Ross Sea Bloom Dynamics Experiment

Food web structure and sinking particulate material in the Ross Sea polynya: December 1995 and January 1996

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Sequential blooms of the prymnesiophyte *Phaeocystis* (DeMaster et al. 1992; Arrigo and McClain 1994; Garrison et al. 1995; Smith et al. 1995) followed by diatom-dominated blooms (e.g., Wilson, Smith, and Nelson 1986; Fitzwater et al. 1996) in the continental shelf region of the Ross Sea provided an opportunity to examine the relationship between seasonal bloom dynamics and vertical carbon flux. In particular, our project focuses on the relationship between the structure of the microbial food web and the sinking particulate material. Our first field season (November and December 1994) sampled the early development of a *Phaeocystis* bloom (Garrison et al. 1995; Gowing et al. 1995; Lessard et al. 1995). Here, we describe some preliminary results from our second field season (December 1995 and January 1996), scheduled to examine the decline and disappearance of the *Phaeocystis* bloom and the onset of the diatom bloom.

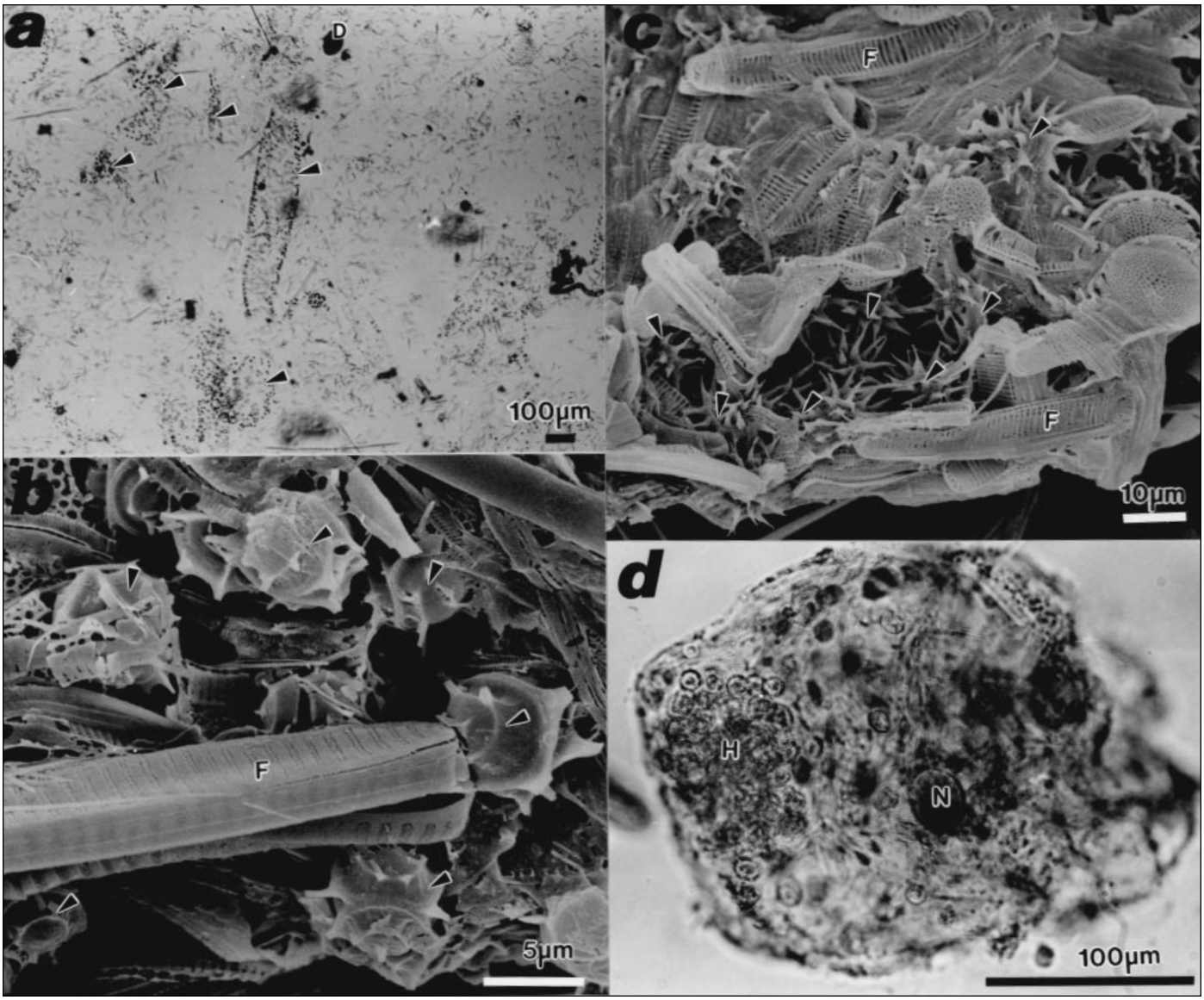
We sampled phytoplankton and microzooplankton in the Ross Sea polynya region from 21 December 1995 through 14 January 1996. Samples were collected from at least five depths in the upper 100 meters (m) of the water column using water sampling bottles. Aliquots of these samples were preserved using methods suitable for quantifying a wide range of autotrophic and heterotrophic nano- and microplankton. Samples were counted using both epifluorescence and tungsten light microscopy. Floating sediment trap arrays with multiple cylindrical traps at five depths in the upper 200 m were deployed five times in the study area during the cruise (table). Traps contained 100 milliliters of 2 percent formaldehyde in a sodium chloride (85 parts per thousand) density gradient overlain with sea water. On recovery, the liquid above the density gradient was removed by siphon and discarded. Autotrophic and heterotrophic plankton as well as fecal pellets were counted as described for the water column samples.

