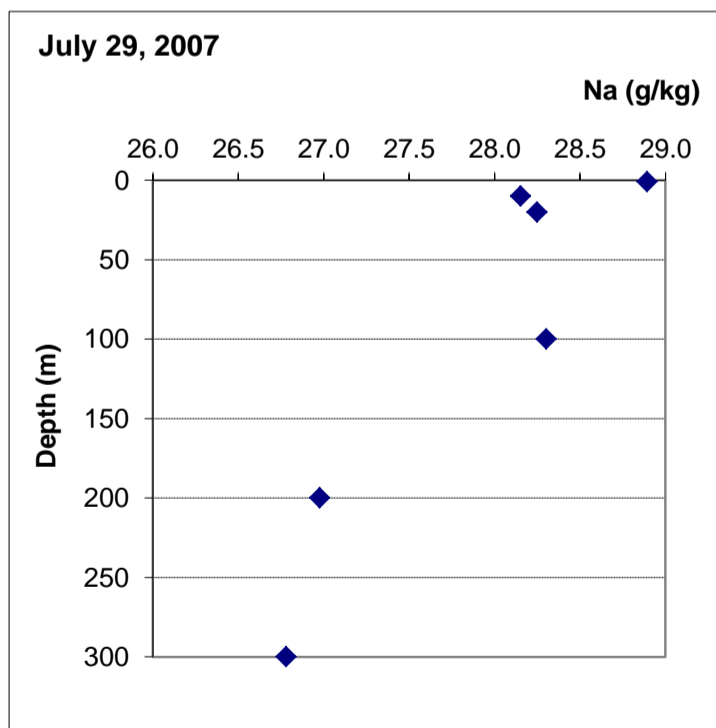
First dilution: mixture with water (1:1) . For second dilution 5ml or 6 ml or 9ml mixture were weighed and diluted to 100ml

Salinity does not include Alkalinity and Sulphate which have not been measured

GSI no.	Sample no.	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na g/Kg	K g/Kg	Ca g/Kg	Mg g/Kg	Sr g/Kg	Cl g/Kg	Br g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
1230	J-1	1	34.37	1.24161	28.89	6.58	14.95	39.3	0.294	187.8	4.27	282.1	0.237	5.97
1232	J-10	10	33.81	1.24159	28.15	6.62	14.64	40.1	0.296	187.5	4.22	281.5	0.231	6.06
1233	J-20	20	32.84	1.24148	28.25	6.70	15.12	39.4	0.293	187.0	4.30	281.1	0.233	5.88
1228	J-100	100	22.76	1.23892	28.30	6.66	15.04	38.8	0.291	186.7	4.30	280.2	0.234	5.83
1220	J-200	200	22.84	1.23897	26.98	6.35	14.43	39.7	0.289	184.7	4.33	276.7	0.225	6.25
1224	J-300	300	23.5	1.23935	26.78	6.29	14.55	40.1	0.289	185.5	4.19	277.6	0.223	6.37
average 1-20m(UWM)			33.67	1.24156	28.43	6.63	14.90	39.60	0.294	187.5	4.26	281.6	0.234	5.97
std. dev.			0.77	0.00007	0.40	0.06	0.24	0.45	0.001	0.4	0.04	0.5	0.003	0.09
std.dev./avg (%)			2.30	0.01	1.41	0.91	1.63	1.14	0.38	0.20	0.93	0.17	1.35	1.47
average 200-300m (LWM)			23.03	1.23908	26.88	6.32	14.49	39.86	0.29	185.1	4.26	277.2	0.224	6.31
±			0.47	0.00027	0.14	0.04	0.09	0.27	0.00	0.59	0.10	0.67	0.00	0.09
%			2.03	0.02	0.52	0.67	0.63	0.68	0.06	0.32	2.26	0.24	0.83	1.35
UWM/LWM					1.058	1.050	1.028	0.994	1.020	1.013	1.001	1.016	1.044	0.946

Comments

- 1 The upper 20 m are thermally and salinity stratified
- 2 The 100m display similar concentrations of Na, K , Cl to the upper 20m (see Table and Figs below), not supported by density data. It is not easy to explain the 100m data. Error of sampling?
- 3 Influence of EB on 300m is shown by temperature increase, slight increase in density at 25°C, lower K and higher Mg/K. Therefore it is not so reasonable to make average of the 2 data points 200m and 300m to represent the LWM
- 4 The concentration of Na in the upper 20m (28.43g/kg) is larger than in May 2007 (at 0m 27.2 g/kg). The Na/Cl ratio is larger (0.234) than in the deeper layers (0.224).Therefore, in addition to increased concentration due to evaporation, halite dissolution in the warmer upper layers is taking place.



Cruise Summary :

November 5, 2007

Station Ein Gedi 320

Lake level 420.55 m bmsl

Lake volume 131.32 km³

Sampling in 100ml pre-weighed glass bottles.

First dilution: mixture with water (2:1) . For second dilution 5ml mixture were weighed and diluted to 100ml

The analytical determinations have been performed twice. Data below are averages of the 2 runs

Salinity does not include Alkalinity and Sulphate which have not been measured

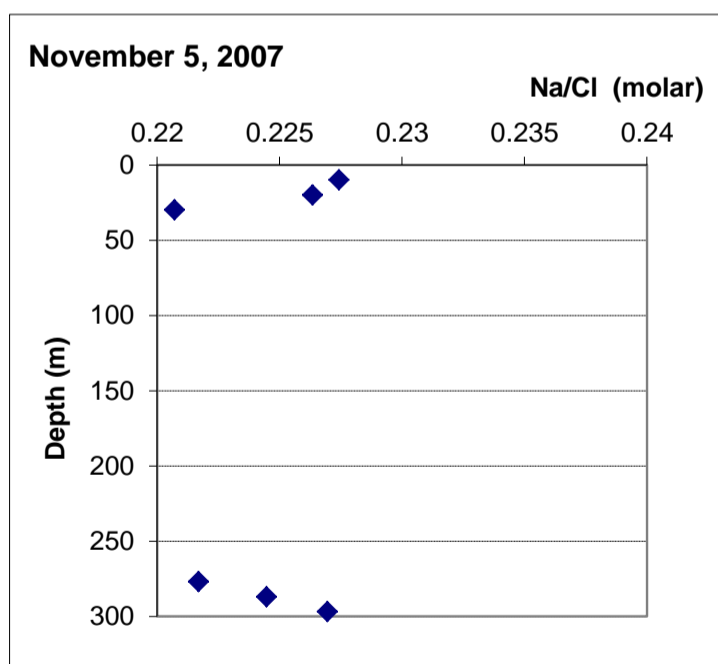
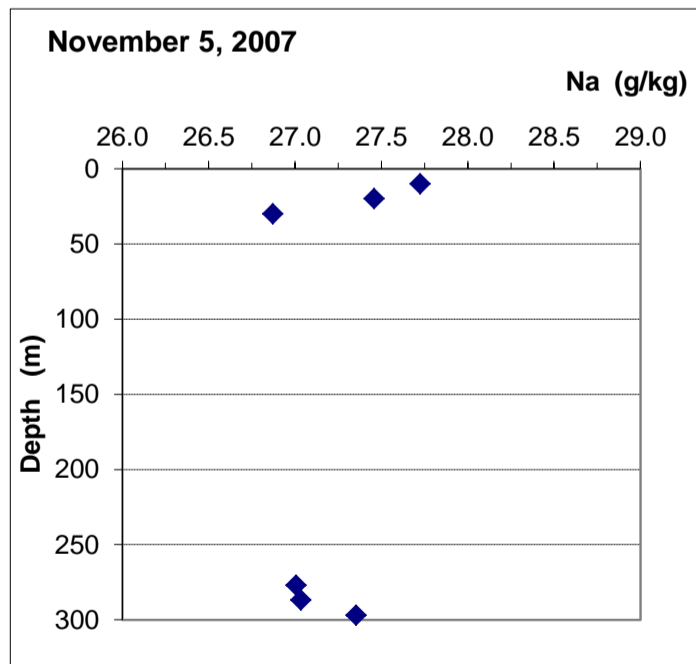
GSI no.	Sample no.	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na g/Kg	K g/Kg	Ca g/Kg	Mg g/Kg	Sr g/Kg	Cl g/Kg	Br g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
1246	N-10	10	28.49	1.24066	27.72	6.61	15.21	40.06	0.282	187.9	4.16	281.9	0.227	6.06
1247	N-20	20	28.48	1.24066	27.46	6.63	15.15	39.66	0.286	187.0	4.09	280.2	0.226	5.98
1248	N-30	30	25.88	1.24018	26.87	6.41	15.00	39.35	0.287	187.6	4.07	279.6	0.221	6.14
1237	N-280	277	24.13	1.23948	27.01	6.37	15.25	39.98	0.277	187.8	4.10	280.8	0.222	6.28
1238	N-290	287	24.35	1.23958	27.03	6.53	15.47	40.00	0.278	185.6	4.11	279.0	0.224	6.13
1239	N-300	297	24.58	1.23974	27.35	6.52	14.67	39.31	0.288	185.8	4.08	278.0	0.227	6.03

average 10-20m			28.49	1.24066	27.59	6.62	15.18	39.86	0.284	187.43	4.12	281.09	0.227	6.021
std.dev.			0.01	0.00000	0.19	0.01	0.05	0.29	0.003	0.64	0.05	1.20	0.001	0.056
std.dev./avg (%)			0.02	0.00000	0.7	0.2	0.3	0.7	1.1	0.3	1.3	0.4	0.3	0.9

average 30-297m			24.74	1.23975	27.07	6.46	15.10	39.66	0.283	186.70	4.09	279.36	0.223	6.145
std.dev.			0.79	0.00031	0.20	0.08	0.34	0.38	0.006	1.16	0.02	1.15	0.003	0.102
std.dev./avg (%)			3.17	0.02494	0.8	1.2	2.3	1.0	2.1	0.6	0.4	0.4	1.3	1.7

Comments

- 1 Profile is not detailed. Few data points.
- 2 The lake is still stratified, but the Na and Na/Cl profiles suggest sliding of upper layers into the deepest ones. Turnover is just about to take place.
- 3 No clear evidence for EB intrusion



Cruise Summary :

December 3, 2007

Station En Gedi 320

Lake level 420.62 m bmsl

Lake volume 131.27 km³

Sampling in 100ml pre-weighed glass bottles.

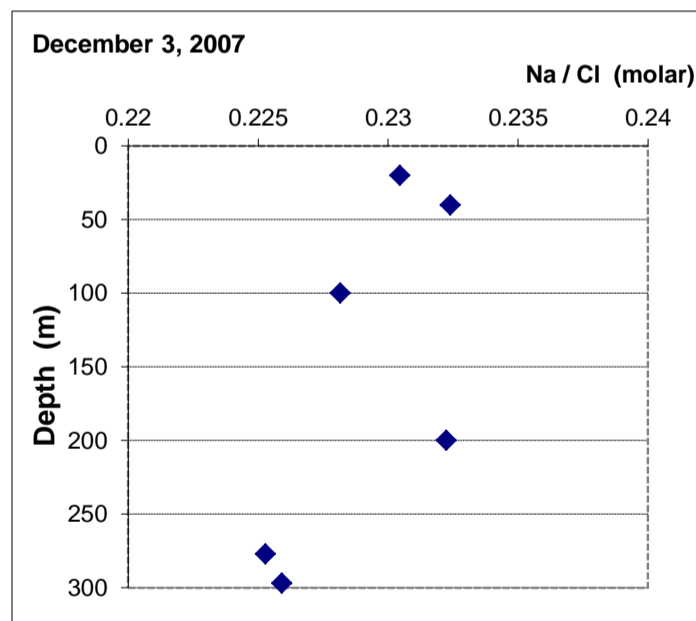
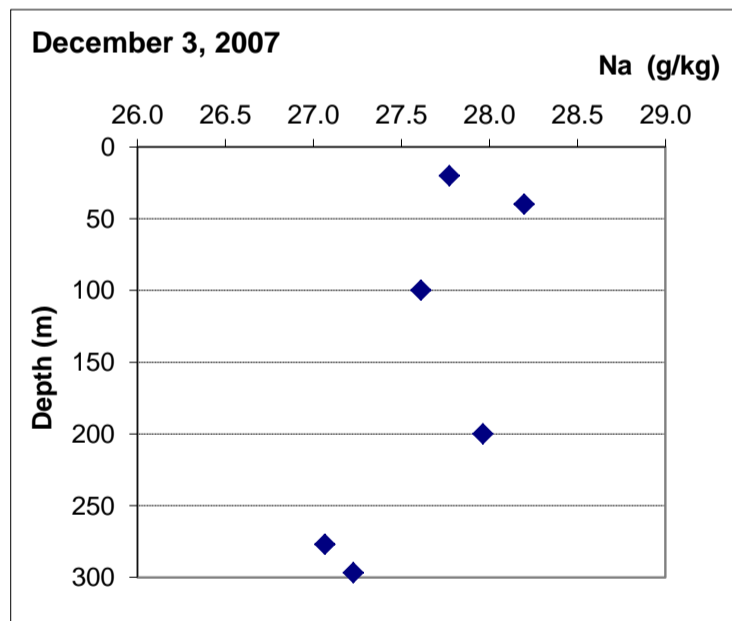
First dilution: mixture with water (2:1) . For second dilution 5ml mixture were weighed and diluted to 100ml

Salinity does not include Alkalinity and Sulphate which have not been measured

GSI no.	Sample no.	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na g/Kg	K g/Kg	Ca g/Kg	Mg g/Kg	Sr g/Kg	Cl g/Kg	Br g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
	D-20	20	24.18	1.23958	27.77	6.64	15.02	39.22	0.291	186.0	4.60	279.6	0.230	5.90
	D-40	40	24.19	1.23958	28.20	6.67	15.13	38.74	0.298	187.3	4.24	280.6	0.232	5.80
	D-100	100	24.21	1.23958	27.61	6.67	14.94	38.55	0.293	186.8	4.45	279.3	0.228	5.78
	D-200	200	24.24	1.23958	27.96	6.69	15.15	38.41	0.298	185.8	4.31	278.7	0.232	5.74
	D-280	277	24.27	1.23958	27.07	6.54	14.85	38.46	0.290	185.4	4.35	277.0	0.225	5.88
	D-300	297	24.28	1.23957	27.23	6.42	14.72	39.08	0.293	186.0	4.44	278.2	0.226	6.09
avg. 0-200m			24.21	1.23958	27.89	6.67	15.06	38.73	0.295	186.5	4.40	279.5	0.231	5.81
std.dev 0-200			0.03	0.00000	0.25	0.02	0.10	0.35	0.00	0.67	0.16	0.79	0.00	0.07
std.dev./avg (%)			0.11	0.00000	0.91	0.31	0.65	0.91	1.20	0.36	3.63	0.28	0.86	1.22
avg. 277 to bottom			24.28	1.23958	27.15	6.48	14.78	38.77	0.292	185.7	4.40	277.6	0.226	5.98
stdev 277 to bottom			0.01	0.00001	0.11	0.09	0.09	0.44	0.00	0.41	0.06	0.85	0.00	0.15
std.dev./avg (%)			0.03	0.00057	0.42	1.34	0.64	1.14	0.66	0.22	1.45	0.31	0.20	2.48
ratio of averages														
0-200m/277m - bottom			1.00	1.00	1.03	1.03	1.02	1.00	1.01	1.00	1.00	1.01	1.02	0.97

Comments

- The profile of density at 25°C suggests complete turnover. Chemical analyses suggest incomplete mixing, the upper 200m are different from the 200m down to bottom layer..



