Relation between ^{234}Th scavenging and zooplankton biomass in Mediterranean surface waters

^{234}Th
Zooplankton
Scavenging
Particle flux

^{234}Th
Zooplancton
Exportation
Flux de particules

Sabine SCHMIDT [a], **Paul NIVAL** [b], **Jean-Louis REYSS** [a], **Mohamed BAKER** [b] **and Patrick BUAT-MENARD** [a]

[a] Centre des Faibles Radioactivités, Laboratoire Mixte CNRS-CEA, B.P. 1, avenue de la Terrasse, 91198 Gif-sur-Yvette Cedex, France.

[b] Station Zoologique, Observatoire Océanologique, B. P. 28, 06230 Villefranche-sur-Mer, France.

Received 16/09/91, in revised form 6/01/92, accepted 13/01/92.

ABSTRACT

Dissolved and particulate ^{234}Th activities were determined and phyto- and zooplankton biomass were periodically measured 8 miles off Nice (Mediterranean Sea) during spring 1987. The results show a strong variability of ^{234}Th distribution on short time scales in northwestern Mediterranean surface waters. The good correlation observed between the zooplankton biomass and the rate of ^{234}Th export to deep water in particulate form is in agreement with the assumption that the residence time of particulate ^{234}Th in oceanic surface waters is controlled by zooplankton grazing. Moreover, our results indicate the importance of salps in particular as efficient removers of small suspended particles in surface waters.

Oceanologica Acta, 1992. **15**, 2, 227-231.

RÉSUMÉ

Relation entre l'exportation du ^{234}Th et la biomasse du zooplancton dans les eaux superficielles méditerranéennes

Au cours du printemps 1987, les activités du ^{234}Th dissous et particulaire des eaux de surface ont été déterminées pour la station située à 8 milles au large de Nice. A cette même période, la biomasse du phyto- et du zooplancton a été mesurée périodiquement. Les résultats montrent une forte variation de la distribution du ^{234}Th sur de courtes échelles de temps. La corrélation observée entre la biomasse zooplanctonique et l'exportation du ^{234}Th particulaire vers les couches profondes est en accord avec l'hypothèse que le temps de résidence du ^{234}Th dans la couche de surface est contrôlé par l'activité de broutage du zooplancton. De plus, nos résultats mettent en évidence l'efficacité des salpes à épurer les particules en suspension dans la couche superficielle.

Oceanologica Acta, 1992. **15**, 2, 227-231.

INTRODUCTION

During the past thirty years, numerous studies have demonstrated that several members of the natural radioactive decay series can serve as powerful tools for understanding how adsorption on to solid surfaces (referred to as scavenging) controls dissolved oceanic concentrations and distributions of many trace metals and pollutants (Bhat *et al.*, 1969 ; Bacon and Anderson, 1982 ; Coale and Bruland, 1985). The ability to determine rates of such oceanic processes from radionuclide activity measurements is due to the existence of disequilibrium within the decay series generated by the preferential scavenging of daughters while dissolved progenitors are nearly constant.

For the study of scavenging in surface waters ^{234}Th, produced in the dissolved phase by ^{238}U, is extensively used because its half-life of 24.1 days is appropriate for assessing spatial and temporal variations in scavenging rates (Buesseler, 1989). In sea water, ^{234}Th reacts with particles and exists in three phases (Fig. 1) : dissolved, small particles (detritus, planktonic organisms) and large particles which present high settling velocity (large organic aggregates, fecal pellets, large planktonic organisms; Fowler and Knauer, 1986). In oceanic surface waters, biological activity is the most important source of particles and can vary considerably on short time scales. Previous studies have shown the close coupling between dissolved ^{234}Th scavenging and new production in the ocean (Coale and Bruland, 1985). It appears in general that the activities of dissolved ^{234}Th are inversely related to the flux of particulate organic matter (Coale and Bruland, 1987). It was also shown that the particulate ^{234}Th residence time in oceanic surface waters is of the order of a few days to a few weeks and appears to be governed by the rate of zooplankton grazing.