Preliminary examination of water column samples indicated that stations in the central and eastern parts of the study (approximately from 172°W through 171°E along 76°30'S) were dominated by *Phaeocystis* and the diatom *Nitzschia subcurvata* during the first occupation of this transect. *Phaeocystis* populations were apparently declining as indicated by the presence of many fragmented colonies (figure, block *A*) and relatively few "healthy" spherical colonies. By the third occupation of the transect, about 17 days later, few *Phaeocystis* colonies were found. West of the *Phaeocystis*/*N. subcurvata*-dominated region larger diatoms (e.g., *Pseudonitzschia pseudodelicatissima*(?)) became more abundant. Drifting sea ice covered the region from approximately 168°26' to 166°W along the 76°30'S transect line, and many ice-associated forms were observed in the water column. West of the pack ice and east of the land-fast ice of the Victoria Land coast, a polynya was present from at least early December, and it increased in area during the course of the cruise as ice melted. The conspicuous diatoms in this region were species of *Fragilariopsis*. This was apparently a rapidly developing diatom assemblage as indicated by healthy cells forming long chains and an apparent increase in populations over the course of our study. Although our population analyses are still in progress, it is apparent from preliminary examination of samples that heterotrophic microplankton, in particular heterotrophic dinoflagellates, were very abundant throughout the region.

Preliminary examination of aliquots of all five sediment traps from 200 m has shown two noteworthy results. First, several of the angular or ovoid fecal pellets (approximately 100–200 micrometers [µm]) from trap sets 3–5 contain Parmales cells (Booth and Marchant 1987) and/or dinoflagellate hypnozygotes (Buck et al. 1992) (figure, blocks *B* and *C*) in addition to the diatom *Fragilariopsis*. Second, large (>200 µm)

Dates, locations, and lengths of deployments of sediment traps

Set	Date deployed	Latitude	Longitude	Duration (days)
1	23 December 1995	76.4998°S	171.7631°E	2.50
2	26 December 1995	76.4990°S	170.7590°E	2.87
3	31 December 1995	76.4997°S	164.9687°E	2.23
4	6 January 1996	76.4907°S	177.6449°W	2.23
5	12 January 1996	76.5007°S	164.9753°E	1.92



Examples of organisms and fecal pellets from the December 1995 and January 1996 field season. *A*. Light micrograph of a Lugol's-preserved sample from the water column showing fragmented *Phaeocystis* colonies (arrows) and a heterotrophic dinoflagellate (D). *B*. Scanning electron micrograph of Parmales cells (arrows) in a fecal pellet from the 200-m trap of trap set 4. *Fragilariopsis* cells (F) are also present. *C*. Scanning electron micrograph of dinoflagellate hypnozygotes (arrows) in a fecal pellet from the 200-m trap of trap set 5. (F denotes *Fragilariopsis* cell.) *D*. Light micrograph of a large protozoan from the 200-m trap of trap set 5. (N denotes nucleus; H denotes cluster of hypnozygotes in its food vacuole.)

protozoans (figure, block *D*) are present in trap sets 1–5. Their feeding vacuole often contains hypnozygotes or Parmales cells as well as pennate diatoms. The protozoans may be dinoflagellates, but their nuclear ultrastructure is not typical of dinoflagellates. We are currently trying to identify this organism. We are also comparing its vacuole contents ultrastructurally with the fecal pellet contents to determine whether it is likely that this organism produced the pellets. We will be analyzing the other types of fecal pellets and microzooplankton and algal cells in the particle flux during the next year.