Cruise Summary :

February 27, 2008 cruise

Station En Gedi 320

Lake level 421.03 m bmsl

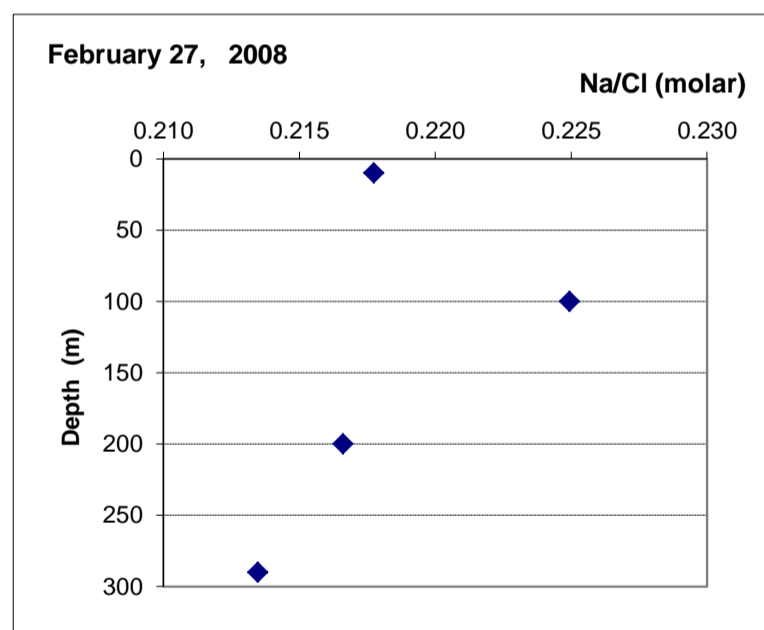
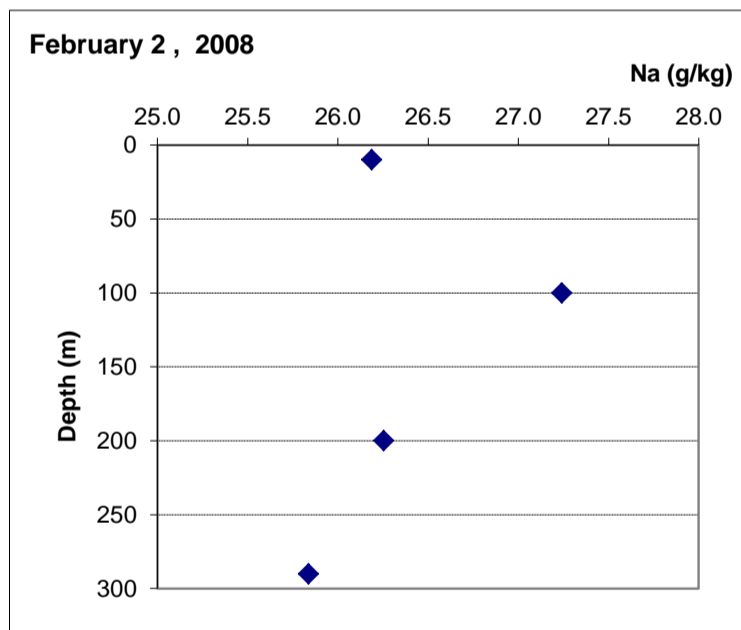
Lake volume 131.01 km³

Sampling in pre-weighed centrifuge tubes. The tubes were filled with DS and weighed again in the lab. The full content of the tube was diluted in lab into pre-weighed 100ml volumetric flasks. The weight of the filled volumetric flasks was too heavy for 4 digits balances. **Therefore semi-analytical balances - 2 digits -** were used. Salinity does not include Alkalinity and Sulphate which have not been measured

GSI no.	Sample no.	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na g/Kg	K g/Kg	Ca g/Kg	Mg g/Kg	Sr g/Kg	Cl g/Kg	Br g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
	F10	10	22.47	1.23932	26.19	6.44	14.85	38.26	0.292	185.4	3.65	275.0	0.218	5.94
	F100	100	22.51	1.23932	27.24	6.29	15.03	37.79	0.287	186.7	4.46	277.8	0.225	6.01
	F200	200	22.54	1.23932	26.26	6.37	14.91	38.06	0.291	186.8	3.70	276.4	0.217	5.97
	F290	290	22.58	1.23933	25.84	6.40	14.93	38.16	0.287	186.6	3.65	275.8	0.213	5.96
average 10-290m			22.53	1.23932	26.38	6.38	14.93	38.07	0.289	186.3	3.87	276.3	0.218	5.97
std.dev.			0.05	0.00001	0.60	0.06	0.08	0.20	0.00	0.66	0.40	1.14	0.005	0.03
std.dev./avg (%)			0.21	0.00	2.28	1.01	0.52	0.54	0.84	0.36	10.24!!	0.41	2.22	0.48

Comments

- 1 The chemical analyses fail to show homogenous profiles. The % deviation from the average is relatively large 2% in the case of Na , 1% for K, and 0.4% to 0.8% for the others.
- 2 According to temperature and density at 25°C the lake is well mixed.
- 3 For the first time Na less than 26 g/kg and Na/Cl ratios lower than 0.22 are encountered in this February 2008 cruise. probably due to halite deposition



Cruise Summary :

May 21, 2008

Station En Gedi 320m

Lake level 421.18 m bmsl

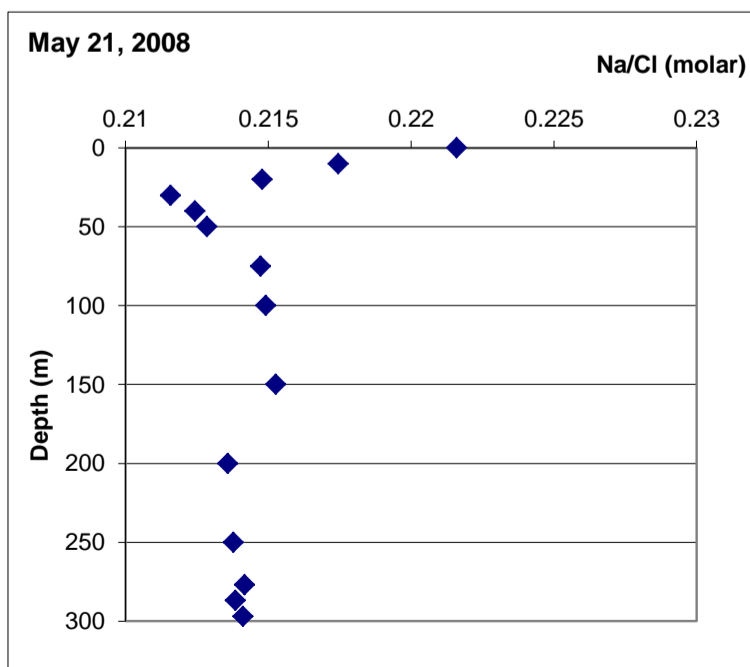
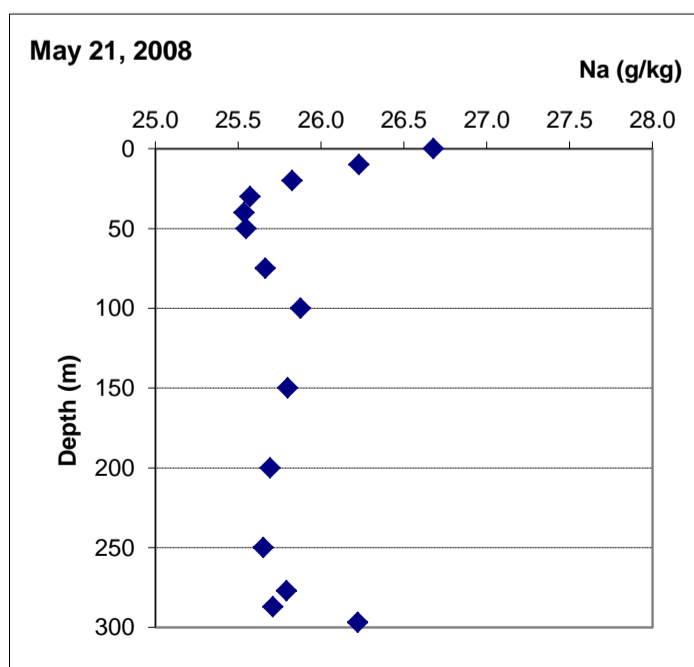
Lake volume 130.92 km³

Samples in pre-weighed plastic bottles Crystals, not many, in all bottles down to 50 m. No crystals at all below 50m.
 Dilutions in the lab, ratio DS:water 2:1. This dilution dissolves the halite crystals.
 Second dilution: 5ml mix into pre-weighed 100ml flasks
 Salinity does not include Alkalinity and Sulphate which have not been measured

GSI no	Sample no.	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na g/Kg	K g/Kg	Ca g/Kg	Mg g/Kg	Sr g/Kg	Cl g/Kg	Br g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
	M0	0	28.00	1.24035	26.68	6.57	15.12	38.88	0.283	185.6	4.97	278.0	0.222	5.92
	M10	10	27.17	1.24036	26.23	6.49	15.10	39.21	0.283	185.9	4.95	278.2	0.217	6.04
	M20	20	26.16	1.24024	25.83	6.49	15.05	38.93	0.283	185.3	4.93	276.8	0.215	6.00
	M30	30	23.83	1.23970	25.57	6.62	15.19	39.44	0.283	186.3	4.98	278.4	0.212	5.96
	M40	40	23.05	1.23945	25.53	6.48	14.87	38.96	0.282	185.3	4.90	276.3	0.212	6.02
	M50	50	22.68	1.23933	25.55	6.53	15.15	38.66	0.282	185.0	5.02	276.2	0.213	5.92
	M75	75	22.64	1.23931	25.66	6.52	15.01	38.58	0.283	184.2	4.89	275.2	0.215	5.91
	M100	100	22.59	1.23930	25.88	6.53	15.16	38.95	0.282	185.6	4.91	277.3	0.215	5.96
	M150	150	22.63	1.23931	25.80	6.80	15.18	38.57	0.283	184.7	4.87	276.2	0.215	5.67
	M200	200	22.65	1.23936	25.69	6.49	15.20	38.54	0.283	185.4	4.84	276.5	0.214	5.94
	M250	250	22.65	1.23936	25.65	6.54	15.47	38.73	0.287	184.9	4.93	276.6	0.214	5.92
	M280	277	22.65	1.23935	25.79	6.55	15.07	38.69	0.281	185.6	4.86	276.9	0.214	5.90
	M290	287	23.06	1.23953	25.71	6.63	15.05	38.86	0.282	185.3	4.93	276.8	0.214	5.86
	M300	297	23.12	1.23955	26.22	6.79	15.71	39.83	0.294	188.8?	4.98	282.6	0.214	5.86
averag 0-20m			27.11	1.24032	26.24	6.52	15.09	39.01	0.283	185.59	4.95	277.69	0.218	5.99
std.dev.			0.92	0.00007	0.43	0.04	0.03	0.18	0.000	0.30	0.02	0.75	0.003	0.06
std.dev./avg (%)			3.40	0.01	1.62	0.68	0.23	0.46	0.114	0.16	0.38	0.27	1.57	1.02
averag 40-287m			22.73	1.23937	25.70	6.57	15.13	38.73	0.283	185.12	4.90	276.42	0.214	5.90
std.dev.			0.18	0.00008	0.11	0.10	0.16	0.16	0.002	0.45	0.05	0.59	0.001	0.10
std.dev./avg (%)			0.81	0.01	0.44	1.52	1.08	0.42	0.63	0.24	1.05	0.21	0.44	1.64
avg.0-20m/avg.40-287m			1.193	1.0008	1.0213	0.9925	0.9976	1.0073	1.0014	1.00257	1.0096	1.0046	1.0187	1.015

Comments

- 1 The density at 25°C of the deep layer is about the same as in the February 2008 water column, while that of the upper layer is somewhat larger, partly due to evaporation.
- 2 Sample M300 at 297m was excluded from deep layer average because it is different from the rest, mainly because of somewhat higher Na and Cl concentrations
- 3 Sample M30 , at 30 m is in transition layer and was also excluded from deep layer average
- 4 Although the upper layer shows higher Na, Cl and Na/Cl than the lower one, the other elements are at about the same concentration in both layers, suggesting that the effect of evaporation is still minimal.
- 5 Due to its larger Na and Na/Cl, the upper layer displays more the effect of halite dissolution than that of evaporation
- 6 The Na minimum at 30-50m suggests halite deposition from the upper layers, that occurred before halite dissolution caused by the warming up at 0-20m had started.



Cruise Summary : August 4, 2008

Station EnGedi 320

Lake level 421.50 m bmsl

Lake volume 130.71 km³

Sampled in weighed 50 ml plastic centrifuge tubes. Almost no crystals

Centrifuges tubes not stored properly (upside down in a plastic bag)

Dilutions in the lab, ratio DS:water 2:1. Second dilution: 5 ml mix into pre-weighed 100 ml flasks.