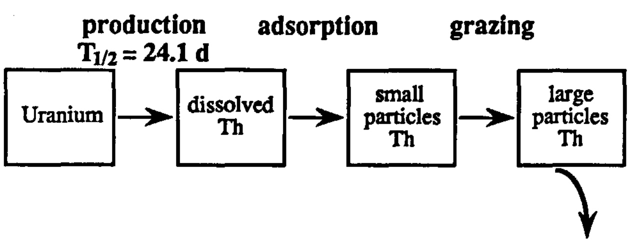

Figure 1

Representation of the ^{234}Th distribution in surface waters including production from ^{238}U, dissolved reservoir, fine (suspended) and large (settling) particles.

Partition du ^{234}Th dans les eaux de surface, une fois sa production à partir de ^{238}U, entre la phase dissoute, les petites et les grandes particules.

As part of the Dyfamed programme (France-JGOFS), a record of ^{234}Th fluxes in the water column has been obtained with sediment traps moored in the Mediterranean Sea near Corsica. The highest fluxes are observed during late winter and early spring, when primary production increases in these waters. We have shown the existence of a strong relationship between particulate ^{234}Th and fecal pellet fluxes during spring 1986 and 1987 in the trap sediments (Schmidt *et al.*, 1990). The purpose of this present investigation is better to define the dependence of the ^{234}Th deficit in surface waters with the amount of zooplankton biomass present.

SAMPLING AND ANALYTICAL METHODS

All the samples were collected between March and May, 1987, during different cruises, 8 miles off Nice (43°35'N-7°29'E) in 2,000 m water depth. For ^{234}Th determination, 30 l of seawater were passed through a Millipore membrane filter (0.45 µm pore size) to separate particulate from dissolved fractions. The chemical treatment of dissolved samples has been previously described (Buat-Ménard *et al.*, 1988). Both dissolved and particulate ^{234}Th activities were determined by γ-counting with a low back-ground well-type Germanium detector.

Planktonic organisms were collected with plankton nets (Omori net: horizontal hauls at 200, 100 and 0 m, mesh size 680 µm - "Triple net": three coupled nets used for vertical hauls 200-0 m, mesh size 500, 200, 50 µm). Plankton counting was carried out at the Station Zoologique, Villefranche-sur-Mer. Zooplankton biomass was estimated as described by Baker (1990). Counts were converted to dry weight using the appropriate factor for each taxonomic group from the literature or from measurements (Baker, 1990). The assumption of a C/dry weight ratio of 0.4 is used to estimate zooplankton biomass in carbon units.

RESULTS AND DISCUSSION

Particulate and dissolved ^{234}Th distribution in surface waters

The dissolved and particulate ^{234}Th activities on March 17 and May 14, 1987 are presented in Table 1. The measured ^{238}U activities are nearly constant *versus* depth with a mean value of 2.90 ± 0.10 dpm l^{-1} (Schmidt and Reyss,

Table 1

Depth, activities of particulate (Th^P) dissolved (Th^D) and total (Th^Σ) ^{234}Th, $^{234}Th/^{238}U$ activity ratio (Th/U), dissolved (τ_D) and particulate (τ_P) residence time.

Profondeur, activités du ^{234}Th particulaire (Th^P), dissous (Th^D) et total (Th^Σ), rapport $^{234}Th/^{238}U$ (Th/U), temps de résidence sous forme dissoute (τ_D) et particulaire (τ_P).

Depth (m)	Th^P dpm l^{-1}	Th^D dpm l^{-1}	Th^P/U	Th^D/U	Th^Σ/U	τ_D days	τ_P days
March 17							
10	1.06 ± 0.17	1.84 ± 0.19	0.37 ± 0.06	0.63 ± 0.07	1.00 ± 0.09		
200	0.88 ± 0.09	2.17 ± 0.24	0.30 ± 0.03	0.75 ± 0.09	1.05 ± 0.08		
May 14							
10	0.61 ± 0.16	1.41 ± 0.12	0.21 ± 0.06	0.49 ± 0.04	0.70 ± 0.07	33 ± 4	24 ± 7
200	0.75 ± 0.23	2.17 ± 0.08	0.26 ± 0.08	0.75 ± 0.04	1.01 ± 0.09		

Table 2

Biomass of phytoplankton (mgChl a m^{-2}) and zooplankton: total zooplankton, salps and siphonophores (mg dry weight m^{-2}) between surface and 200 m depth during spring 1987. The coefficient of variation is indicated in brackets.

Biomasse de phyto- (mgChl *a* m^{-2}) et de zooplancton (total, salpes et siphonophores, mg poids sec m^{-2}) dans la couche 0-200 m, printemps 1987. Le coefficient de variation est indiqué entre parenthèses.

