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# OCEANOGRAPHY OF THE CILICIAN BASIN

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## ABSTRACT

*Physical Oceanography:* The Levantine basin circulation, described by a new synthesis (Özsoy et al., 1989; 1991; 1993; Robinson et al., 1991; 1992; Sur et al., 1993) based on recently collected data, consists of a series of dynamically interacting sub-basin scale eddies (the Rhodes cyclonic, Mersa Matruh anticyclonic and Shikmona anticyclonic gyres) and embedded coherent structures (the Anaximander, Antalya, Cilician and southwest Cretan anticyclonic eddies) fed by bifurcating jet flows (the Central Levantine Basin Current and Asia Minor Current, AMC). The cyclonic Rhodes Gyre(RG) is a permanent member of the Levantine basin circulation, with a cold dome hydrographic structure (Özsoy et al., 1989; 1991; 1993; Tziperman and Malanotte-Rizzoli, 1991). The main water types (Hecht et al., 1988; Özsoy et al., 1989) seasonally maintained in the circulation system are the Levantine Surface Water (LSW), identified with the mixed layer during stratification seasons, the Atlantic Water (AW) reaching the Levantine basin from its origin in the Atlantic Ocean, the Levantine Intermediate Water (LIW), which is locally produced in the northern Levantine basin and the Levantine Deep Water (LDW). Recently, wintertime deep water formation and convective overturning have been shown to occur in the RG (Gertman et al., 1990; Sur et al., 1993).

In general, small scale anticyclonic eddies are observed and the Asia Minor Current (AMC) is the most prominent dynamical feature in the Cilician basin. There appears distinctly different water masses in the upper 1000m throughout the year as definitely characterized by Hecht et al., (1988) and; Özsoy et al., (1989). The surface layer is occupied by more saline (S=39.4-39.8 ppt) and warmer (Pot. T= 26-28 °C) waters than the RG (S=39.2-39.4 ppt, Pot.T=22-24 °C) during summer and autumn. The surface layer is separated from the less saline Atlantic origin waters by a seasonal halocline. The occurrence of salty and warm surface waters in the Levantine basin is the result of the high rate of evaporation much exceeding fresh water input to the system (Özsoy et al., 1989). The relatively cool and less saline surface waters observed in the core of the Rhodes cylonic eddy is the result of doming, mixing and even overturning of the LDW which may reach as far as the surface layer and this region therefore constitutes a unique system within the entire Levantine basin. Cooling of the surface layer allows the disappearance of both the thermohaline feature and the signature of the Atlantic waters during late autumn. The less saline waters of Atlantic origin top a more saline and warmer (characterized by S=39.1 ppt and Pot. T=15.5 °C) intermediate layer, the so-called the

Levantine Intermediate Water (LIW). It has been suggested (Özsoy et al., 1989; 1991;1992; Brenner et al., 1991) that LIW is formed locally in the RG in the northern Levantine basin during storm events in cold winter months and spreads along its peripheries and sinks down to 300-700m in the anticyclonic areas. The less saline deep waters are separated from the LIW layer by a permanent halocline in the anticyclonic eddies. The thickness of the halocline changed from summer to winter, depending on the magnitude and duration of deep convective mixing in winter; for example halocline became as thin as 50m in the severe winter of 1992. Deep winter mixing in 1992 also modified the hydrographic properties of the entire water column extending down to at least 800m in the Cilician anticyclonic region. The surface layer became less saline when the LIW mixed with the surface layer and the temperature and salinity remained almost constant (S=39.1-39.2ppt and Pot. T=15.7 °C) down to 600-700m. The lower parts of this mixed layer possessed more saline and warmer waters with respect to waters of almost the same depths during other winters and during summer-autumn periods. In other words, the convective winter mixing influenced the LDW through the permanent halocline in the Cilician anticyclonic eddy in the 1992 winter. Below such depths (600-700m) the LDW possessed its characteristic temperature, salinity and densities throughout the whole basin and for all other years excluding the Rhodes chimney for 1992 and 1993.