Salinity does not include Alkalinity and Sulphate which have not been measured

GSI no.	Sample no.	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na g/Kg	K g/Kg	Ca g/Kg	Mg g/Kg	Sr g/Kg	Cl g/Kg	Br g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
	A-0	0	35.62	1.24229	26.01	6.64	15.46	39.52	0.283	189.1	4.91	281.9	0.212	5.95
	A-5	5	33.44	1.24219	25.60	6.68	15.55	39.41	0.283	185.0	4.92	277.5	0.213	5.90
	A-10	10	33.23	1.24228	26.15	6.63	15.43	39.34	0.280	188.1	4.96	280.9	0.214	5.93
	A-20	20	32.76	1.24219	25.66	6.68	15.47	39.41	0.280	187.6	4.95	280.1	0.211	5.90
	A-30	30	25.15	1.24024	25.99	6.62	15.32	39.07	0.280	180.4	4.97	272.6	0.222	5.90
	A-200	200	22.91	1.23940	25.34	6.46	15.16	38.53	0.276	183.4	4.88	274.1	0.213	5.96
	A-250	250	22.93	1.23944	25.41	6.57	15.21	38.79	0.276	185.6	4.88	276.7	0.211	5.90
	A-280	274	23.41	1.23967	26.02	6.60	15.45	39.09	0.278	185.1	4.95	277.5	0.217	5.92
	A-290	284	23.45	1.23975	25.33	6.56	15.37	38.88	0.281	186.2	4.89	277.5	0.210	5.93
	A-300	294	23.59	1.23987	25.76	6.73	15.77	39.82	0.285	188.2	4.96	281.5	0.211	5.92

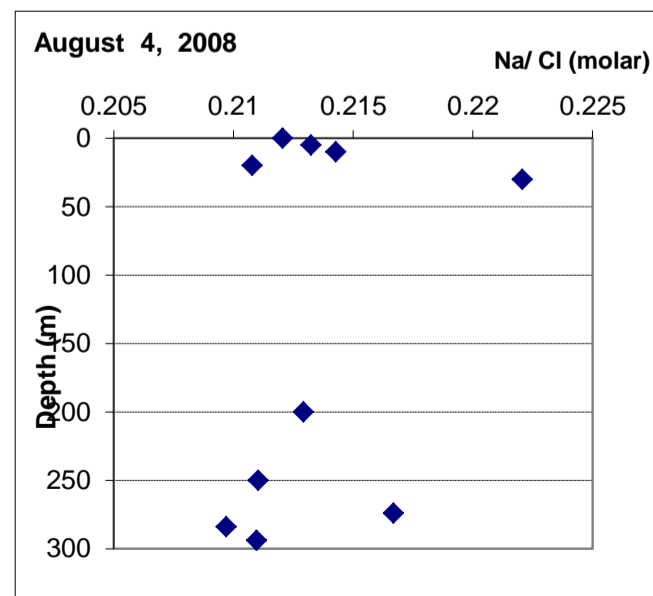
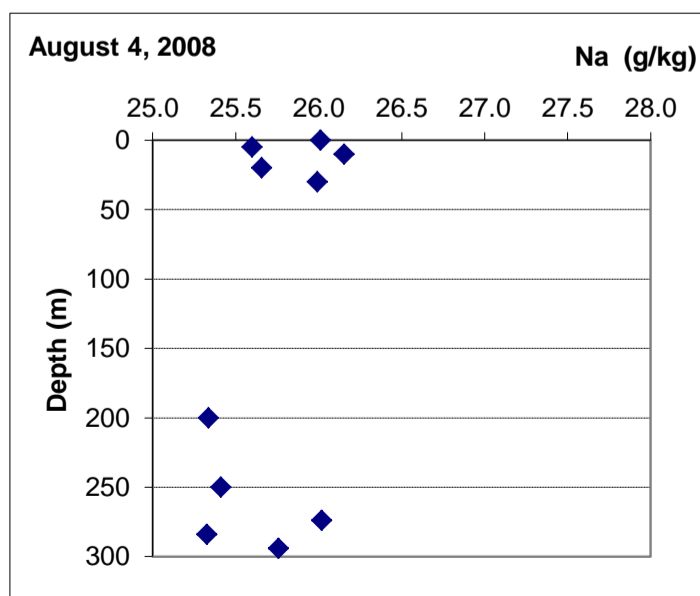
Averages according to layerings of temperature and of density at 25°C

average 0-20m	33.76	1.24224	25.86	6.66	15.48	39.42	0.28	187.45	4.93	280.1	0.213	5.92
std.dev.	1.27	0.00006	0.27	0.03	0.05	0.07	0.00	1.73	0.02	1.90	0.002	0.02
std.dev./avg (%)	3.76	0.00	1.04	0.38	0.33	0.18	0.60	0.92	0.42	0.68	0.710	0.41
average 200-300m	23.26	1.23963	25.57	6.58	15.39	39.02	0.279	185.7	4.91	277.4	0.212	5.93
std.dev.	0.32	0.00020	0.31	0.09	0.24	0.49	0.00	1.73	0.04	2.67	0.003	0.02
std.dev./avg (%)	1.36	0.02	1.20	1.43	1.56	1.26	1.29	0.93	0.80	0.96	1.28	0.35

avg.0-20m/avg.200-300 1.452 1.002 1.011 1.011 1.006 1.010 1.008 1.010 1.005 1.010 1.002 0.999

Comments

- 1 There is no clear trend with depth neither in Cl nor in Na probably due to analytical difficulty. But, if averaged according to density layering, the concentrations of all the elements are higher by about 1% in the upper layer, which may emphasize the effect of evaporation on the concentrations in this layer
- 2 It is noteworthy that the sum of Cl equivalents of the differences in cation concentrations between the upper and lower layers is 1.85 g Cl/kg, in agreement with the measured difference in Cl concentration between the 2 layers. It is also noteworthy that the difference in salinity between the 2 layers, 2.64 g/kg, is in good agreement with the difference in density at 25°C between the 2 layers, which is 2.61 sigma units.
- 3 The Na/Cl ratio is actually the same in the two layers, which may mean that the higher concentrations of Na and Cl in the upper layer are due to evaporation only.



Cruise Summary : November 11, 2008

Station En Gedi 320

Lake level 421.91 m bmsl

Lake volume 130.5 km³

Sampled in weighed centrifuge tubes. Some crystals at 1-30m depth and at 250m

Centrifuges tubes stored ρ in vertical position

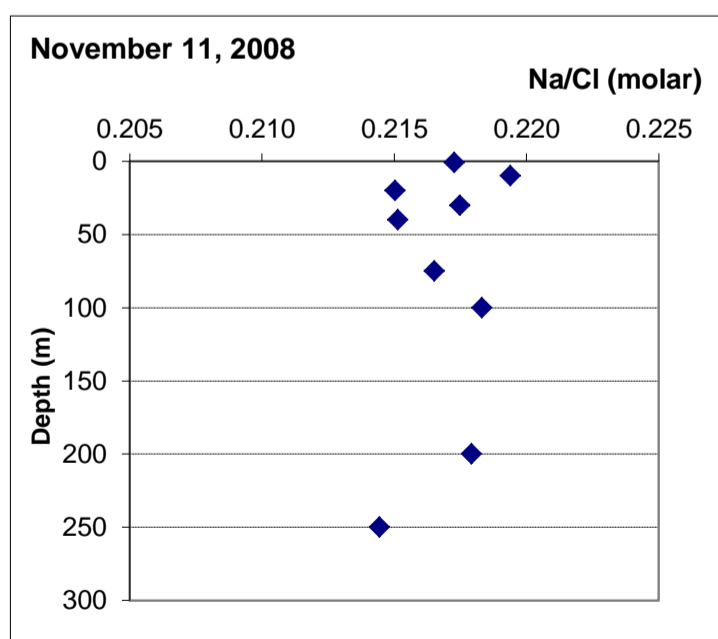
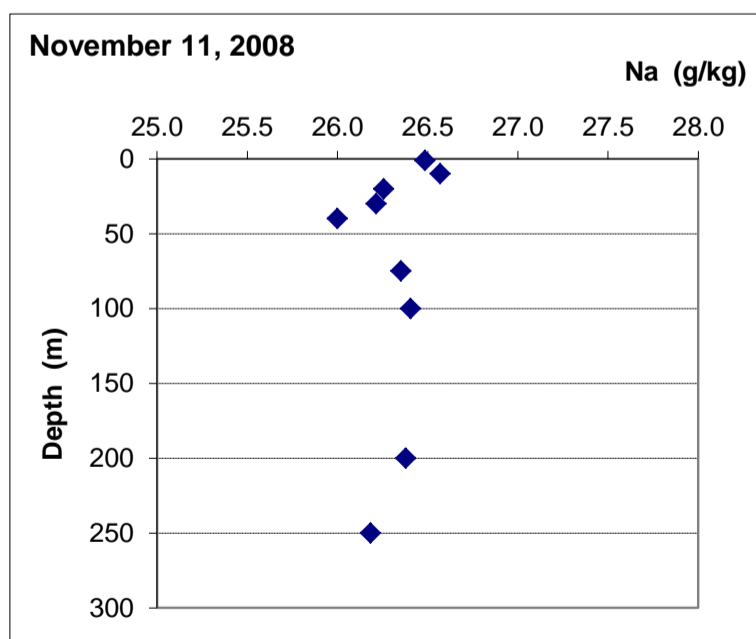
Dilutions in the lab, ratio DS:water 2:1. Second dilution: 5 ml mix into pre-weighed 100 ml flasks.

Salinity does not include Alkalinity and Sulphate which have not been measured

Sample no.	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na g/Kg	K g/Kg	Ca g/Kg	Mg g/Kg	Sr g/Kg	Cl g/Kg	Br g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
N1	1	26.8	1.24074	26.49	6.18	15.19	40.19	0.277	187.9	5.01	281.2	0.217	6.50
N10	10	26.8	1.24085	26.57	6.37	15.18	39.78	0.276	186.7	4.94	279.8	0.219	6.24
N20	20	26.7	1.24089	26.26	6.31	15.11	40.16	0.278	188.2	4.89	281.2	0.215	6.37
N30	30	26.4	1.24077	26.22	6.48	15.50	39.41	0.277	185.8	4.87	278.6	0.217	6.08
N40	40	24.6	1.24003	26.00	6.44	14.90	40.13	0.275	186.3	4.89	278.9	0.215	6.24
N75	75	24.0	1.23992	26.35	6.33	14.80	39.48	0.275	187.6	4.91	279.7	0.217	6.23
N100	100	23.9	1.23988	26.41	5.85	14.99	39.53	0.273	186.4	4.85	278.3	0.218	6.76
N200	200	23.9	1.23987	26.38	6.32	14.86	39.17	0.273	186.6	4.87	278.4	0.218	6.20
N250	250	23.9	1.23987	26.18	6.39	15.04	39.28	0.276	188.2	4.86	280.2	0.214	6.14
	260	24.2											
average 1-30m		26.7	1.24081	26.38	6.34	15.25	39.88	0.28	187.1	4.93	280.2	0.217	6.30
average 40-250		24.1	1.23991	26.26	6.27	14.92	39.52	0.27	187.0	4.88	279.1	0.216	6.31
std. dev. 1-30m		0.19	0.00007	0.17	0.12	0.18	0.36	0.00	1.11	0.06	1.28	0.002	0.18
std.dev.40-250m		0.30	0.00007	0.17	0.24	0.09	0.37	0.00	0.84	0.02	0.83	0.002	0.25
std.dev./avg (%)													
1-30m		0.71	0.01	0.65	1.97	1.15	0.91	0.36	0.60	1.27	0.46	0.82	2.83
std.dev./avg (%)		1.27	0.01	0.65	3.80	0.63	0.94	0.53	0.45	0.49	0.30	0.78	3.99
40-250m													

Comments

- 1 It seems that turnover has started because there is much "noise" in the Na and Cl profiles.
- 2 At 250 m there could be End Brine intrusion: lower Na and higher Cl, lowest Na/Cl
- 3 There is a sudden increase in Mg/K ratio compared to previous cruises, which is due to a sudden decrease in K concentration. Analytical artifact?



Cruise Summary :

February 12, 2009

Station En Gedi 320

Lake level -422.21 m bsl

Lake volume 130.27 km³

Sampled in weighed centrifuge tubes. More crystals at 20-150m depth, less at 280-300m

Centrifuges tubes stored properly in vertical position

Dilutions (2:1) with deionized water performed 17.02.09. Densities of the dilutions measured 20-100m, then interrupted

Density measurements continued on 1.03.09 and then further dilutions of weighed 5ml to 100ml

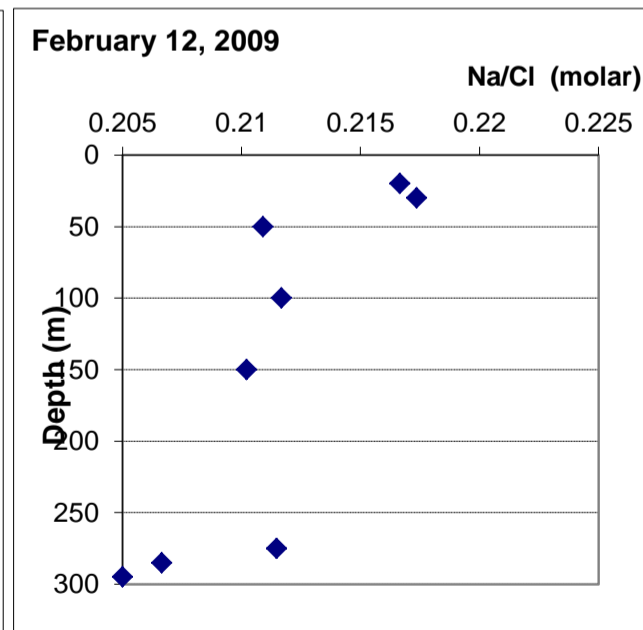
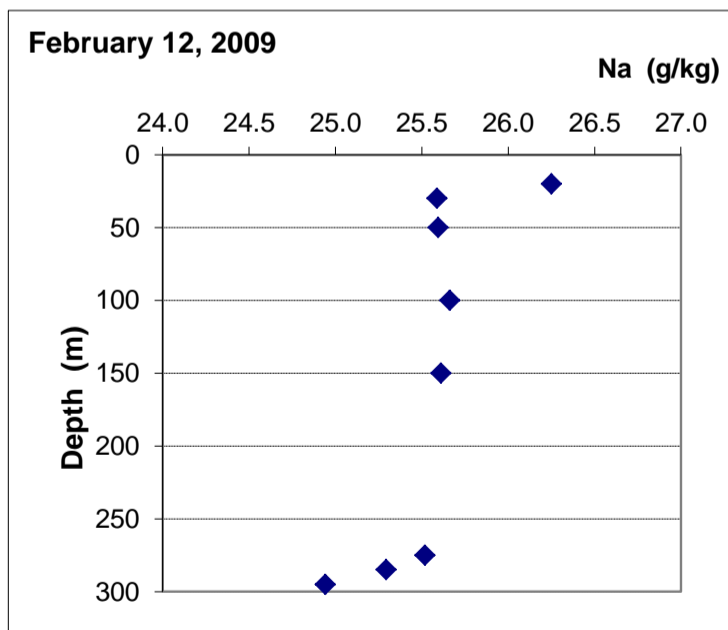
Nominal 280,290,300m changed to actual 275.285 and 295 m

Salinity does not include Alkalinity and Sulphate which have not been measured

Sample no.	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na g/Kg	K g/Kg	Ca g/Kg	Mg g/Kg	Sr g/Kg	Cl g/Kg	Br g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
F20	20	23.18	1.23996	26.25	6.16	14.99	37.33	0.284	186.8	4.81	276.57	0.217	6.06
F30	30	23.22	1.23999	25.59	6.22	15.19	37.66	0.289	181.4	4.75	271.13	0.218	6.06
F50	50	23.21	1.23999	25.59	6.17	14.95	37.64	0.285	187.0	4.71	276.38	0.211	6.11
F100	100	23.23	1.24000	25.66	6.18	15.00	37.42	0.287	186.9	4.82	276.23	0.212	6.05
F150	150	23.24	1.24000	25.61	6.18	15.22	37.68	0.289	187.8	4.60	277.36	0.210	6.10
F280	275	23.29	1.24003	25.52	6.18	15.17	37.69	0.287	186.0	4.69	275.51	0.211	6.10
F290	285	23.31	1.24002	25.29	6.14	15.00	37.13	0.285	188.7	4.91	277.42	0.207	6.05
F300	295	23.31	1.24002	24.94	6.09	15.23	36.88	0.290	187.5	4.70	275.63	0.205	6.06
without F30													
average 20-295m		23.25	1.24000	25.56	6.16	15.09	37.43	0.29	187.2	4.75	276.4	0.210	6.07
std. dev.		0.05	2.2E-05	0.37	0.04	0.12	0.30	0.00	2.19	0.10	2.00	0.00	0.02
std.dev./avg (%)		0.21	0.00	1.44	0.62	0.79	0.80	0.79	1.17	2.04	0.72	2.06	0.40

Comments

- 1 Cl is too low at 30m. This is not supported by a lower Na.
- 2 Mg is too low compared to Nov 2008 all along the profile and especially at 295m. It "causes" too low salinity at most depths.
- 3 Likewise Mg, Na concentrations are too low too at all depths. Although Halite precipitation is expected it cannot account for the enormous amount of Na that is missing since Nov 2008, 130 million ton Na!!
- 4 It must therefore be concluded that an analytical error caused too low Mg and Na concentrations. However the general appearance of the profiles reflects the vertically mixed water column
- 5 Lower Na and lower Na/Cl at 295m suggest end brine intrusion, but this is not supported by temperature and density



Cruise Summary :

June 29, 2009

Station En Gedi 320

Lake level 422.46 m bmsl

Lake Volume 130.1 km³

Sampled in centrifuge tubes . No duplicates sampling.