Date	Chl *a*	Zooplankton	Salps	Siphonophores
March, 17	78.0	1297.4 (23.5%)	14.6 (76%)	140 (23.5%)
May, 14	24.5	8456.4 (23.5%)	2468 (28%)	3534 (23.5%)

1991). At 200 m depth, total ^{234}Th is always in close equilibrium with its parent. In contrast, ^{234}Th activities at 10 m depth differ strongly between the two sampling periods. On March 17, total ^{234}Th (Th^{Σ}) is in equilibrium with ^{238}U [$Th^{\Sigma}/U = 1.00 \pm 0.09$] which means that for this period there is no significant export of thorium to deep waters. On the other hand, a 30 % deficit relative to ^{238}U occurred on May 14. These data suggest that during the second period the export of ^{234}Th out of the surface layer was more rapid than its production from ^{238}U. The residence times are calculated with the scavenging model previously described by Coale and Bruland (1985) : $\tau_d = Th^d / [\lambda*(U - Th^d)]$ and $\tau_p = Th^p / [\lambda*(U - Th^{\Sigma})]$, with λ the ^{234}Th radioactive decay (0.0288 d^{-1}).

Biomass development during spring 1987

Collections of planktonic organisms were performed weekly between March 17 and May 29, 1987. The results are presented in Table 2 and Figure 2. Phytoplankton biomass, as indicated by chlorophyll measurements, was higher during March than during May. For the layer 0-200 m, the integrated phytoplankton biomass decreases by a factor of about 3 between these two periods. The temporal evolution of total zooplankton and salps is presented in Figure 2. An indication of the variability of salp biomass estimations can be obtained from a study made by Nival *et al.* (1990) in Ligurian Sea. A log-log graph between mean and variance for 3 to 9 replicates of plankton hauls is used to estimate coefficients of variation (ratio of standard error to mean) from numbers collected. As the transformation from numbers to biomass is linear, these coefficients stay the same (Tab. 2). A study of the variability of different species numbers, between 3 vertical hauls was made at the same time in Villefranche Bay by Baker (1990). Coefficients of variation of numbers per haul (including the subsampling process) were in the range 12 to 23.5 %. The upper limit of this range gives a conservative estimate for the zooplankton and siphonophores biomass estimation. The collected samples show a maximum for pteropod, salp, larvacean and siphonophore biomass in the 0-200 m layer on May 14, as well as total zooplankton biomass. Euphausiid biomass shows a decreasing trend from a maximum on March 27. Pteropods, appendicularians and salps are able to collect small particles. Salps (*Salpa fusiformis* in these samples) are efficient filter feeders producing compact fecal pellets. Their biomass exhibits the largest increase between March 17 and May 14 (by a factor of about 170).

Influence of biological activities on ^{234}Th deficit

Our observations allow us to compare directly ^{234}Th activities and plankton biomasses for two different periods. During March, when phytoplankton levels were relatively high (0.47 mg Chl.*a* l^{-1}) and the particulate thorium/uranium activity ratio (Th^P/U) was equal to 0.37 ± 0.06, we observed no deficit for total ^{234}Th at 10 m depth (Tab. 1). Two months later, on May 14, with lower phytoplankton levels (0.27 mg Chl.*a* l^{-1} ; integrated content between 0 and 200 m depth lower by a factor of 3 compared to March 17) and a Th^P/U ratio of 0.21 ± 0.06, total thorium showed a significant deficit in surface waters. If we assume that suspended particles on which ^{234}Th is adsorbed are dominated by living organisms, this allows us to calculate the Th^P/C ratio using Th^P (particulate ^{234}Th) and the organic carbon content of living organisms. The Th^P/C ratio in the 0-200 m layer was nearly constant : 20.4 and 23.4 dpm mgC^{-1} for the two periods and is of the same order as the Th^P/C ratio measured on trap sediment samples at 200 m depth in the Ligurian Sea (4 to 24 dpm mgC^{-1}: Lambert *et al.*, 1991). The simultaneous decreases of Th^P/U and phytoplankton biomass and the relatively constant Th^P/C ratio are in agreement with the hypothesis that adsorption of dissolved thorium onto particles is proportional to the quantity of biogenic particles present (Coale and Bruland, 1987).