***Chemical Oceanography:*** The nutrient regime of the eastern Mediterranean has been studied extensively in recent years (Krom et al.,1991a; 1991b; 1992; 1993; Salihoğlu et al., 1990; Yılmaz et al.,1994; Yılmaz and Tuğrul, 1997). Phytoplankton production (PP) dominated by the input from the lower layers especially by wintertime vertical mixing in the basin (Krom et al., 1992; Ediger and Yılmaz, 1996). The phytoplankton biomass and PP are relatively higher in the cyclonic regions where the nutricline ascends to the base of the euphotic zone (Salihoğlu et al., 1990; Yılmaz et al.,1994; Ediger and Yılmaz, 1997). In the anticyclonic regions, such as in the Cilician basin, the nutricline is situated at greater depths (as deep as 400-500m) (Salihoğlu et al., 1990; Yılmaz et al.,1994), limiting the nutrient input to the surface waters during winter mixing. Limited winter data have revealed that sub-basin scale deep convective mixing processes are observed in severe winters, signinificantly altering the hydrochemical properties of the upper water column from the surface down to at least 1000m. Thus, the surface layer of the entire cyclonic Rhodes Gyre (RG) was occupied by the relatively nutrient-rich Levantine Deep Waters (LDW) under the prolonged unfavorable winter conditions observed in 1987 (Gertman et al., 1990), 1992 (Sur et al.,1993) and 1993. However, in the anticyclonic eddies, such as in the Cilician Basin, the nutrient supply from the lower layer to the upper productive waters (the euphotic zone) by convective vertical mixing is relatively limited due to the establishment of a permanent nutricline much below the euphotic zone, as deep as 400-500m, though it shallows at peripheral regions (Salihoglu et al.,1990; Krom et al., 1991a; 1992; 1993; Yılmaz et al.,1994; Ediger and Yılmaz, 1997). In the seasons of stratification, a nutrient-poor aphotic layer is formed between the euphotic zone and the nutricline; interestingly, it consistently extends down to depths of about 29.0-29.05 isopycnal surfaces, but nearly vanishes in the core of the cyclonic Rhodes Gyre (RG) due to the upwelling of the Levantine Deep Water (LDW) up to the base of the euphotic zone. Accordingly, the nutricline is much sharper and shallower in the cyclonic RG; nevertheless, it is consistently established between the density surfaces of 29.00-29.05 and 29.15 throughout the basin. In the severe winters of 1992 and 1993, the upper 1000m of the cyclonic Rhodes Gyre was occupied by the LDW with its associated chemical properties and abnormally high nutrient concentrations ($NO_3$=3.8-4.7 µM; $PO_4$=0.14-0.16 µM and Si=7.3-7.8 µM) were observed in the euphotic zone. However, the surface nutrient concentrations of the anticyclonic regions were raised merely from the summer-autumn values of <0.02 and nearly 0.2

μM to about 0.03 and 0.8 μM for phosphate and nitrate, respectively. The molar ratios of nitrate to phosphate in the water column range between 5-20 in the euphotic zone but exhibit well-defined peak values (as large as 40-120) at the top of the nutricline (corresponding to nearly depths of the 29.05 isopycnal surfaces) for most of the year. Such prominent maxima are the result of the apparent shift between the onsets of the nitracline and phosphacline due to as yet undefined factors. Below the nutricline the N/P ratios decrease regularly and reach an almost constant deep value (=28) over the basin. The mean ratio, derived from linear regression of the pooled phosphate and nitrate data from March 1991 to March 1994 is about 23.6, substantially higher than deep ocean values. In the Mediterranean deep waters, molar ratios of nitrate to phosphate are anomalously high and range from 22.5 in the western basin (Coste et al., 1984) to 28 in the eastern Mediterranean deep waters (Krom et al., 1991a; Yılmaz and Tuğrul, 1997). This process is suggested to lead to the export of biogenic particles with anomalously high N/P ratios from the surface waters in the western basin (Bethoux and Copin-Montegut,1988; Bethoux, 1989). However, the low N/P ratios of sestons from the productive upper layer of the Eastern Mediterranean (Abdel-Moati,1990; Ediger, 1995) do not corroborate this suggestion.