Dilutions by weight (2:1) with deionized water

To improve precision, weighed 2 ml of the 2:1 dilution were further diluted to 250ml

Na data from the 2ml diluted to 250ml rejected because of too high results and too high N290 (internal standard) .

Na repeated and measured in a 5 ml to 100ml dilution.

Salinity does not include Alkalinity and Sulphate which have not been measured

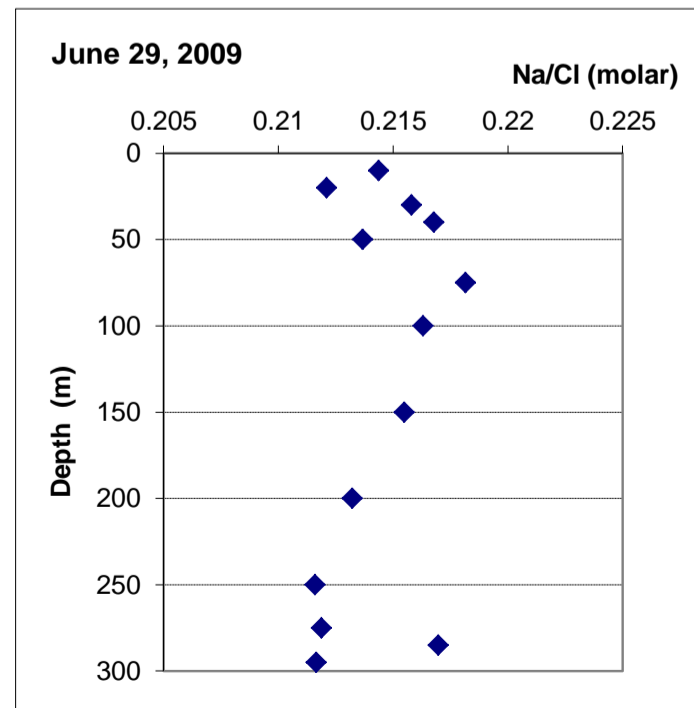
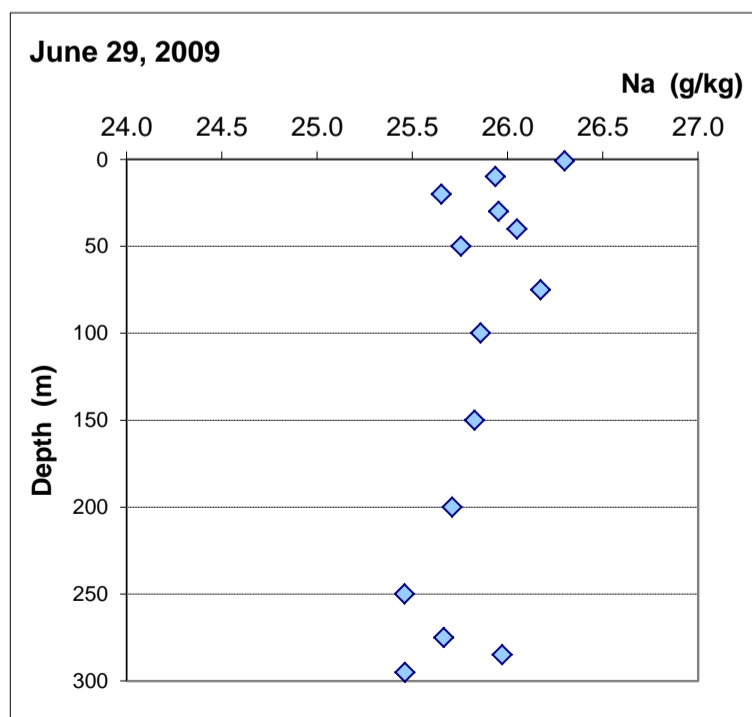
Sample	Depth	Temp.	Density	Na+	K+	Ca++	Mg++	Sr	Cl-	Br-	Salinity	Na/Cl	Mg/K
	m	in situ °C	at 25°C g/cm ³	g/Kg	g/Kg	g/Kg	g/Kg	g/Kg	g/Kg	g/Kg	g/Kg	molar	w/w
J1	1	33.99	1.24187	26.30	6.50	15.44	38.99	0.292	180.3	4.9	272.8	0.225	6.00
J10	10	32.26	1.24164	25.94	6.61	15.49	38.88	0.290	186.5	4.9	278.6	0.214	5.88
J20	20	28.19	1.24153	25.65	7.10	15.32	39.02	0.290	186.4	5.0	278.8	0.212	5.50
J30	30	25.00	1.24046	25.95	7.32	15.27	38.82	0.286	185.4	5.1	278.1	0.216	5.30
J40	40	23.66	1.24000	26.05	6.49	15.26	38.96	0.292	185.2	5.0	277.2	0.217	6.00
J50	50	23.35	1.23995	25.76	6.53	15.14	38.72	0.287	185.8	4.9	277.2	0.214	5.93
J75	75	23.04	1.23988	26.17	6.56	15.20	38.71	0.288	184.9	5.0	276.8	0.218	5.90
J100	100	23.06	1.23986	25.86	6.67	15.09	38.44	0.286	184.2	4.9	275.5	0.216	5.76
J150	150	23.15	1.23990	25.83	6.59	15.10	38.39	0.289	184.7	4.9	275.8	0.215	5.83
J200	200	23.22	1.23990	25.71	6.60	15.39	38.93	0.286	185.8	4.9	277.7	0.213	5.90
J250	250	23.52	1.24007	25.46	6.63	15.04	38.97	0.291	185.4	4.9	276.7	0.212	5.88
J280	275	23.79	1.24020	25.67	6.59	15.10	38.88	0.289	186.7	4.7	277.9	0.212	5.90
J290	285	23.92	1.24031	25.97	6.60	15.29	38.64	0.290	184.5	5.0	276.3	0.217	5.85
J300	295	23.93	1.24032	25.46	6.71	15.17	38.97	0.287	185.4	4.9	276.9	0.212	5.81

nominal 280, 290, 300m are actually 275,285,295 m

									without 1m	without 1m	without 1m		
average 1-20	31.48	1.24168	25.96	6.74	15.41	38.97	0.291	186.45	4.93	278.68	0.213	5.79	
std. dev.	2.98	0.00017	0.32	0.32	0.09	0.08	0.001	0.05	0.02	3.40	0.01	0.26	
std.dev./avg (%)	9.46	0.01	1.25	4.70	0.55	0.20	0.42	0.03	0.34	1.22	3.16	4.50	
avg. 30-bottom	23.60	1.24008	25.81	6.66	15.19	38.77	0.288	185.29	4.92	276.92	0.215	5.82	
std. dev.	0.57	0.00021	0.23	0.23	0.11	0.21	0.002	0.69	0.11	0.84	0.00	0.18	
std.dev./avg (%)	2.41	0.02	0.88	3.39	0.71	0.53	0.73	0.37	2.25	0.30	1.10	3.15	

Comments

- 1 The stratification shown clearly by the density at 25°C data is less visible in the concentration profiles of the elements
- 2 The sample from 1m depth is awkward: it has the highest Na concentration and the lowest Cl concentration of the profile
1m has been therefore excluded from the depth average of Cl concentrations
- 3 Mg is too low all along the profile and especially at 295m. It "causes" too low salinity
- 4 The decreasing Na/Cl ratio in the hypolimnion, 75 -250m, suggests Halite formation within this layer



Cruise Summary :
Station En Gedi 320

August 4 , 2009

Lake level 422.67 m bmsl

Lake volume 130.0 km³

At lab temp , no crystals at all depths

Sampled in centrifuge tubes . No duplicates sampling.

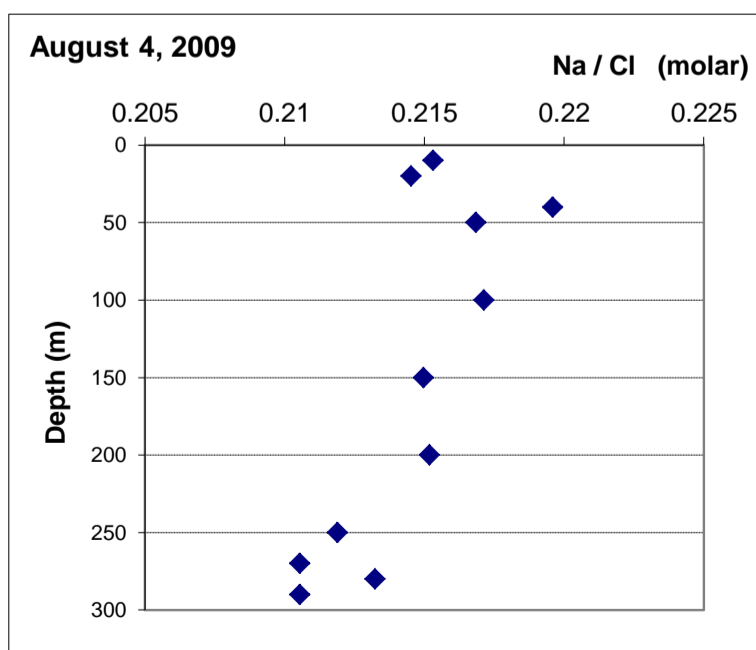
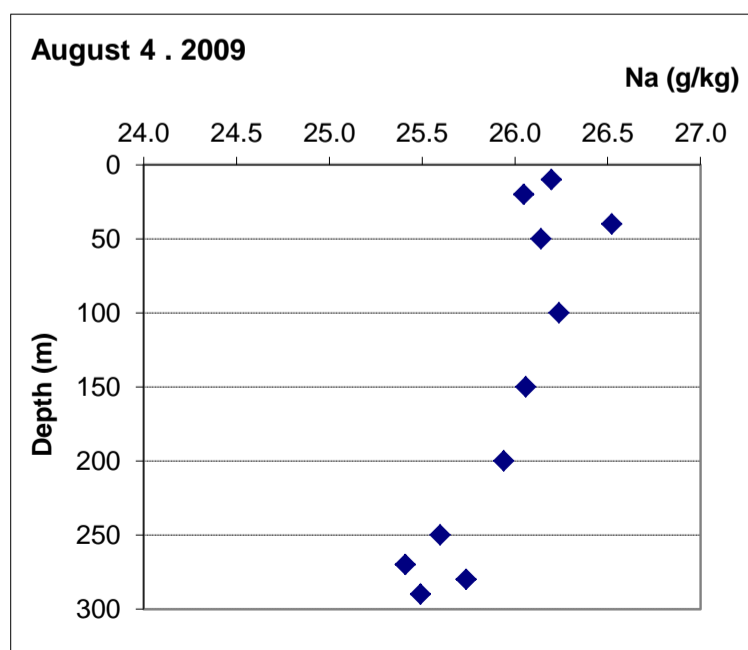
Dilutions by weight (2:1) with deionized water . Then 2ml of first dilution are weighed and diluted to 250ml

Salinity does not include Alkalinity and Sulphate which have not been measured

Sample	Depth m	Temp. in situ °C	Density at 25°C g/cm ³	Na ⁺ g/Kg	K ⁺ g/Kg	Ca ⁺⁺ g/Kg	Mg ⁺⁺ g/Kg	Sr ⁺⁺ g/Kg	Cl ⁻ g/Kg	Br ⁻ g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
A-10	10	33.72	1.24266	26.20	6.60	14.89	39.01	0.283	187.5	5.28	279.8	0.215	5.91
A-20	20	33.64	1.24262	26.05	6.47	14.60	38.49	0.265	187.1	5.14	278.2	0.215	5.95
A-40	40	25.16	1.24035	26.52	6.59	14.66	39.04	0.280	186.2	5.11	278.4	0.220	5.93
A-50	50	23.6	1.24010	26.14	6.45	14.56	38.55	0.265	185.8	4.96	276.7	0.217	5.97
A-100	100	23.12	1.23989	26.24	6.44	14.65	38.63	0.274	186.2	4.99	277.5	0.217	6.00
A-150	150	23.26	1.23996	26.06	6.39	14.42	38.52	0.262	186.8	5.08	277.6	0.215	6.03
A-200	200	23.27	1.23992	25.94	6.48	14.59	38.59	0.276	185.8	5.03	276.7	0.215	5.95
A-250	250	23.54	1.24008	25.60	6.20	14.02	38.48	0.261	186.2	5.05	275.8	0.212	6.21
A-280	270	23.89	1.24025	25.41	6.35	14.33	38.28	0.261	186.0	5.05	275.7	0.211	6.03
A-290	280	24.02	1.24035	25.74	6.52	14.66	38.93	0.277	186.0	5.05	277.2	0.213	5.98
A-300	290	24.04	1.24039	25.49	6.37	14.54	38.73	0.278	186.6	5.07	277.1	0.211	6.08
upper													
average 10-20m		33.68	1.24264	26.12	6.53	14.74	38.75	0.274	187.3	5.21	279.0	0.215	5.93
std.dev. 10-20m		0.04	0.00002	0.07	0.06	0.14	0.26	0.009	0.19	0.07	0.81	0.000	0.02
std.dev./avg (%)		0.12	0.002	0.29	0.96	0.98	0.67	3.15	0.10	1.28	0.29	0.18	0.34
intermediate													
average 40-200m		23.68	1.24004	26.18	6.47	14.58	38.67	0.271	186.2	5.03	277.4	0.217	5.98
std. dev. 40-200m		0.84	0.00019	0.22	0.07	0.10	0.22	0.01	0.43	0.06	0.69	0.002	0.04
std.dev./avg (%)		3.57	0.015	0.84	1.14	0.65	0.56	2.77	0.23	1.20	0.25	0.86	0.66
deep													
average 250-290m		23.75	1.24027	25.56	6.36	14.39	38.60	0.269	186.2	5.05	276.5	0.212	6.07
std.dev. 250-290m		0.34	0.00014	0.14	0.13	0.28	0.29	0.01	0.28	0.01	0.81	0.001	0.10
std.dev./avg (%)		1.41	0.011	0.55	2.06	1.95	0.74	3.57	0.15	0.15	0.29	0.61	1.67
upper / intermediate													
avg. 10-20 / avg. 40-200				0.998	1.010	1.012	1.002	1.010	1.006	1.035	1.006	0.992	0.993

Comments

- 1 There are apparently 3 layers: upper and intermediate more saline layers with relatively higher Na and Na/Cl ratios than in the deep one.
- 2 With the exception of Na, the upper layer has slightly higher ionic concentrations than the intermediate one, (see respective ratios) indicating the effect of evaporation.
- 3 The lack of Na enrichment in the upper layer and the slightly lower Na/Cl in it, may hint NaCl precipitation
- 4 Lower Na, lower Na/Cl and higher Mg / K in the deep layer (250-290 m) are markers of End Brine intrusion.



