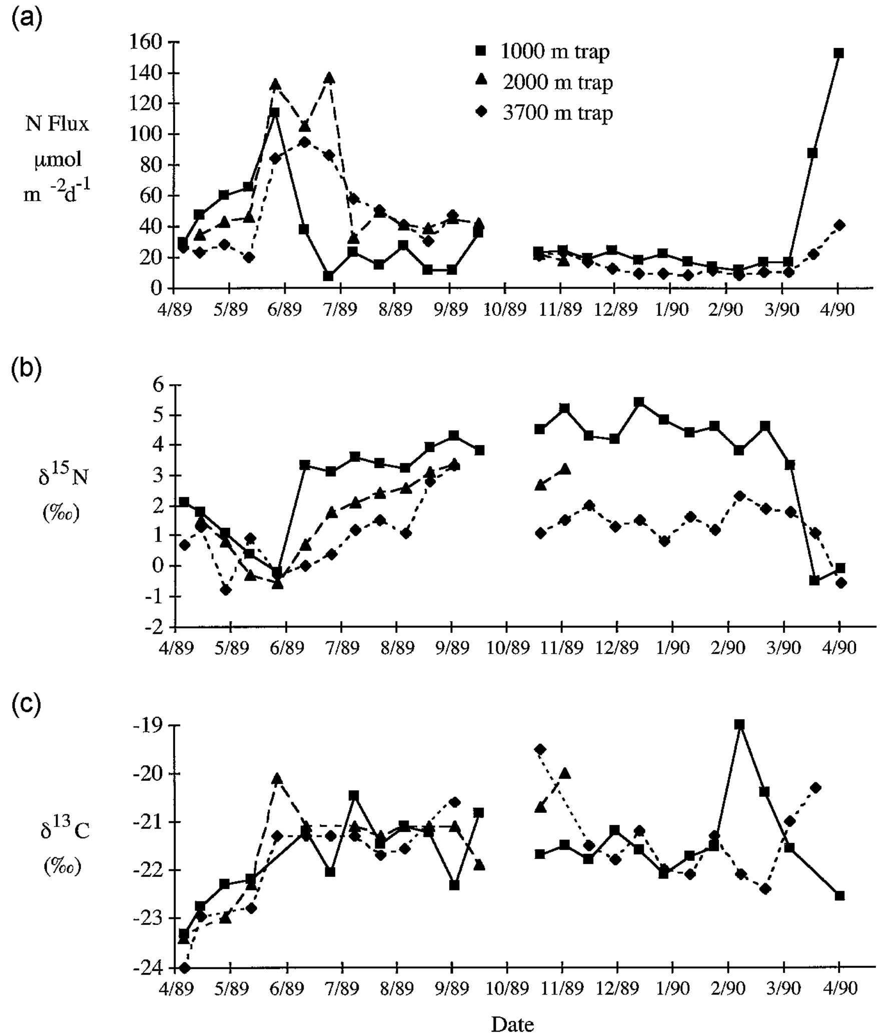

Figure 8.11 Deep-moored sediment trap time series taken during JGOFS NABE between April 1989 and April 1990 with 2-week sampling intervals. (a) PN flux at 1000, 2000 and 3700 m. (b) Corresponding $\delta^{15}N$ values. (c) Corresponding $\delta^{13}C$ values for the organic carbon fraction.

convective mixing in late fall and winter would have elevated surface NO_3^- and CO_2(aq) concentrations (lowered temperature would also raise [CO_2(aq)]) resulting in lowered $\delta^{15}N$ and $\delta^{13}C$ for any newly produced POM to values at least as low as the minima observed. In contrast, deeply sinking particles reaching