But it does not explain the existence of a 30 % deficit for total thorium observed on May 14. Another factor should be taken into account to understand the export of ^{234}Th to deep waters. The major difference between the two sampling periods was that of the zooplankton biomass. Total zooplankton biomass, between the surface and 200 m depth was only 1,297 mg (dry weight) m^{-2} on March 17 whereas it had a maximum value of 8,456 mg m^{-2} - on May 14 (Baker, 1990). This increase by a factor of 6.5 between the two periods should imply an associated enhancement of

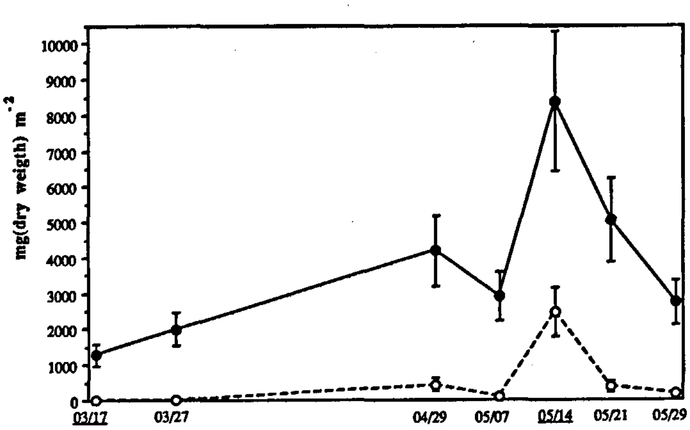

Figure 2

Temporal evolution of total zooplankton (dark circles) and salps (open circles) biomass for the layer 0-200 m during spring 1987. The underlined dates correspond to the simultaneous prelevements for the measurements of ^{234}Th and planktonic organisms.

Évolution temporelle du zooplancton total (cercles pleins) et des salpes (cercles vides) dans la couche 0-200 m au cours du printemps 1987.

zooplankton grazing. Moreover, the detailed composition of the zooplankton reveals that predominant species were different between March and May (Tab. 2). During March, copepods and euphausiids were the most important species, whereas salps and siphonophores were found to dominate two months later. Salps are well known for their high filtration rates and are suspected to limit phytoplankton growth when they are abundant. Because of their large size, salp fecal pellets have relatively high settling velocities and thus leave surface waters rapidly (Bruland and Silver, 1981). Furthermore, salp feces from this region of the northwestern Mediterranean are known to contain relatively high activities of ^{234}Th (750 dpm g^{-1} dry weight; Krishnaswami *et al.*, 1985). There is no evidence that this species undertakes a vertical migration out of the 0-200 m layer during late spring in the Ligurian Sea (unpublished data, Nival, Braconnot).

As a crude estimate of the role of salps in removing ^{234}Th adsorbed on to suspended particles during the studied period, we made the following calculation. Salp biomass was 2,468 mg (dry weight) m^{-2} on May 14. During this period, the average length of *Salpa fusiformis* blastozoids was 25 mm : estimated mean dry weight: 2.5 mg - filtration rate: 0.68 l h^{-1} ind^{-1} (Andersen, 1985). The volume of water filtered by the salp population (calculated as 2,468 mg m^{-2} / 2.5 mg $salp^{-1}$) was 16.3 ± 4.5 m^3 day^{-1} on May 14. Assuming that the efficiency of filtration is 100 % in the layer 0-200 m, the turn-over time of particulate matter, and consequently of $^{234}Th^P$, can be estimated as 12.4 ± 3.5 days. This value can be compared with the calculated ^{234}Th residence time of 24 ± 7 days (Tab. 1). Since the two residence times are of the same order of magnitude, these results strongly suggest that salp activity was a predominant factor in controlling ^{234}Th export at this period of the year. This conclusion is similar to the hypothesis advanced by Coale and Bruland (1985) to explain a particularly low $^{234}Th^P$ residence time in California current waters.

However we also suspect that this situation depends indirectly on some carnivorous species. A large increase in siphonophore biomass was noted during this period of time (Tab. 2). The dominant siphonophore species (*Chelophyes appendiculata*) is carnivorous. It feeds mainly on copepods and cannot eat the large species *Salpa fusiformis*. The consequent increase in predation on copepods decreases their grazing pressure and reduces the trophic competition between the two herbivores, salps and copepods. As they reduce the small fecal pellet producers, siphonophores affect indirectly the vertical flux of ^{234}Th.