Cruise Summary : August 3, 2009 continued

Station C and sampling of End Brine

Sample	Depth m	T in situ °C	density 25°C	Na ⁺ g/Kg	K ⁺ g/Kg	Ca ⁺⁺ g/Kg	Mg ⁺⁺ g/Kg	Sr ⁺⁺ g/Kg	Cl ⁻ g/Kg	Br ⁻ g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
no SO ₄ no Alk													
<u>Aug 3, 09</u>													
C1-5	5			25.91	6.44	14.19	38.78	0.281	188.4	5.12	279.14	0.212	6.03
C1-10	10			26.01	6.54	14.84	38.94	0.271	188.3	5.11	280.01	0.213	5.95
C1-22	22			23.93	6.19	14.49	38.26	0.261	189.4	5.21	277.70	0.195	6.18
C1-25	25			24.47	6.40	15.11	39.91	0.279	188.5	5.26	279.95	0.200	6.23
C1-27	27			24.64	6.28	15.30	39.95	0.274	188.5	5.15	280.05	0.202	6.36
<u>Aug 3, 09</u>													
End brine			~1.35	3.39	2.83	25.74	68.42	0.467	254.3	9.17	364.3	0.021	24.18

Comments

The end brine is very depleted in Na and depleted in K, when compared to the Dead Sea brine. According to the "conservative Mg and Ca, 1 kg of end brine derives from about 1.76 kg of evaporated Dead Sea. The End brine is characterized by a lower Na/Cl molar ratio (about 0.02) and by a higher Mg / K weight ratio (24.2) than in the Dead Sea

At station C1 the salinity is generally higher than at EnGedi 320. The Na and Na/Cl ratios are lower than at EnGedi 320, probably because of End Brine intrusion. The probable intrusion of End Brine is evident in the 25-27m depths not only from the low Na/Cl ratios, about 0.200 vs 0.215 in the lake center at st. EnGedi, but also from the higher Mg/K ratios, up to 6.36 vs. about 6.0

Cruise Summary :

February 9, 2010

Station En Gedi 320

Lake level 423.13 m bmsl

Lake volume 129.7 km³

Sampled in duplicates in weighed centrifuge tubes. Diluted with water: in the centrifuge tube: 2 DS to 1 water

Data are from weighed 2ml of the first dilution to 250 ml dilutions

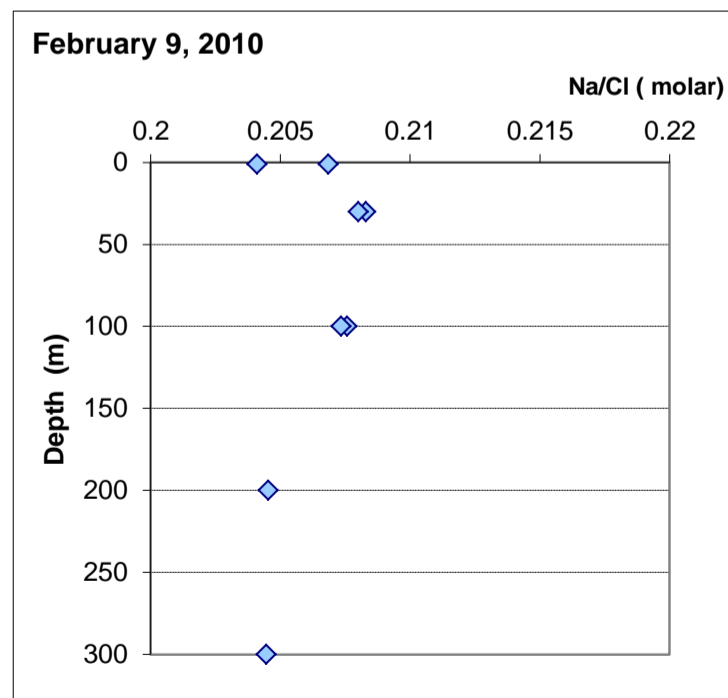
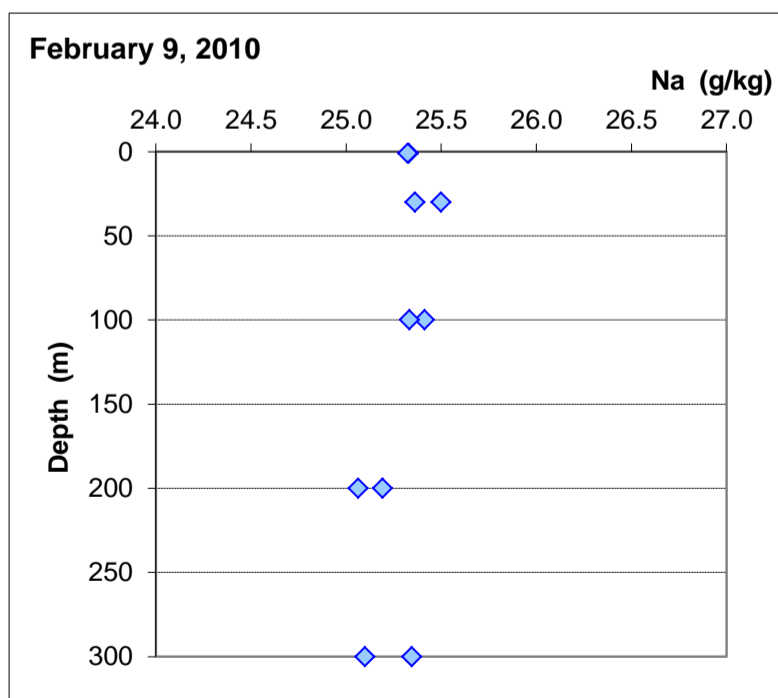
Salinity does not include Alkalinity and Sulphate which have not been measured

Sample	Depth m	Temp in situ °C	Density 25°C g/cm ³	Na+ g/Kg	K+ g/Kg	Ca++ g/Kg	Mg++ g/Kg	Sr++ g/Kg	Cl g/Kg	Br g/Kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
1m*	1	24.28	1.24058	25.33	6.33	15.00	39.16	0.267	191.5	5.18	282.8	0.204	6.18
1mA	1			25.32	6.29	14.73	39.06	0.265	189.0	5.11	279.7	0.207	6.21
30m	30	23.77	1.24050	25.36	6.38	14.73	38.94	0.262	187.9	5.12	278.7	0.208	6.10
30mA	30			25.50	6.42	14.64	38.99	0.263	189.2	5.15	280.2	0.208	6.08
100m	100	23.79	1.24050	25.41	6.39	14.59	38.69	0.262	189.0	5.10	279.4	0.208	6.05
100mA	100			25.33	6.21	14.55	38.73	0.261	188.6	5.10	278.8	0.207	6.24
200m	200	23.79	1.24048	25.06	6.22	14.58	38.50	0.262	189.1	5.08	278.8	0.205	6.18
200mA*	200			25.19	6.26	14.65	38.69	0.263	185.6	5.10	275.8	0.209	6.18
300m*	300	23.75	1.24046	25.34	6.50	15.27	40.13	0.276	198.1	5.30	290.9	0.197	6.18
300mA	300			25.10	6.28	14.53	38.48	0.264	189.5	5.05	279.2	0.204	6.13
average 30-300m		23.78	1.24050	25.29	6.32	14.60	38.72	0.26	188.88	5.10	279.18	0.207	6.13
std dev		0.02	4.6E-05	0.17	0.09	0.07	0.22	0.00	0.55	0.03	0.55	0.002	0.07
std.dev./avg (%)		0.08	0.004	0.69	1.44	0.49	0.56	0.39	0.29	0.65	0.20	0.84	1.13

*samples 1m, 200mA and 300m have been deleted from the average because of outlying Cl analyses.

Comments

- 1 As indicated by the density 25°C data, also the depth average concentrations show a well mixed water column
- 2 The duplicates of Na and Cl at 30 m and 100m are good and the Na/Cl ratios of these duplicates are just the same, indistinguishable on the Figure
- 3 The Na/Cl ratio has decreased in the upper 100m sensibly since Oct 2009, to less than 0.21, indicating halite precipitation from the upper layer



Cruise Summary :

February 26, 2012

Station En Gedi 320

Lake level -425.73m

Lake Volume 128.1 km³

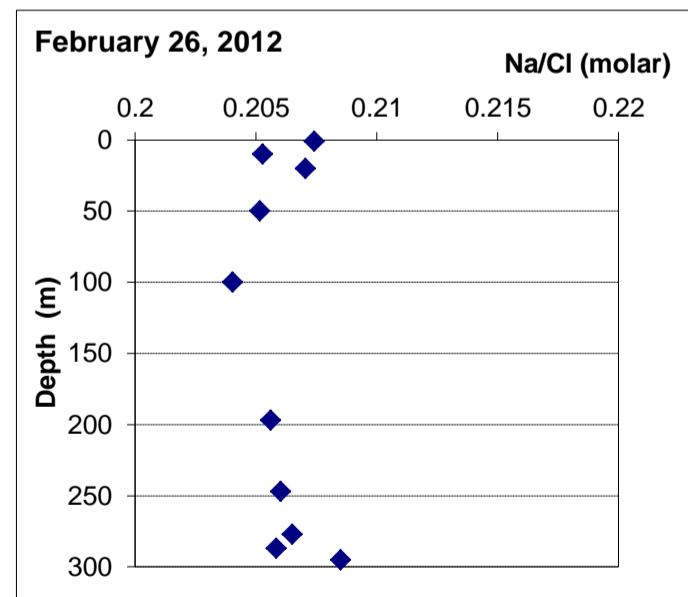
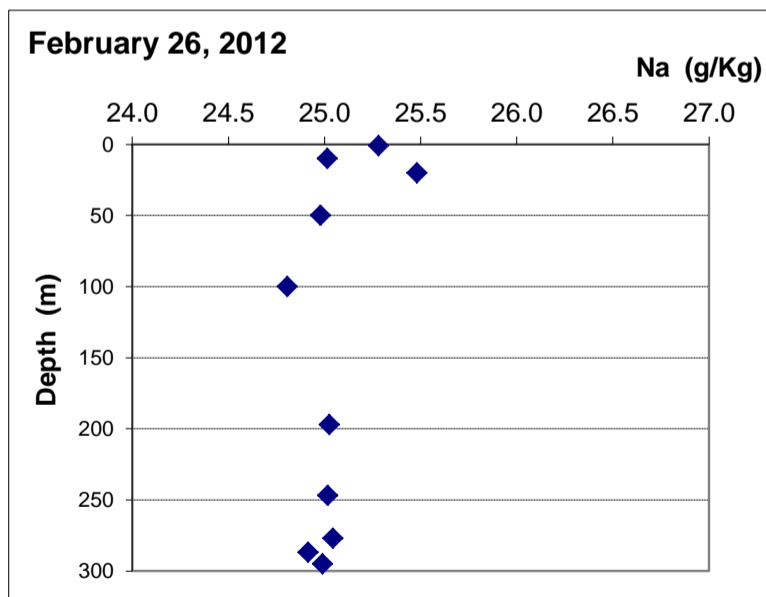
Sampled in weighed centrifuge tubes. Diluted with water, added into the the centrifuge tube: 2 DS to 1 water (first dilution)
 2ml of the first dilution are weighed and then diluted to 250ml. Analyses by Dina and Olga
 Salinity does not include Alkalinity and Sulphate which have not been measured

The data below for each depth are averages of duplicates

Depth m	Temp in situ °C	Density 25°C g/cm ³	Na+ g / kg	K+ g / kg	Ca++ g / kg	Mg++ g / kg	Sr++ g / kg	Cl- g / kg	Br- g / kg	Salinity g/kg	Na/Cl molar	Mg/K w/w
1	23.42	1.24158	25.28	6.60	15.4	41.4	0.323	187.9	5.32	282.2	0.207	6.27
10	23.42	1.24158	25.01	6.63	15.4	41.6	0.323	187.8	5.30	282.1	0.205	6.27
20	23.42	1.24158	25.48	6.66	15.5	40.8	0.326	189.7	5.35	283.7	0.207	6.13
50	23.42	1.24157	24.98	6.54	15.3	39.5	0.322	187.7	5.30	279.6	0.205	6.04
100	23.43	1.24158	24.81	6.55	15.3	39.5	0.321	187.4	5.27	279.1	0.204	6.03
197	23.45	1.24157	25.03	6.56	15.3	40.5	0.323	187.6	5.30	280.6	0.206	6.18
247	23.48	1.24157	25.02	6.56	15.3	41.1	0.323	187.2	5.31	280.8	0.206	6.28
277	23.49	1.24157	25.04	6.57	15.3	41.3	0.322	186.9	5.32	280.7	0.207	6.28
287	23.49	1.24156	24.92	6.54	15.2	41.1	0.319	186.6	5.30	279.9	0.206	6.28
295	23.41	1.24156	24.99	6.51	15.1	40.8	0.319	184.7	5.26	277.8	0.209	6.27
Average												
1-295m	23.44	1.24157	25.06	6.57	15.31	40.76	0.322	187.34	5.30	280.7	0.206	6.20
std dev	0.03	0.00001	0.19	0.04	0.10	0.73	0.002	1.24	0.03	1.71	0.001	0.10
std.dev./avg (%)	0.14	0.00064	0.76	0.67	0.67	1.79	0.62	0.66	0.50	0.61	0.62	1.64