**The Anticyclonic Cilician Basin:** Nutrient concentrations of the surface waters were very low during summer and autumn in the Cilician basin where, in general, anticyclonic eddies and AMC are observed. The surface values rose slightly due to input from the lower layers by deep convective mixing which actually affected the whole Levantine basin during the cold winter of 1992 (Sur et al., 1993). The nitrate concentration increased from ~0.2 μM (summer-autumn surface concentration level) to 0.8 μM during March 1992 while it increased only to 0.4-0.6 μM during mild winters of March 1991 and March 1994. However, the seasonal changes in phosphate concentration were less pronounced than the changes in nitrate, due to the inefficiency of the analytical method at concentrations below 0.02 μM. In other words, the winter phosphate content of the Levantine surface waters are very close to the detection limit of the method (0.02 μM). Similarly, increases in the silicate content of the surface layer during mild winters were less pronounced than those which appeared in the nitrate data; the average concentrations varied insignificantly (from 1.3-1.5 μM in July-October to levels of 1.5-1.7 μM in mild winters of 1991 and 1994).

Throughout the year, the aphotic layer extending from the base of the euphotic zone down to the top of the main nutricline established within the LIW layer was also relatively poor in dissolved nutrients. This layer is termed the "Nutrient Deficient Aphotic Layer" (NDAL) and it coincides with the LIW layer. A seasonal nutricline separated the productive surface waters from the NDAL or nutrient-poor LIW layer which, vertically, is almost isohaline and isothermal during the stratification seasons. The nutrient concentrations in NDAL change little with depth but seasonal and interannual changes are quite significant depending upon the intensity of winter mixing determined by the climatology and the related hydrodynamical regime of the Levantine basin. For example, during the severe winter of 1992 and the summer 1993 (following the 1993 severe winter), the NDAL was apparently enriched with inorganic nutrients, relative to its content for example in October 1991, due to input from the lower layers through the nutricline. During this period, the thickness of the LIW and NDAL also increased markedly and was observed to enlarge down to 600-700m. When the saltier surface waters were mixed throughly with the LIW by winter convective mixing, a net export of nutrients occurred from the LIW to the productive surface layer. In other words, the euphotic zone and NDAL mixed with each other and a homogeneous water column formed down to the main nutricline. The winter mixing provided a small increase in the salinity but some decrease in the nutrient content of the LIW layer. The LIW layer is stagnant during the stratification seasons (starting from late spring to late autumn) and it receives a net input of labile particulate nutrient from the productive surface. During this period, the inorganic nutrient content of LIW is expected to increase slightly. For instance, the nitrate concentrations of the LIW or the NDAL were observed to vary seasonlly from 0.5-1.0 µM (in March 1991 and March 1994) to 1.0-1.5 µM in October 1991 and up to 3 µM in July 1993. The seasonal nutricline (especially the nitracline) was very pronounced in July, 1993 due to marked increases in the nitrate content of the LIW by the input from the LDW via the main nutricline during the severe winter of 1993. Similarly, the phosphate concentration of this layer showed seasonal changes (e.g. from 0.02-0.03 µM up to 0.1 µM). However, the seasonal change in the silicate content of the LIW was less pronounced (e.g. from 1.5µM to 3.5 µM). This may have resulted from the smaller decay of silicious biogenic materials than of nitrogeneous biogenic compounds oxidized in the LIW layer during the late-spring - late-autumn period. Comparable seasonalities were also observed in LIW situated in the core of a permanent anticyclone in the southern Levantine Sea (Krom et al., 1992).