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Dimethylsulfide concentrations in the southern Ross Sea during austral summer 1995–1996

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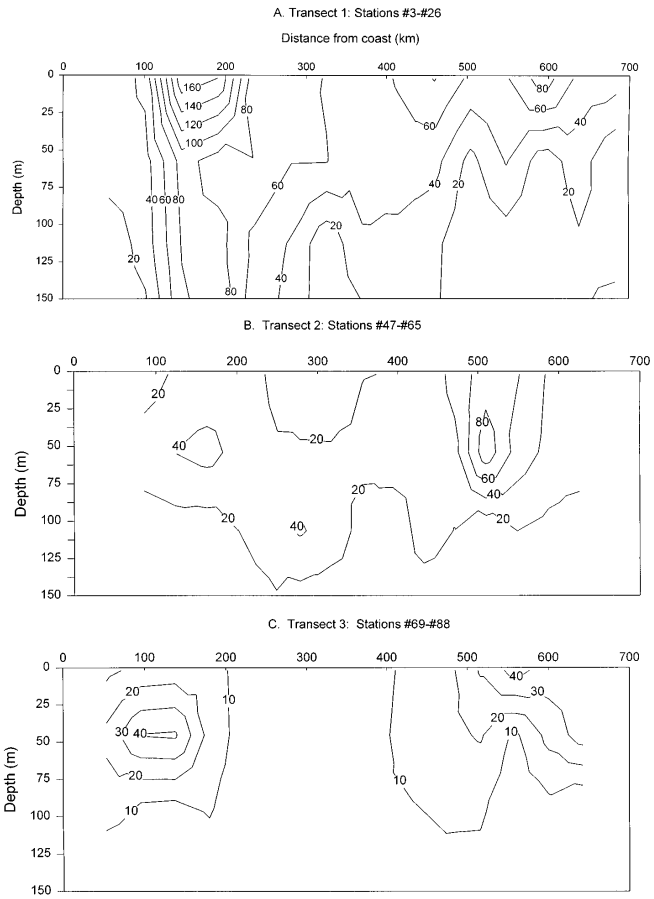
The volatile sulfur compound dimethylsulfide (DMS) represents approximately half of the natural biogenic emissions to the atmosphere (Andreae 1990). DMS concentrations are important with respect to global climate change processes and may have played a role in the atmospheric drawdown of carbon dioxide during the last glacial maximum (Martin 1992, pp. 123–138). In the southern Ross Sea, *Phaeocystis antarctica* typically forms large colonial blooms during the early austral summer (El-Sayed, Biggs, and Holm-Hansen 1983; Palmisano et al. 1986). DMS can be used as a proxy for the presence of this organism in the southern Ross Sea, especially during bloom conditions (DiTullio and Smith 1995). Although other phytoplankton also produce the DMS precursor dimethylsulfoniopropionate (DMSP), high concentrations [>100 nanomolar (n*M*)] of DMS in the Ross Sea are typically found only in the southern sector during periods when *P. antarctica* proliferates (DiTullio and Smith 1995).

We surveyed the southern Ross Sea along 76°30'S aboard the R/V *Nathaniel B. Palmer* (*see* Sedwick, DiTullio, and Mackey, *Antarctic Journal*, in this issue). We performed three transects during the time interval from 20 December 1995 to 12 January 1996. Transect 1 (20–28 December 1995) had the highest integral primary production rates, chlorophyll-*a* biomass, and particulate organic carbon concentrations relative to transect 2 (3–7 January 1996) or transect 3 (7–12 January 1996) (Smith personal communication). Those data as well as plankton microscopic analyses (Garrison personal communication) suggested that transect 1 probably represented the beginning of the spring bloom senescence stage.