Comments

- 1 The depth profiles of the elements look almost homogeneous, but do not display complete mixing as well as do display the depth profiles of temperature and density at 25°C along the water column
- 2 Mg data displays the largest deviations along the water column (1.8%). Probaly analytical error which also causes an apparent large error in Mg/K ratio
- 3 Average Na concentration is slightly lower in Feb. 2012 (25.06g/kg) than in Feb 2010 (25.3g/kg) indicating halite deposition from the water column.
- 4 The salinity is apparently larger (by 1.0 g/kg) in February 2012 (280.7g/kg) than in Feb 2010 (279.7 g/kg)
 The lake volume has meantime decreased by 1.6km³



Cruise Summary :

October 17, 2012

Station S3

Lake level 426.59 m bmsl

Lake volume 127.5 km³

Sampled in centrifuge tubes. They were kept in upright position
 Diluted with water, added into the the centrifuge tube: 2 DS to 1 water (first dilution)
 2ml of the first dilution are weighed and then diluted to 250ml.
 Salinity does not include Alkalinity and Sulphate which have not been measured

At each depth the concentrations are averages of duplicate samplings

Depth m	Temp in situ °C	Density 25°C g/cm ³	Na g / kg	K g / kg	Ca g / kg	Mg g / kg	Sr g / kg	Cl- g / kg	Br g / kg	Salinity g/Kg	Na/Cl molar	Mg/K w/w
1	31.56	1.24359	24.94	6.62	15.37	39.99	0.173	186.5	5.07	278.7	0.206	6.04
10	31.07	1.24355	24.33	6.65	15.51	40.21	0.336	186.6	5.04	278.7	0.201	6.04
20	31.1	1.24359	24.73	6.66	15.45	40.26	0.337	187.6	5.01	280.0	0.203	6.05
50	24.04	1.24185	25.08	6.57	15.42	40.01	0.325	187.3	4.95	279.6	0.207	6.09
100	24.05	1.24185	25.09	6.52	15.27	39.87	0.330	187.5	5.03	279.6	0.207	6.11
140			25.19	6.53	15.28	39.73	0.330	187.5	5.04	279.6	0.207	6.09
150	24.05	1.24185	25.04	6.56	15.32	39.95	0.332	187.3	4.94	279.4	0.206	6.09
160			24.96	6.48	15.32	39.79	0.324	186.5	4.94	278.3	0.207	6.14
168	24.02	~1.24184	24.17	6.59	15.62	40.52	0.334	187.6	4.96	279.8	0.199	6.15

Upper 1-20m

average	31.24	1.24358	24.67	6.64	15.44	40.15	0.336	186.9	5.04	279.1	0.204	6.04
std dev	0.27	0.00002	0.31	0.02	0.07	0.15	0.001	0.6	0.03	0.8	0.003	0.01
std.dev./avg (%)	0.88	0.00186	1.25	0.28	0.43	0.36	0.2	0.3	0.57	0.3	1.27	0.10

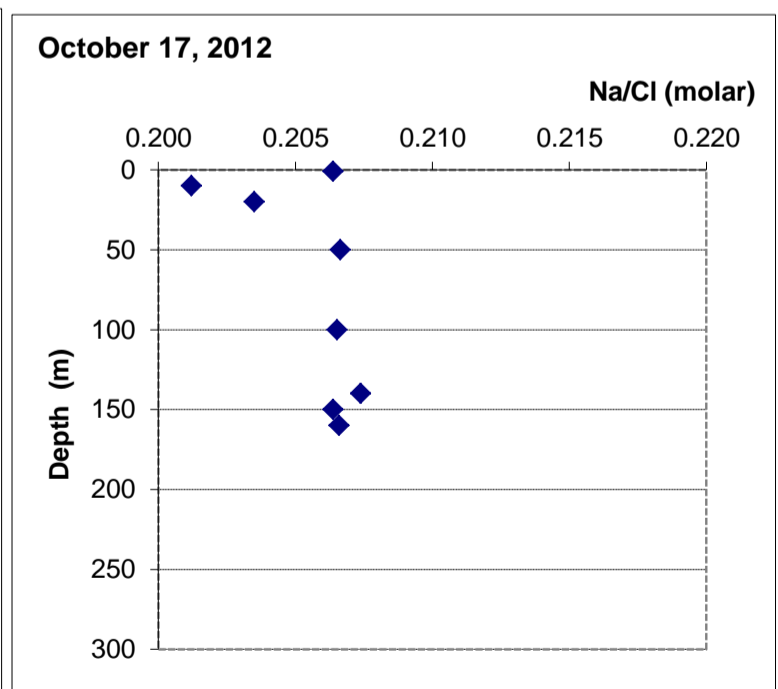
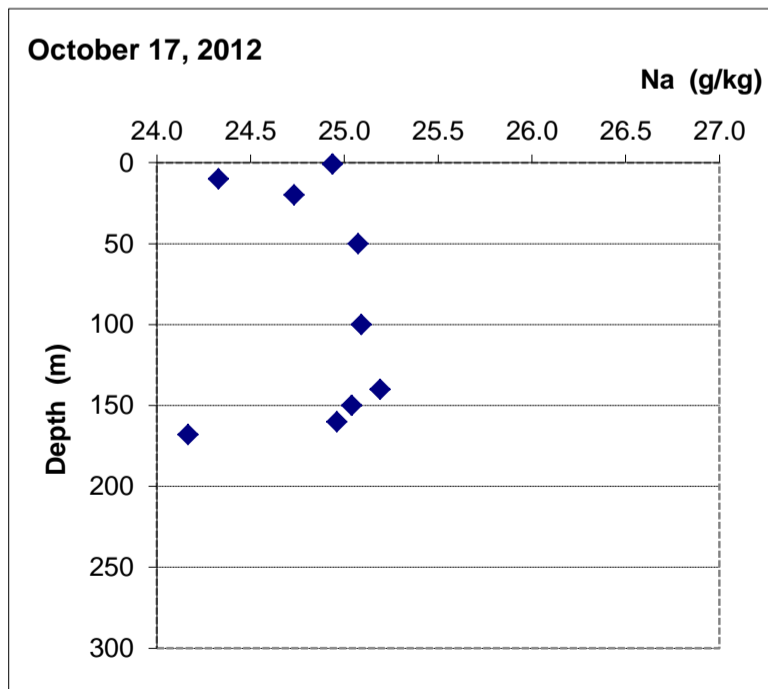
Lower 50-150m

average	24.05	1.24185	25.10	6.55	15.32	39.89	0.329	187.4	4.99	279.6	0.207	6.09
std.dev	0.006	0.00000	0.07	0.03	0.07	0.12	0.00	0.13	0.05	0.10	0.0005	0.01
std.dev./avg (%)	0.024	0.00000	0.26	0.41	0.44	0.30	1.00	0.07	1.04	0.04	0.22	0.22

averages (Upper / Lower) 0.983 1.015 1.008 1.007 1.022 0.997 1.010 0.998 0.985 0.992

Comments

- The chemical composition indicates that there is less Na and slightly less Cl in the upper layer, but somewhat more K, Ca, Mg, Sr and Br. These facts suggest the effect of NaCl precipitation (lees Na) and the effect of evaporation (more K, Ca, Mg, Br) in the upper layer. The Na/Cl ratio is somewhat smaller in the UWM and confirms NaCl removal



Cruise Summary :

December 18, 2012

Station En Gedi 320

Lake level -426.85 m bmsl

Lake volume 127.4 km³

Sampled in weighed centrifuge tubes and kept in upright position

All depths have been sampled in duplicates.

All samples analysed twice, in 2 separate runs

Samples have been first diluted, DS to water 2:1, and then 2ml of first dilution were weighed and diluted to 250 ml.

Salinity does not include Alkalinity and Sulphate which have not been measured

Data below are averages of duplicates from 1st and 2nd run

except Mg, where only 1st run seemed reliable

Depth	Temp in situ	Density 25°C	Na	K	Ca	Mg	Sr	Cl	Br	Salinity	Na / Cl	Mg / K
m	°C	g/cm ³	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	molar	w/w
40	24.559	1.24219	24.48	6.60	15.60	39.6	0.31	186.4	4.8	277.8	0.204	6.00
50	24.55	1.24219	24.68	6.63	15.67	40.5	0.31	186.4	4.9	279.0	0.205	6.11
75	24.55	1.24219	25.09	6.70	15.57	40.45	0.31	186.1	4.9	279.1	0.206	6.04
100	24.56	1.24219	24.58	6.62	15.68	40.35	0.31	186.9	4.9	279.3	0.203	6.09
150	24.585	1.24219	24.72	6.74	15.75	40.9	0.32	186.7	4.9	280.0	0.204	6.06
200	24.603	1.24219	24.50	6.63	15.63	40.15	0.31	186.4	4.9	278.5	0.203	6.05
250	24.6	1.24219	24.59	6.67	15.57	40.2	0.32	185.9	4.9	278.2	0.204	6.03
269	24.6	1.24219	24.66	6.73	15.53	40.35	0.31	186.3	4.9	278.7	0.204	6.00
279	24.61	1.24219	24.54	6.68	15.53	40.25	0.31	186.1	4.8	278.2	0.203	6.03
288	24.626	1.24220	24.60	6.73	15.57	40.15	0.31	186.3	4.8	278.5	0.203	5.97

average

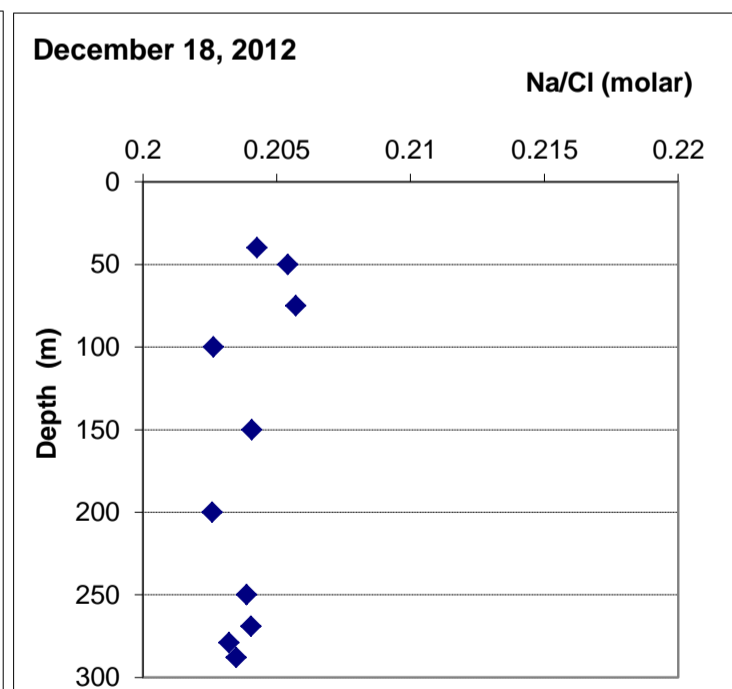
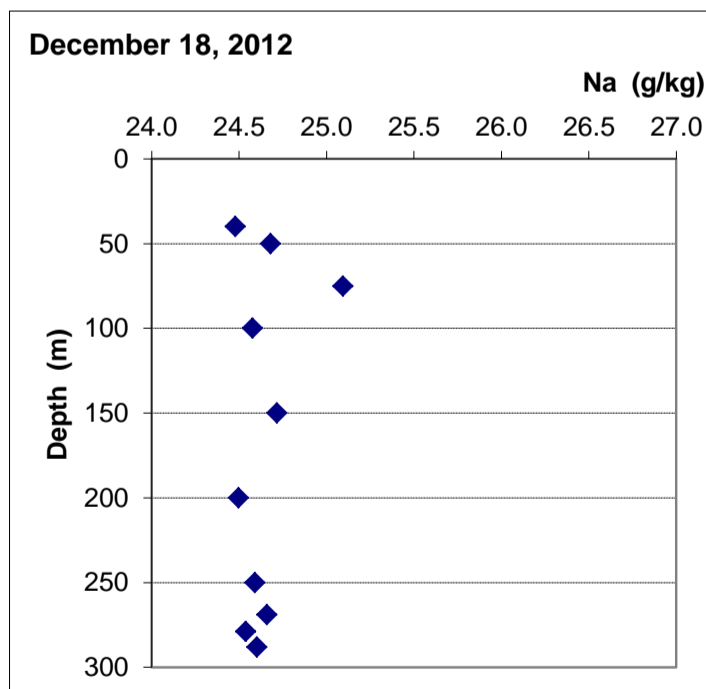
40-288m 24.58 1.24219 24.64 6.67 15.61 40.29 0.31 186.35 4.86 278.74 0.204 6.04

std dev 0.03 0.00000 0.18 0.05 0.07 0.33 0.00 0.29 0.04 0.65 0.001 0.04

std.dev./avg (%) 0.11 0.00 0.71 0.76 0.46 0.82 1.10 0.16 0.76 0.23 0.51 0.73

Comments

- 1 The water column is apparently well mixed: see homogenous temperature and density 25°C data
- 2 For most elements, the standard deviation (%) of the average of all depths is less than 1%, which suggests efficient vertical mixing
- 3 The Na concentration and the Na/Cl ratio are somewhat lower than in Oct 2012 indicating halite formation



Cruise Summary :

February 11, 2013 cruise

Station En Gedi 320

Lake level 426.79 m bmsl

Lake volume 127.4 km³

Sampled in pre-weighed centrifuge tubes, in duplicates, and kept upright. Dilutions on 17.02.2013
 1st run Cl results were very bad. Titrator sent to repair. Cl results in 2nd run, after repair, are good
 Salinity does not include Alkalinity and Sulphate which have not been measured

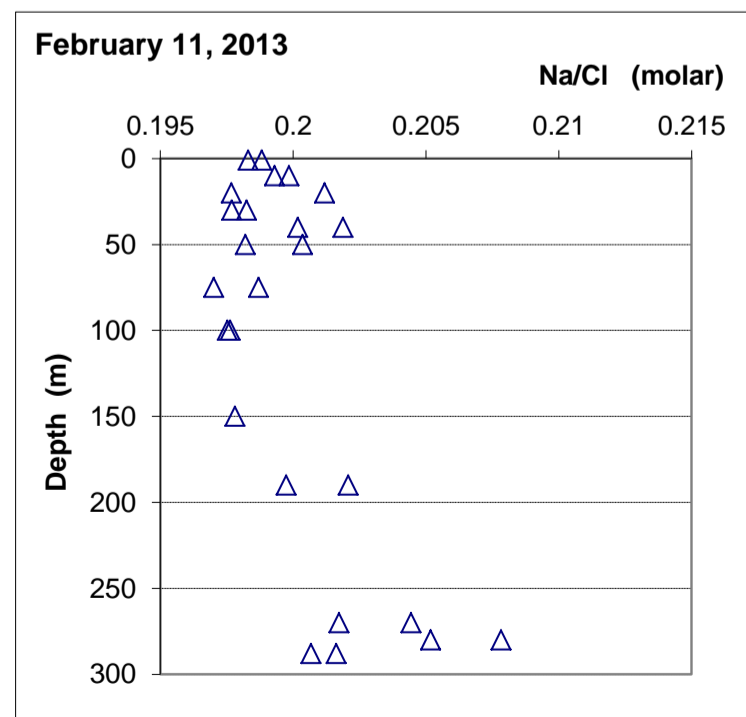
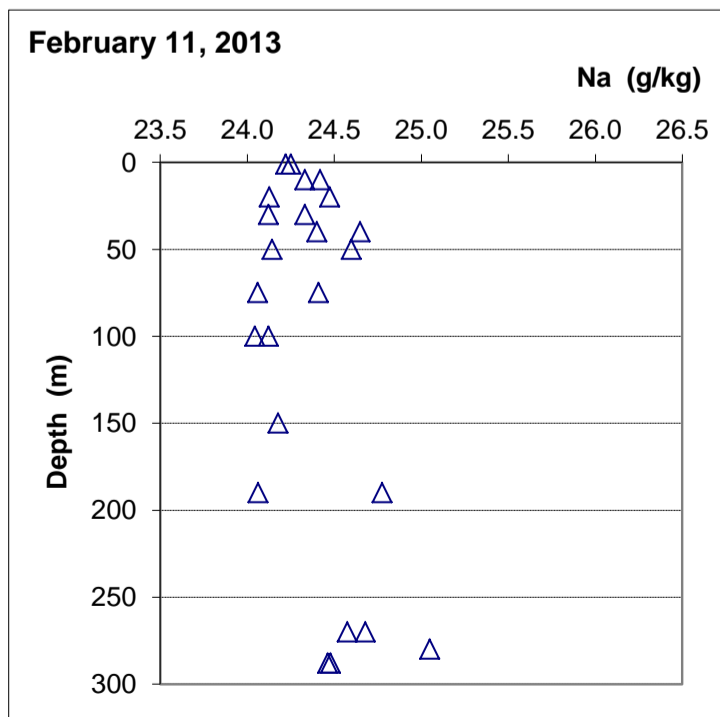
Analyses of duplicates are shown in Figures below. The data in the Table below are averages of duplicates.