The main nutricline is established just below the LIW layer, coinciding with the permanent halocline formed within the LIW-LDW interface. The thickness and the depths of the nutricline boundaries vary with season, depending on the duration and intensity of winter mixing in the basin. The nutricline weakens and deepens under severe winter conditions due to greater chemical input from the LDW to the LIW as occured in March 1992. The main nutricline appeared at shallower depths (200-250 m) in the less severe winters of 1991 and 1994, deepened to 500-600m in March, 1992 and July, 1993, in parallel to the deepening of LIW layers during these periods. In the LDW, below the quasi-permanent nutricline, nitrate and phosphate concentrations remained almost constant with depth (down to at least 1000m), whereas silicate profiles still displayed a gradual increase with depth. The average LDW concentrations were determined as 0.2 µM for phosphate, 5.5 µM for nitrate and 9.7 µM for silicate, which are very consistent with those reported for the southeastern Mediterranean deep waters (Dowidar,1984; Krom *et al.*, 1991a; 1991b; 1992; 1993). The phosphate and nitrate concentrations appeared to be markedly less than the concentrations ($PO_4$=0.38µM; $NO_3+NO_2$= 7.6µM ) reported for the western Mediterranean deep waters but silicate concentrations are at comparable levels (Mc Gill,1965; Delmas and Treguer, 1984; Bethoux et al.,1992). And they all much lower than those found typically at similar depths in other oceans (Weiss et al., 1983).

***Basinwide Vertical Distributions:*** The chemical properties of the upper water column (the top 1000m) in the Levantine Sea appeared to exhibit distinctly different vertical features in the cyclonic and anticyclonic eddies. The scale of spatial and temporal changes in the thickness of both LIW (NDAL) and the main nutricline as well as the LDW-LIW interface are principally determined by changes in the hydrophysical forces and hydrological features of the Levantine basin. Based on the close correlations observed between the chemical and hydrographic features, all the basin-wide nutrient data (obtained in the upper 1000 m) have been examined with respect to temperature, salinity and water density (sigma-theta) irrespective of sampling locations. The composite profiles produced from the combined data sets provides to define not only the boundaries of the hydrochemically different water masses but also the ranges of the nutrient concentrations in the physically similar or different water masses over the Levantine basin. For instance, the very low nutrient concentrations appearing in the upper nutricline represent data from the less saline Atlantic waters topping the more saline LIW during the stratification seasons.

The density-dependent nutrient profiles clearly show that the nutrient-poor upper layer (euphotic zone plus NDAL) extends consistently down to the depths of the 29.00-29.05 density surfaces, independent of region and the time of year. Salinities and temperatures at the base of this layer were in the range of 15.5-16.0 °C and 39.1-39.2 ppt over the entire Levantine basin. The phosphate gradient zone appears at isopycnal surfaces nearly 0.05 density units greater than the nitracline (and silicacline). This apparent shift between the nitracline and phosphacline onsets may have resulted either from selective accumulation of labile nitrogen or from selective removal of reactive phosphate at the base of the quasi-permanent pycnocline. Heterotrophic and chemosynthetic activities in the lower pycnocline may contribute to the selective accumulation of labile dissolved organic nitrogen which eventually oxidized to nitrate and may have caused high nitrate concentrations relative to phosphate.

The nutrient gradient zone (the nutricline) extends down to the first appearance of the 29.15 density surface which defines the upper boundary of LDW throughout the entire Levantine basin (Özsoy et al., 1989; 1991). At the base of the main nutricline, LDW has a salinity of 38.7 ppt and a temperature of 13.8 °C. The main nutricline is a permanent feature of the anticyclonic eddy and is always much below the euphotic zone; though it appears quasi-permanently at the lower boundary of the euphotic zone in the cyclonic Rhodes Gyre. When LDW reaches as far as the surface in severe winters (such as occurred in 1992 and 1993), the nutricline decomposes and a homogeneous water column forms.