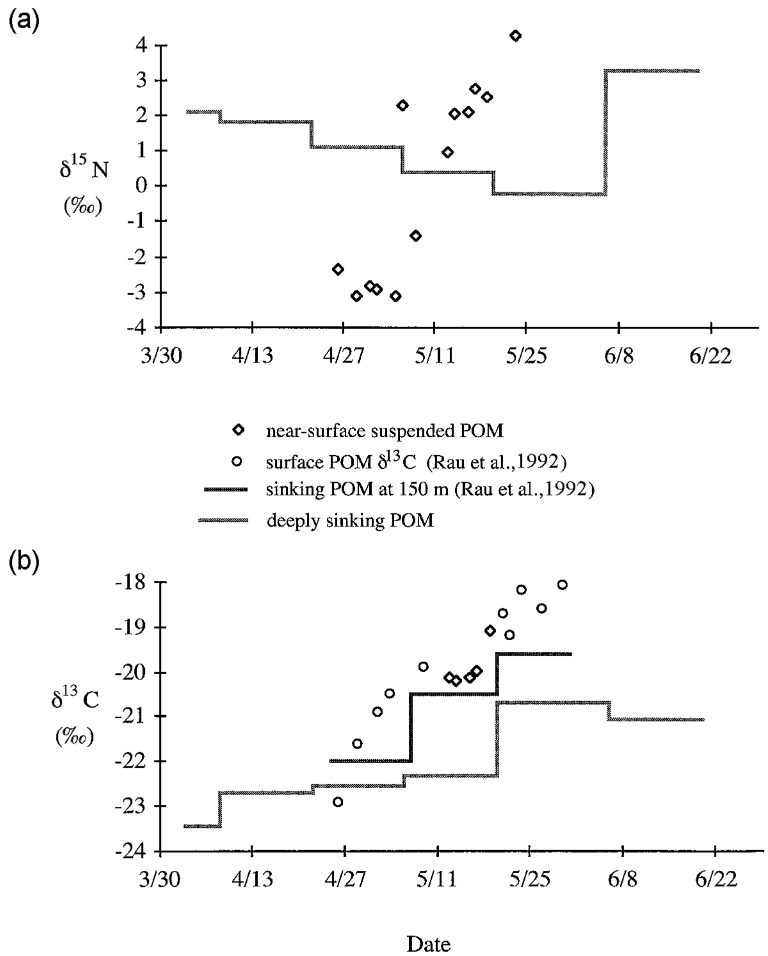

Figure 8.12 Comparison of near-surface and deep time series for the JGOFS NABE (1000 m). (a) δ^{15}N data. (b) δ^{13}C data. The data are plotted to make apparent the instantaneous nature of suspended POM collections (points) relative to the moored sediment traps which collected material in 2-week intervals (lines).

1000 m during these seasons instead appear to be derived from a source that is more enriched in ^{15}N and ^{13}C as compared to presumed late fall/wintertime production. This source could be from the aggregation of suspended particles in the region above 1000 m, but clearly not contemporaneous surface production transported directly by the uninterrupted sinking of large particles. It follows that, during initiation of the bloom (April to early May), there is a transition in dominance from this 'background' source to the near-surface bloom-production source causing the decreasing trend in $\delta^{15}N$ at 1000 m observed in April and May. Similar observations would be likely to have been made for $\delta^{13}C$ if the time series began earlier since, on average, wintertime values in 1989/90 were elevated as compared to the beginning of the time series.

Damping at depth of the surface-generated isotopic time-series signal during the bloom peak in particle flux is evidence for a steady influence from a background, water column source of moderate isotopic composition even during this time of the year (Figure 8.12). Wintertime $\delta^{15}N$ and $\delta^{13}C$ values at 1000 m are consistent with this perspective; 4 to 5‰ as compared to near-surface range of -3 to 9‰ and -22 to -20‰ vs. -23 to -18‰, respectively. If suspended particles at depth are a water column source for sinking particles, they should have an isotopic composition similar to the wintertime particle flux. Unfortunately samples of this type were not collected and $\delta^{15}N$ and $\delta^{13}C$ for suspended particles were too regionally variable (Saino and Hattori, 1987) to rely on the results of studies distant from the NABE site.

Both the $\delta^{15}N$ and $\delta^{13}C$ time series exhibit a 2–3 week time lag between near-surface and the 1000 m time series during the bloom period (Figure 8.12). In the case of $\delta^{15}N$, this time lag is identified based on the difference in date of the rapid rise in values found for both times series. For $\delta^{13}C$, the lag was given by the temporal offset between the time series for the 150 m sediment trap data of Rau et al. (1992) and our moored sediment trap results. A 2 to 3 week time-lag translates into an average sinking rate of 50 to 70 m/day, similar to the estimate of 30 to 70 m/day based on lags between peaks in flux components for these same samples (Honjo and Manganini, 1992).