Depth m	sample no.	Temp in situ °C	Density 25°C g/cm ³	Na g/kg	K g/kg	Ca g/kg	Mg g/kg	Sr g/kg	Cl g/kg	Br g/kg	Salinity g/kg	Na/Cl molar	Mg/K w/w
1	MS-25,24	23.87	1.24162	24.24	6.70	15.63	40.50	0.287	188.1	4.84	280.32	0.199	6.05
10	MS-23,22	23.34	1.24160	24.38	6.67	15.56	40.35	0.288	188.3	4.96	280.46	0.200	6.05
20	MS-20,21	23.41	1.24167	24.30	6.61	15.33	40.14	0.286	187.8	4.98	279.45	0.199	6.07
30	MS-19,18	23.67	1.24177	24.23	6.68	15.61	40.40	0.282	188.6	4.86	280.68	0.198	6.05
40	MS-17,16	23.71	1.24187	24.52	6.80	15.54	40.47	0.291	188.0	4.92	280.58	0.201	5.95
50	MS-15,14	23.77	1.24191	24.37	6.69	15.53	40.22	0.287	188.5	4.86	280.45	0.199	6.01
75	MS-13,12	23.72	1.24190	24.23	6.81	15.35	40.58	0.282	188.8	5.02	281.07	0.198	5.96
100	MS-11,10	23.75	1.24192	24.08	6.74	15.24	40.51	0.286	187.9	5.05	279.78	0.198	6.01
150	MS-9	23.76	1.24191	24.18	6.44	15.39	40.35	0.283	188.4	5.02	280.40	0.198	5.98
190	MS-8,7	23.75	1.24191	24.42	6.71	15.36	40.36	0.285	187.3	4.99	279.46	0.201	6.01
270	MS-6,5	23.76	1.24191	24.63	6.70	15.21	40.26	0.289	186.9	4.91	278.91	0.203	6.01
280	MS-4,3	23.79	1.24191	25.05	6.80	15.43	40.48	0.282	188.2	4.88	281.10	0.207	5.82
288	MS-2,1	23.8	1.24191	24.47	6.70	15.62	40.75	0.281	187.5	5.09	280.43	0.201	6.09

all depths average													
1-288m	avg.	23.68	1.24183	24.39	6.70	15.45	40.41	0.285	188.0	4.95	280.24	0.200	6.005
1-288m	std dev	0.15	0.00011	0.25	0.10	0.15	0.16	0.003	0.5	0.08	0.65	0.003	0.068
	std.dev./avg (%)	0.65	0.01	1.02	1.43	0.94	0.40	1.13	0.28	1.63	0.2	1.26	1.14

Comments

- 1 According to the density at 25°C data, the water column is not well mixed. The upper 20- 30 m are slightly more diluted Compared to December 2012, the density at 25°C is slightly more diluted in the upper 20-30m and also somewhat diluted in the rest of the water column
- 2 **The average of differences between the duplicates, along the water column are: Na 0.98%, K 0.9%, Ca 0.70%, Mg 0.66%, Sr 2.2%, Cl 0.62%, Br 2.6% Salinity 0.56%. The concentrations given above in the Table are averages between the duplicates.**
- 3 Na and Cl are slightly larger in deepest 270-288m than in the rest of the water column. Also the Na/Cl ratio is slightly larger in this layer. Is it pre-turnover heavier surface water that penetrated to the lake bottom?
- 4 **Na/Cl ratios lower than 0.200 have been attained for the first time in this profile of February 2013**



Cruise Summary :

October 3, 2013

Station En Gedi 320

Lake level -427.57m

Lake volume 126.9 km³

Sampled in centrifuge tubes kept in upright position

Duplicate sampling for each depth (except 30,40 and 75 m)

Dilutions (DS water (2:1); 2ml mix weighed into a volumetric flask of 250ml and submitted to analysis

Dilutions performed on October 10, 2013

Results received on October 16, 2013

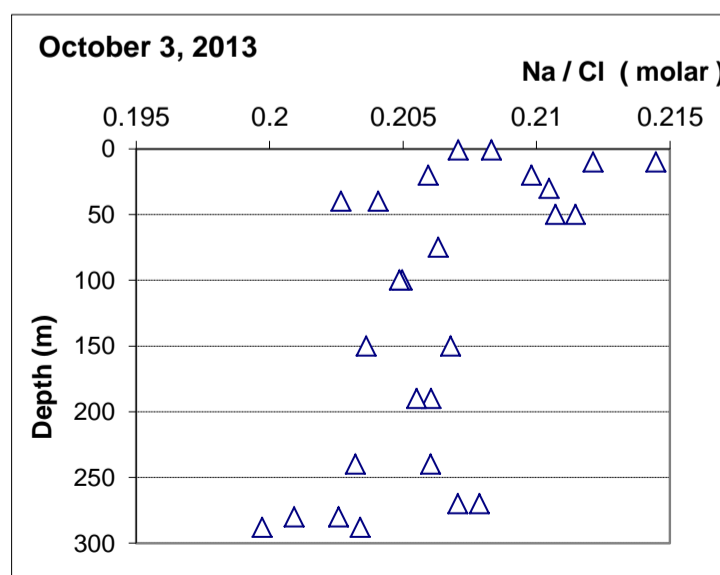
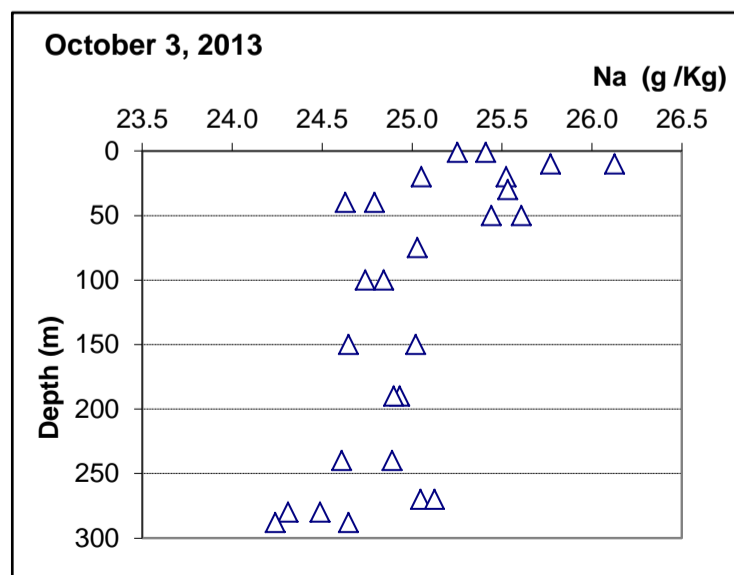
Salinity does not include Alkalinity and Sulphate which have not been measured

Duplicates analyses are shown in Figures below. The data in Table below are averages between duplicates.

Depth	Temp in situ	Density 25°C	Na	K	Ca	Mg	Sr	Cl	Br	Salinity	Na/Cl	Mg/K
m	°C	g/cm ³	g/kg	g/kg	g/kg	g/kg	g/kg	g/Kg	g/kg	g/kg	molar	w/w
1	31.60	1.24400	25.33	6.89	15.6	41.4	0.289	188.0	4.43	282.0	0.208	6.01
10	30.94	1.24392	25.95	7.00	15.7	41.7	0.293	187.5	5.00	283.2	0.213	5.97
20	30.65	1.24388	25.29	6.83	15.5	40.9	0.293	187.5	5.15	281.4	0.208	5.99
30	24.75	1.24242	25.53	6.95	15.5	41.4	0.291	187.0	3.77 ?	280.4	0.210	5.95
40	24.75	1.24243	24.71	6.44	15.0	39.9	0.285	187.3	4.34	277.9	0.203	6.19
50	23.81	1.24242	25.53	6.84	15.5	41.1	0.290	186.3	5.20	280.8	0.211	6.00
75	24.73	1.24241	25.03	6.87	15.7	41.6	0.294	187.0	3.76	280.2	0.206	6.05
100	24.72	1.24241	24.79	6.79	15.5	41.4	0.278	186.5	5.15	280.4	0.205	6.10
150	24.77	1.24240	24.83	6.45	15.2	40.2	0.282	186.5	5.15	278.7	0.205	6.20
190	24.79	1.24239	24.92	6.68	15.2	40.6	0.277	187.0	4.30	279.1	0.205	6.09
239	25.00	1.24253	24.75	6.67	15.3	40.4	0.289	186.4	4.83	278.6	0.205	6.06
269	25.23	1.24270	25.09	6.69	15.6	40.9	0.284	186.4	5.11	280.0	0.207	6.11
279	25.40	1.24280	24.40	6.56	15.4	40.6	0.288	186.4	5.15	278.8	0.202	6.20
289	25.32	1.24286	24.44	6.55	15.7	40.2	0.288	186.9	5.14	279.2	0.202	6.13
average												
1-20m	31.06	1.24393	25.52	6.91	15.59	41.36	0.29	187.66	4.86	282.20	0.210	5.99
std dev	0.49	0.00006	0.37	0.08	0.13	0.42	0.00	0.28	0.38	0.89	0.003	0.02
%	1.6	0.005	1.4	1.2	0.8	1.0	0.8	0.1	7.7	0.3	1.5	0.4
average												
30-239m	24.66	1.24243	25.01	6.71	15.38	40.81	0.29	186.75	4.68	279.51	0.206	6.08
std dev	0.36	0.00004	0.33	0.19	0.23	0.63	0.01	0.35	0.55	1.06	0.003	0.09
%	1.4	0.004	1.3	2.8	1.5	1.5	2.2	0.2	11.8	0.4	1.4	1.4
average												
269-289m	25.32	1.24279	24.64	6.60	15.52	40.57	0.29	186.57	5.14	279.32	0.204	6.15
std dev	0.08	0.00008	0.38	0.08	0.15	0.36	0.00	0.30	0.02	0.60	0.003	0.04
%	0.3	0.007	1.6	1.2	1.0	0.9	0.7	0.2	0.4	0.2	1.6	0.7
avg.1-20m/avg.30-239m			1.02	1.03	1.01	1.01	1.02	1.005	1.04	1.01	1.02	0.985

Comments

- 3 distinct layers shown by Na, Cl and Na/Cl profiles and by temperature and density at 25°C as well: 0-20, 30-240 and 270-289m. All major ions concentrations are larger in upper layer vs. middle layer.
- Na and Cl are higher in the upper 20m. In addition to the effect of evaporation, the also higher Na/Cl molar ratio indicates some dissolution of halite, first perhaps in floods in spring 2013 and then in warm summer brines.
- Na in 0-20m in October 2013 is higher than expected by evaporation enrichment (estimated by the ratio of Mg in upper 20m in Oct 2013 divided by average Mg in upper in Feb 2013 of 1.023). The respective Na ratio is 1.046 and supports evidence for halite dissolution in the upper layer
- Intrusion of end brines is suggested by lower Na and lower Na/Cl in the deepest layer. Somewhat lower K and higher Mg (and higher Mg/K ratio) provide supporting evidence



Cruise Summary :
Station En Gedi 320

February 24, 2014 cruise

Lake level 427.96 m bmsl

Lake volume 126.7 km³

Sampled in duplicates in centrifuge tubes that were kept in upright position

Dilutions, (DS:water, 2:1) and then 2ml weighed and diluted to 250ml, and analyses performed in March 2014