***N/P Ratios:*** The molar ratios of nitrate to phosphate (N/P) in the water column of the Levantine basin vary substantially with depth. In the euphotic zone, the ratio generally ranged between 5 and 20. It should be noted here that the lower ratios for the euphotic zone were mostly obtained by assuming phosphate concentrations of about 0.02 μM, whenever the samples contained nearly undetectable phosphate values with the present analytical method (<0.02 μM). Therefore, the low ratios derived from such low phosphate data were probably underestimates for the stratification seasons. When the surface waters were enriched with nutrients by input from the lower layer during severe winters of 1992 and 1993; the phosphate concentrations exceeded the detection limit (>0.02 μM), leading to reliable and relatively high N/P ratios of 25-30.

Below the euphotic zone, the ratios exhibited anomalously high values (N/P=40-120) at the top of the nutricline during mild winters and stratification seasons. The peak ratios originated from the apparent shift between the onsets of the nitracline and phosphacline depths. In addition, they were situated at much shallower depths (50-100m) in the Rhodes cyclonic region than in the core of the anticyclonic eddies (150-300m). In the cores of the Mersa Matruh and Shikmona anticyclonic eddies, the N/P peak was observed to remain at 500-600m during October 1991. Interestingly, the N/P maxima consistently appeared at specific salinity and density surfaces of nearly 39.1ppt and 29.05, respectively. The ratios then decreased steadily at the LIW-LDW interface down to the specific density surface ($\sigma_t$ = 29.15). Below this surface or in the LDW, the basin-wide average of the N/P ratios remained almost constant and ranged merely between 27.0 and 28.5.

Similar anomalous peak ratios were reported by Krom et al., (1992) for the southern Levantine basin; they attributed these maxima to the preferential uptake of reactive phosphate by planktonic species. As was emphasized above, though the maximum ratios appear at markedly different depths (from 50 m to 600m ) regionally, they were always situated at the 29.05 isopycnal surface. This finding weakens the suggestion of preferential uptake of phosphate by photosynthesis because there is no light at such depths for photosynthetic production in anticyclonic regions. Instead, it suggests a selective nitrogen accumulation by heterotrophic or chemosynthetic activities which might be intensified within the indicated density range. This phenomenon needs further investigation.

In the LDW, the ratios were in the range of 27.0-28.5, higher than the N/P ratios (between 10-18) determined in the particulate matter (PM) from the surface waters of the northern Levantine basin for the same period (Ediger, 1995). They were much higher than the ratios in the deep oceans, e.g. N/P=15.2 for N.Atlantic deep waters (Bainbridge, 1981) but similar to ratios (N/P=28.1) which were reported for the southern Levantine basin (Krom et al., 1991a). This finding strongly suggests that the higher N/P ratios obtained in the deep waters of the Levantine basin have originated from as yet undefined factors but not from the decay of biogenic PM exported from the surface. Negative preformed values of phopshate derived from the dissolved oxygen-phosphate regressions (Krom et al., 1991b) indicate the oxidation of nitrogen-rich organic matter (both in particulate and dissolved forms) in the entire water column of the LDW. These findings suggest that the principal factor determining the high N/P ratios measured in LDW may originate from the anomalously high N/P ratios of labile nutrients in the upper layer which sink to deeper layers. Confirmation of this requires examination of the principal chemical properties of LDW at the source point.

Mean molar N/P ratios, estimated from the slope of the linear regression analysis of nutrient data from LIW depths to the upper LDW depths, were about 23.6 for the period of 1991-1994. This value was found to be very similar to the value given for the southern Levantine basin (=22.9) (Krom et al., 1991a) and higher than the N/P ratio (=19.1) for the western Mediterranean (Coste et al., 1984) and the one (=14.5) for the north Atlantic deep waters (Bainbridge, 1981). The anamolously high N/P ratio observed in the LDW suggest that the input from the deep layer may result a phosphorus-limited primary production in the Levantine basin.

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