DMS concentrations were measured at various stations along the transect using the cryogenic purge-and-trap methodology described in DiTullio and Smith (1995). DMS comparisons between filtered and nonfiltered samples displayed spatial variability due to the presence and physiological state of *Phaeocystis antarctica* colonies. The unfiltered data are presented here to facilitate direct comparison among transects. We observed a similar pattern in DMS concentrations among transects (figure) as described for other biological and chemical parameters noted above. DMS concentrations were highest during transect 1 (reaching a maximum concentration of 340 n*M* at station 22) and declined progressively on later transects to values less than 40 n*M* in the same region (figure). Integral water column [to 150 meters (m)] DMS concentrations reached a maximum value of 22 micromoles per square meter approximately 200 kilometers (km) from the coast (station 22) during transect 1. Integral DMS concentrations for transects 1 and 2 ranged between 1 and 4 micromoles per square meter. The range in the dissolved and particulate DMSP pools each represented approximately 10–40 percent of the DMS pool. The disappearance of the *P. antarctica* bloom was rapid as evidenced in the change in DMS concentrations between transects 1 and 2. It is unclear whether ventilation to the atmosphere or biological consumption processes (Kiene and Bates 1990) were responsible for this rapid decline in the DMS concentrations. Ammonium concentrations reached a maximum of approximately 2.5 micromolar between 50 to 100 m at station 22 (Gordon personal communication) indicating enhanced grazing processes. The fact that the dissolved DMSP pool and the dissolved organic carbon concentrations (Carlson personal communication) did not increase significantly during the demise of the bloom (transects 2 and 3) suggests a potential rapid turnover mechanism for these pools. Future experiments will investigate the biological consumption rates of DMS in the Ross Sea.

This research would not have been possible without the assistance of the chief scientist, David Garrison, as well as Walker Smith and Steve Kottmeier (Antarctic Support Associates). I also would like to thank the captain and crew of the R/V *Nathaniel B. Palmer*. This research was supported by National Science Foundation grant OPP 93-17431.



Vertical sections of dimethylsulfide (DMS) concentrations (n*M*) in the Ross Sea along 76.5°S during (*A*) transect 1, (*B*) transect 2, and (*C*) transect 3.

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Dissolved iron and manganese in surface waters of the Ross Sea, austral summer 1995–1996

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The availability of dissolved trace metals such as iron (Fe), manganese (Mn), and zinc (Zn) may play an important role in regulating the growth and biomass of phytoplankton in waters of the antarctic continental shelves (Martin, Fitzwater, and Gordon 1990a). Little information is available, however, regarding the concentrations of trace metals in these waters during the phytoplankton growing season. Very low dissolved Fe concentrations of approximately 0.1 nanomole/liter (nM) have been reported for surface waters of the Ross Sea in January 1990 (Fitzwater et al. 1996), which, together with the results of bottle-incubation experiments (Martin et al. 1990a), suggest that Fe-deficiency may limit algal production in this region during the middle to late summer. During spring (November and December) 1994, we measured significantly higher dissolved Fe concentrations of 0.5–3.8 nM in these waters, and dissolved Mn concentrations of 0.08–0.83 nM (Sedwick, DiTullio, and Mackey 1995). These observations suggest that the dissolved Fe content of seawater in the Ross Sea may vary widely by season and that dissolved Fe availability decreases during the summer. The results we present here, from a survey of dissolved iron and manganese in this region during the early summer, are consistent with this hypothesis.

During an expedition aboard R/V *Nathaniel B. Palmer* in December 1995 and January 1996, water-column samples were collected at nine stations in the southern oceans and Ross Sea (*see* figure 1 and table) using trace-metal clean techniques as described in Sedwick et al. (1995). Samples were filtered through 0.4 micrometer-pore polycarbonate membranes, and dissolved Fe and Mn were determined at sea by flow-injection analysis following modifications of the methods of Measures, Yuan, and Resing (1995) and Resing and Mottl (1992). Station K1 was an ice-free, deep-ocean location well away from the antarctic continent, where low concentrations of both metals were expected in the upper water column. Stations K2–K9 were on the continental shelf, in water depths of less than 1 kilometer, and were occupied in conditions ranging from heavy pack ice to ice-free (*see* table). Dissolved major nutrients, nitrate plus nitrite, phosphate, and silicate were abundant at all trace-metal stations (concentrations >14 micromole/liter, 0.8 micromole/liter, and 45 micromole/liter, respectively; data not shown). Vertical concentration profiles of dissolved Fe and Mn for stations K1 and K3–K9 are presented in figure 2.