CONCLUSION

This study has highlighted the importance of some zooplankton species such as salps in affecting the downward flux of particles in the sea and consequently in exporting trace-elements from surface to deep waters. Our results are in agreement with the assumption that salp blooms could bring about a rapid export of particles and so are responsible of the deficit for ^{234}Th in surface waters. These results, obtained in the context of Dyfamed in the Ligurian Sea, are preliminary. Nevertheless, they point out the necessity of coupling biological and chemical measurements at similar time scales for studying biogeochemical ocean fluxes.

Acknowledgements

This research was supported in part by the Centre National de la Recherche Scientifique, the Commissariat à l'Énergie Atomique and the Institut National des Sciences de l'Univers (DYFAMED, France, JGOFS). We thank the crew and officers of R.V. Korotneff. We also thank A. Vigot and P. Bourdon for their help in the sampling, V. Andersen and M.-D. Pizay for allowing us to use their data on chlorophyll. This is a CFR contribution n° 1238.

REFERENCES

Andersen V. (1985). Filtration and ingestion rates of *Salpa fusiformis* : effect of size, individual weight and algal concentration. *J. expl mar. Biol. Ecol.*, **87**, 13-29.

Bacon M.P. and R.F. Anderson (1982). Distribution of thorium isotopes between dissolved and particulate forms in the deep sea. *J. geophys. Res.*, **97**, 2045-2056.

Baker M. (1990). Estimation du bilan de matière dans l'écosystème pélagique en Mer Ligure. *Thèse Doct., University Paris VI, Paris, France.*

Bhat S.G., S. Krishnawami, D. Lal, Rama and W.S. Moore (1969). ^{234}Th/^{238}U ratios in the ocean. *Earth planet. Sci. Letts*, **5**, 483-491.

Bruland K.W. and M.W. Silver (1981). Sinking rates of fecal pellets from gelatinous zooplankton (salps, pteropods, doliolids). *Mar. Biol.*, **63**, 295-300.

Buat-Ménard P., H.V. Nguyen, J.-L. Reyss, S. Schmidt, Y. Yokoyama, J. La Rosa, S. Heussner and S.W. Fowler (1988). Temporal changes of ^{234}Th concentrations and fluxes in the northwestern Mediterranean Sea, in: *Radionuclides: a tool for oceanography*, J.-C. Guary, P. Guegueniat and R.J. Pentreath, editors, Elsevier, Amsterdam, 121-130.

Buesseler K.O. (1989). Marking time with thorium clocks. *US JGOFS Newsletter, December 1989*, 5-11.

Coale K.H. and K.W. Bruland (1985). ^{234}Th:^{238}U disequilibria within the California Current. *Limnol. Oceanogr.*, **30**, 22-33.

Coale K.H. and K.W. Bruland (1987). Ocean stratified euphotic zone as elucidated by ^{234}Th:^{234}U desequilibria. *Limnol. Oceanogr.*, **32**, 189-200.

Fowler S.W. and G.A. Knauer (1986). Role of large particles in the elements and organic compounds through the oceanic water column. *Prog. Oceanogr.*, **16**, 147-194.

Krishnaswami S., M. Baskaran, S.W. Fowler and M. Heyraud (1985). Comparative role of salps and other zooplankton in the cycling and transport of selected elements and natural radionuclides in Mediterranean waters. *Biogeochemistry*, **1**, 353-360.

Lambert C.E., S.W. Fowler, J.-C. Miquel, P. Buat-Ménard, F. Dulac, V.H. Nguyen, S. Schmidt, J.-L. Reyss and J. La Rosa (1991). ^{234}Th : an ambiguous tracer of biogenic particle export from northwestern mediterranean surface waters, in: *Radionucleides in the Study of Marine Processes*, P.J. Kershaw and D.S. Woodhead, editors, Elsevier, London, 116-128.

Nival P., J.-C. Braconnot and T. Oberdoff (1990). Structure démographique d'une population de salpes en Mer Ligure. *Mar. Nat.*, **3**, 1-8.

Schmidt S. and J.-L. Reyss (1991). Uranium concentrations of Mediterranean seawaters with high salinities. *C. r. Acad. Sci., Paris, sér. 2*, **312**, 479-484.

Schmidt S., J.-L. Reyss, H.V. Nguyen and P. Buat-Ménard (1990). ^{234}Th cycling in the upper water column of the northwestern Mediterranean Sea. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **89**, 25-33.