8.7.4 MODIFICATIONS OF THE LARGE PARTICLE FLUX BELOW 1000 M

Between 1000 and 3700 m the isotopic time series exhibit several distinct features (Figure 8.11). $\delta^{13}C$ variations are generally temporally in phase with depth except for a few spikes during the fall and winter. $\delta^{15}N$ variations are in phase with depth only prior to the peak in flux. The apparent phase lags afterward are mirrored in the N flux time series. In fall and winter, there is a substantial drop in $\delta^{15}N$ with depth which Altabet et al. (1991) have discussed in detail. Focusing first on the post-bloom period (June to September), the increasing time delay with depth in the particle flux and $\delta^{15}N$ signals is consistent with estimated sinking speeds. Observed time broadening is consistent with the progressive influence of a background flux with depth. $\delta^{13}C$ shows no coherent phase lag during this period because its signal had already become relatively time invariant. The background flux between 1000 m and 3700 m evidently has relatively low $\delta^{15}N$ values. There is a progressive decrease in the $\delta^{15}N$ of the total flux with depth following the bloom and continuing into winter. It would be unusual if suspended particle $\delta^{15}N$

decreased with depth below 1000 m at this site since all previous observations have shown consistently enriched values in the deep ocean (Saino and Hattori, 1980; Altabet and McCarthy, 1986; Saino and Hattori, 1987; Altabet, 1988). Altabet et al. (1991) speculated that bacterial utilization of NO_3^- or DON could be the source. $\delta^{13}C$ in contrast shows no clear depth-dependent variation indicating no change in carbon isotopic composition of the background source with depth.

8.8 SUMMARY AND RECOMMENDATIONS FOR FURTHER RESEARCH

The JGOFS NABE study illustrates both many of the processes influencing $\delta^{15}N$ and $\delta^{13}C$ values for POM and how they can be used as natural tracers of particle dynamics. Large temporal variations in $\delta^{15}N$ and $\delta^{13}C$ of primarily produced organic matter occured during the course of the bloom as the result of the drawdown of inorganic N and C substrates. These temporal signatures rapidly propagate into sinking particles leaving the euphotic zone and then being transported deep into the ocean's interior. However, there is substantial modification of the near-surface temporal signal. As discussed above, the isotopic evidence confirms the importance of surface productivity in directly supporting particle fluxes in the deep ocean but is also proof for other important sources which are only indirectly linked to surface processes. This approach making use of a 'natural' tracer experiment has several advantages: nitrogen and carbon isotopic composition characterizes the bulk properties of POM in contrast to the trace metal or trace organic compositions. Processes occurring on difficult to examine time and space scales (10's to 1000's m and weeks to months) can be effectively probed. Results are not dependent on experimental manipulations which may introduce artifacts.

Future studies need to better characterize the processes creating the primary isotopic signatures. Does ε for NO_3^- uptake vary principally as a function of species or is the range in growth conditions found in the ocean a contributor? These results should be compared with additional field estimates of ε_u. More detail is needed in understanding how N recycling influences $\delta^{15}N$ values for suspended POM: what are $\delta^{15}N$ values for recycled forms of NH_4^+? Similarly, the physiological basis for the relationship between CO_2(aq) and $\delta^{13}C$ needs to better detailed: does the expression of HCO_3^--uptake at low CO_2(aq) play a role?

While the shifts in isotopic composition with trophic level are fairly well characterized (though not their physiological basis), microbially-based diagenetic effects in the water column have not been identified, let alone mechanistically understood. Does the ubiquitous increase in $\delta^{15}N$ of suspended POM with depth in the ocean's interior reflect diagenetic processes or contributions of the fragmentation of sinking particles? Sediments appear to be typically several ‰ enriched in

$\delta^{15}N$ relative sinking particles. Does this shift reflect isotopic fractionation at the molecular level or selective preservation of resistant components of sinking particles enriched in ^{15}N? For $\delta^{13}C$, it is not clear if there are significant diagenetic effects on $\delta^{13}C$. In both instances, what are the implications of diagenetic effects on the use of these isotopes for paleoceanographic reconstruction?

For the present, the NABE study provides a good model for how isotopic studies of particle dynamics in the open ocean should be carried out. Settings need to be chosen in which there are likely to be large isotopic transients (either in time or in space as in the JGOFS EqPac study). Sampling resolution needs to be sufficient to resolve the isotopic signals. Furthermore, all the compartments of interest need to be sampled. In this respect, the NABE study lacked time-series sampling for NO_3^- and suspended POM in the region below the euphotic zone.

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