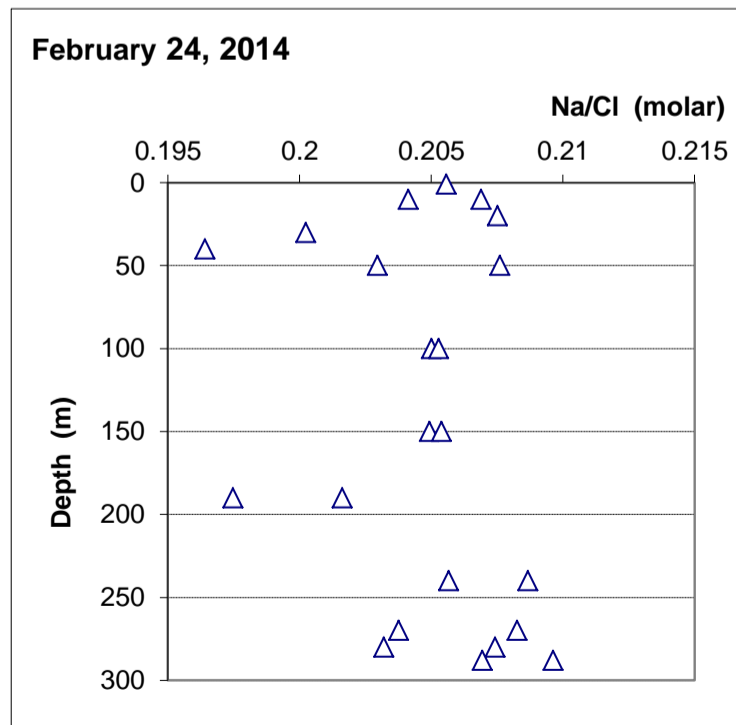
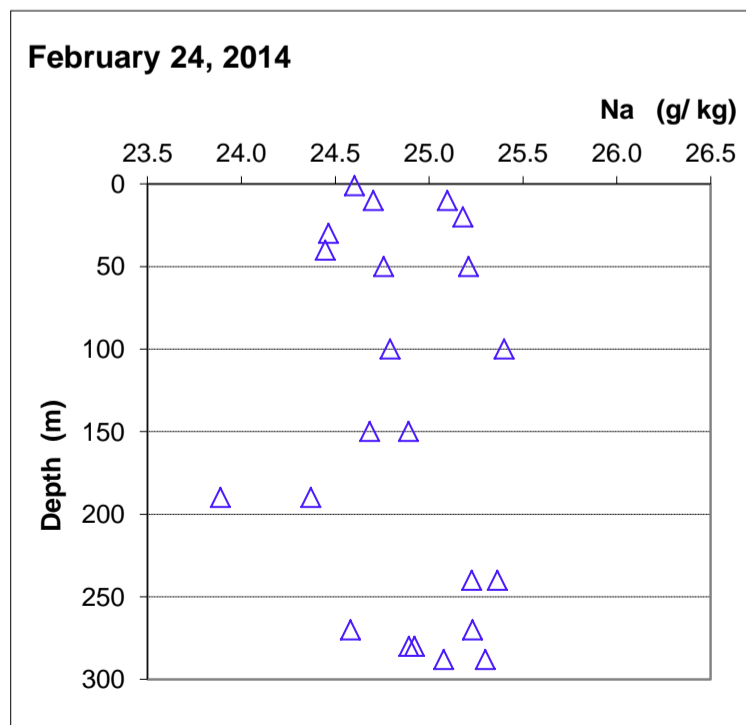
No duplicates sampled for 30m,40m. Duplicate for 1m and 10m were rejected

Depth	Temp	Density	Na	K	Ca	Mg	Sr	Cl	Br	SO4	Salinity	Salinity SO ₄	Na/Cl	Mg/K
m	in situ °C	25°C g/cm ³	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	molar	
1	19.2	1.24249	24.60	6.62	15.53	40.87	0.319	184.5	5.09	0.74	277.5	278.3	0.206	6.18
10	23.87	1.24253	24.90	6.69	15.84	41.23	0.321	186.7	4.95	0.84	280.7	281.5	0.206	6.17
20	23.82	1.24259	25.18	6.79	16.10	41.72	0.324	187.0	5.03	0.75	282.2	282.9	0.208	6.17
30	23.82	1.24259	24.47	6.53	15.63	39.96	0.320	188.3	5.28	0.74	280.5	281.2	0.200	6.12
40	23.82	1.24259	24.45	6.69	15.70	40.66	0.322	191.8	5.15	0.78	284.8	285.6	0.196	6.08
50	23.81	1.24259	24.98	6.66	15.74	41.07	0.320	187.6	5.06	0.86	281.4	282.3	0.205	6.16
100	23.82	1.24259	25.10	6.72	16.06	41.35	0.325	188.6	5.14	0.92	283.3	284.2	0.205	6.15
150	23.88	1.24259	24.79	6.65	15.65	40.83	0.320	186.2	5.08	0.87	279.6	280.4	0.205	6.14
190	23.88	1.24259	24.13	6.47	15.52	39.90	0.314	186.4	5.15	0.76	277.9	278.6	0.200	6.16
240	23.89	1.24259	25.30	6.65	15.96	40.85	0.328	188.2	5.09	0.84	282.4	283.2	0.207	6.15
270	23.88	1.24259	24.91	6.55	15.57	40.31	0.318	186.3	5.17	0.83	279.2	280.0	0.206	6.15
280	23.9	1.24262	24.91	6.71	16.02	41.27	0.321	187.0	5.18	0.79	281.4	282.2	0.205	6.15
288	23.92	1.24261	25.19	6.68	16.09	41.08	0.325	186.4	5.16	0.86	280.9	281.8	0.208	6.15
average														
1- 288m	23.86	1.24258	24.84	6.65	15.80	40.85	0.321	187.2	5.12	0.82	280.8	281.7	0.205	6.15
std. dev.	1.29	0.00003	0.34	0.09	0.22	0.54	0.004	0.87	0.08	0.06	1.55	2.08	0.003	0.03
% std dev	0.16	0.00275	1.38	1.28	1.40	1.31	1.10	0.46	1.61	7.01	0.55	0.74	1.34	0.43

marked red are not included in averages

Comments

- The temperature profile shows the water column is well mixed between 10m and 288m
The cations have large std. dev., more than 1%. Cl has smaller std. dev. than all cations, only 0.5%
- Average Na in Feb 2014 is 24.84±0.34 g/kg; in Feb 2013 it has been lower, 24.39±0.25 g/kg, but still within the respective std.dev.'s. Due to declining lake level since Feb 2013, in Feb 2014 the expected Na is 24.54 g/kg. It seems that, although within the std.dev limits, from Feb 2013 to Feb 2014 there might have been ~ 0.4 g Na added by dissolution.
The larger Na concentration in Feb 2014 than in preceding Feb is a single such occurrence during this survey
- Average Cl in Feb 2014 is 187.2 ± 0.87 g/kg, while in Feb 2013 it has been been 188.0 ± 0.5 g/kg, which is within the respective std.dev.'s
- Na/Cl (0.205) looks higher than in Feb 2013 (0.200) because Na is now higher . Is it real?
- Ca and Mg concentrations are larger in Feb 2014 by about 1-2% than in Feb 2013, in accord with the decrease in volume by about 0.6%



Cruise Summary :

February 9, 2015

Station Ein Gedi 320

Lake Level -428.89 m

Lake volume 126.1 km³

Sampled in centrifuge tubes that were kept in upright position. For 100 m, 200 m and 290 m sampled (and analysed) in triplicates

Samples first diluted DS with DDW (2:1) and then 2ml were withdrawn, weighed and diluted to 250 ml.

Analyses performed in March 2015. Salinity does not include Alkalinity and Sulphate

The % standard deviations (std. dev./average)*100 of the triplicates are shown below

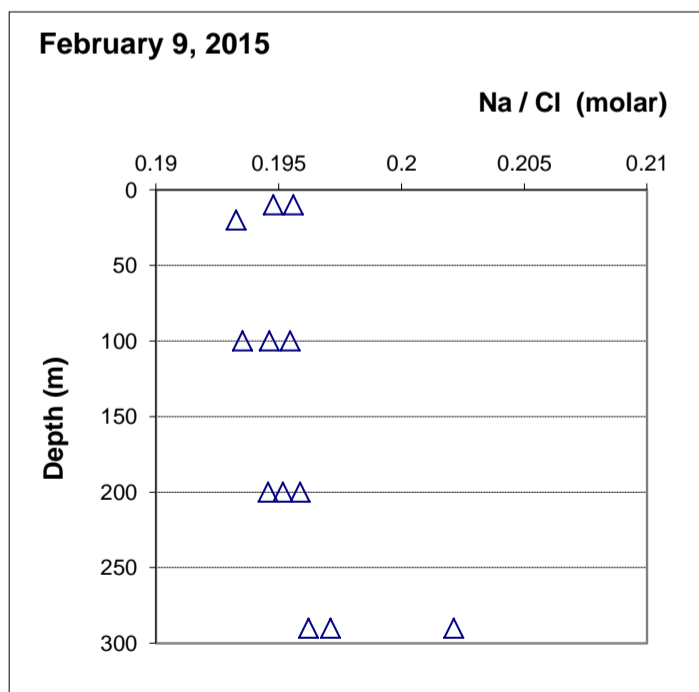
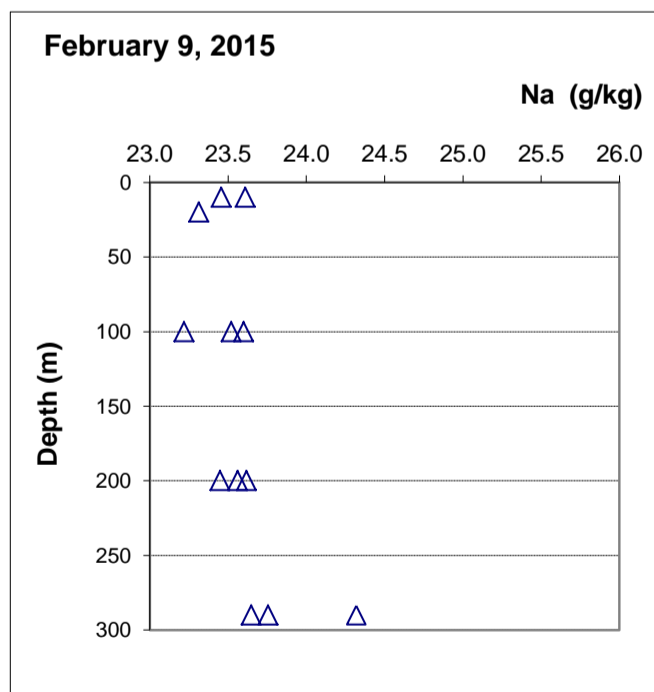
	Na	K	Ca	Mg	Sr	Cl	Br
std. dev (%) at 100 m	0.86	2.12	0.85	1.11	1.91	0.40	0.26
std. dev (%) at 200 m	0.37	0.89	0.06	0.18	1.21	0.09	1.73
std. dev (%) at 290 m	0.32	1.14	1.02	0.28	1.56	0.10	0.82

Average concentrations of each depth

Depth sample no.	Temp in situ °C	Density 25°C g/cm ³	Na g/kg	K g/kg	Ca g/kg	Mg g/kg	Sr g/kg	Cl g/kg	Br g/kg	Salinity g/kg	Na/Cl molar	Mg/K w/w
10 MS1,MS1A	24.1	1.24299	23.53	6.67	15.6	40.9	0.29	185.8	5.14	276.8	0.196	6.13
20 MS2	24.07	1.24298	23.31	6.57	15.4	40.6	0.30	185.9	5.25	277.3	0.193	6.18
100 MS3,MS4,MS5	24.11	1.24299	23.45	6.57	15.5	40.6	0.29	185.8	4.97	276.2	0.194	6.18
200 MS6,MS7,MS8	24.16	1.24299	23.54	6.66	15.5	41.0	0.29	185.9	5.02	278.0	0.195	6.16
290 MS9,MS10,MS11	24.19	1.24299	23.70	6.70	15.7	41.0	0.30	185.6	5.03	278.3	0.198	6.12
average10-290 m	24.13	1.24299	23.51	6.63	15.55	40.82	0.294	185.8	5.08	277.3	0.195	6.15
std dev	0.048	4.5E-06	0.14	0.06	0.10	0.22	0.002	0.11	0.11	0.84	0.002	0.03
% stdev	0.2	0.00036	0.61	0.93	0.61	0.55	0.66	0.06	2.25	0.30	1.01	0.45

Comments

- 1 Temperature and salinity indicate well mixed water column
- 2 About half of the std. dev (%) of the triplicates are less than 1%. The other half is between 1% and 2% (and one outlier with 2,1%). **These numbers represent the precision that can be expected from the analytical data.** The precision of the temperature and salinity data is much better; this can be seen also in averages and std. dev. of the previous February cruises.
- 3 The std. dev. (%) of the average concentration along the water column of all the major ions is less than 1%, with the exception of Br. The water column appears to be well mixed.
- 4 The decrease in Na since Feb 2014 (1.3 g/kg) is too large compared to the decrease in Cl (1.4g/kg)



תקציר

ההרכב הכימי של ים המלח נבדק בין השנים 2005-2015 על 25 פרופילים שנדגמו בתחנה עמוקה (~300 מטר עומק) במרכז האגם. תוצאות הבדיקות מדווחות בסיכומים נפרדים לכל תאריך ופרופיל דיגום. על פי ירידת המפלס ועל פי יחסי נפח-מפלס של האגם, במשך 10 שנות המעקב נפח האגם קטן בפקטור של 0.949. בהתאם לכך, הריכוז של היונים הקונסרבטיביים צפויים לעלות באופן יחסי הפוך להקטנת הנפח, כלומר ב 1.054. פקטור זה אינו לוקח בחשבון ירידת נפח אגם נוספת בתקופה הזאת של בערך 10%, הנובעת מהצטברות הליט על קרקעית האגם. ואכן, פקטור העלייה בריכוז המגנזיום, היסוד העיקרי (major ion) הקונסרבטיבי ביותר בים המלח, גבוה יותר, ועומד על 1.066. ריכוז הסיידן עלה רק בפקטור של 1.057, נמוך מעט בהשוואה למגנזיום ועשוי להיות מוסבר בחלקו על ידי השקיעה המועטה של ארגוניט וגבס מהתמלחת. העלייה בריכוז האשלגן היא רק בפקטור של 1.048 ומעידה על הירידה באוגר של האשלגן באגם כתוצאה מיצור האשלג ע"י התעשיות הכימיות באגן הדרומי. כריית האשלג מהאגם מתבטאת כמובן גם בעליה ביחס המשקלי מגנזיום/לאשלגן. ריכוז הנתרן באגם במשך עשר שנות המעקב אינו עולה עם הקטנת נפח האגם, וריכוזו אף קטן בפקטור של 0.877. הקטנה זו הינה תוצאה של השקיעה המסיבית של הליט על קרקעית ים המלח ובבריכות האידי של התעשייה הכימית. שקיעת ההליט מתבטאת גם בהקטנת היחס המולרי של נתרן לכלור מ-0.228 ל-0.197. השינוי השנתי בריכוז היסודות העיקריים, פרט לנתרן, הוא פחות מ-1%. לכן, בהינתן שהדיוק האנליטי במדידת ריכוז היסודות העיקריים בים המלח אינו טוב מ-1% - 2%, קשה להבחין במגמת השינויים שתוארו מעלה בין שנה לשנה, אלא רק על פני תקופות ארוכות יותר של שנים אחדות. כאמור, יוצא דופן הוא הנתרן בו השינוי השנתי בריכוז הוא הגדול ביותר וניתן לזהות ירידה ממוצעת של כ-1.3% לשנה בריכוזו באגם המעורבב. את השינויים העונתיים במהלך השנה, בהיותם בתוך תחום הדיוק העכשווי של האנליזות, לא ניתן לזהות. על סמך מאזני כלור ונתרן ובהנחה ששקיעת ההליט היא אחידה על פני שטח רצפת האגם, חושב קצב הצטברות הליט של 10.4 ו-12.1 ס"מ לשנה, בהתאמה, לשנים 2005-2015. ערכים אלו דומים מאד להערכות של קצבי הצטברות הליט שנעשו לתקופות קודמות, מאז שנות ה-1980.