Our ability to collect open-ocean seawater and measure dissolved Fe and Mn without significant contamination is demonstrated by the smooth vertical concentration profiles and low concentrations (0.12–0.30 nM Fe, 0.21–0.28 nM Mn) obtained at station K1 (figure 2*A*), which are very similar to data reported by Martin et al. (1990b) for the southern Drake Passage. Except for station K3, water-column dissolved Fe concentrations were generally low (0.09–0.38 nM) in shelf waters of the Ross Sea, and tend to increase with depth, suggesting removal from the upper water column due to biological uptake or other scavenging processes (Landing and Bruland 1987). At station K3 (figure 2*B*), significantly higher dissolved Fe concentrations were measured at the surface (2.25 nM) and 20 meters depth (0.72 nM); we attribute these findings to the release of Fe from the melting sea ice (brash ice), which was present at this location. Martin et al. (1990b) have suggested melting sea ice as a possible source of Fe for surface seawater, and total Fe concentrations above 30 nM have been measured in snow collected from antarctic sea ice (Edwards and Sedwick 1996). The highest mixed-layer dissolved Mn concentrations of approximately 0.6 nM were also observed at station K3, consistent with dust inputs from melting sea ice. Dissolved Mn concentrations were low (<0.6 nM) in the upper water column at all other stations, increasing to higher concentrations (approximately 0.5–0.8 nM) below 100 meters depth, again suggesting biological/scavenging removal from the mixed layer.

Our data suggest that the concentrations of dissolved Fe and Mn are typically low (0.09–0.38 nM Fe, 0.03–0.58 nM Mn) in the upper hundred meters of the water column of the Ross Sea during the early summer, except where brash ice is present. These results are consistent with those of Martin et al. (1990a) and Fitzwater et al. (1996), who suggest that low concentrations of dissolved Fe may limit phytoplankton production in this region during the mid- to late-summer. The elevated concentrations of dissolved Fe and Mn observed in association with brash ice suggest that melting sea ice may be an important source of Fe and Mn into surface seawater around Antarctica and may explain the significantly higher dissolved Fe and Mn concentrations observed in these waters during the spring (Sedwick et al. 1995), when large amounts of annual sea ice are melting.

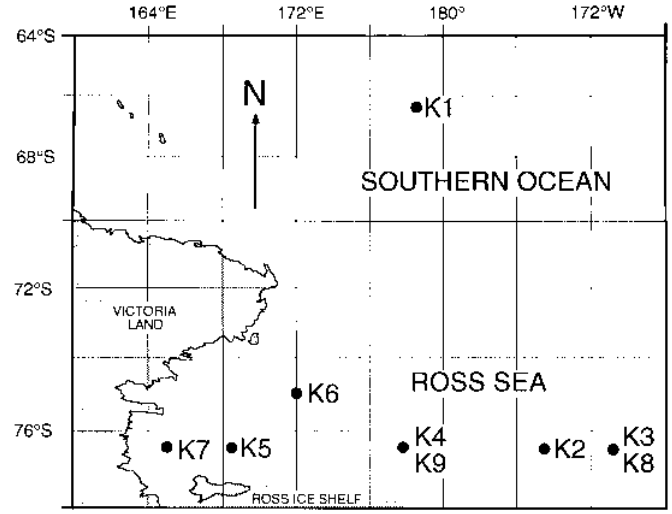

Figure 1. Location map of trace-metal hydrocast stations K1–K9 in the southern ocean and Ross Sea, Antarctica, austral summer 1995–1996.

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Trace-metal hydrocast stations, Ross Sea, austral summer 1995–1996

Station	Location	Date	Sea-ice conditions
K1	66°30'S 178°50'E	19 December 1995	No ice visible
K2[a]	76°31'S 174°32'W	21 December 1995	No ice visible
K3	76°30'S 170°44'W	21 December 1995	Extensive brash ice
K4	76°30'S 177°46'E	24 December 1995	No ice visible
K5	76°30'S 168°30'E	28 December 1995	Approximately 9/10 pack ice cover
K6	75°00'S 172°00'E	31 December 1995	No ice visible
K7	76°31'S 164°58'E	4 January 1996	Occasional bergy bits
K8[b]	76°30'S 170°37'W	8 January 1996	No ice visible
K9[c]	76°30'S 177°43'W	10 January 1996	No ice visible

[a]Surface-water sample only, 0.38 nM dissolved iron, 0.58 nM dissolved manganese.
[b]Approximately same location as station K3.
[c]Approximately same location as station K4.

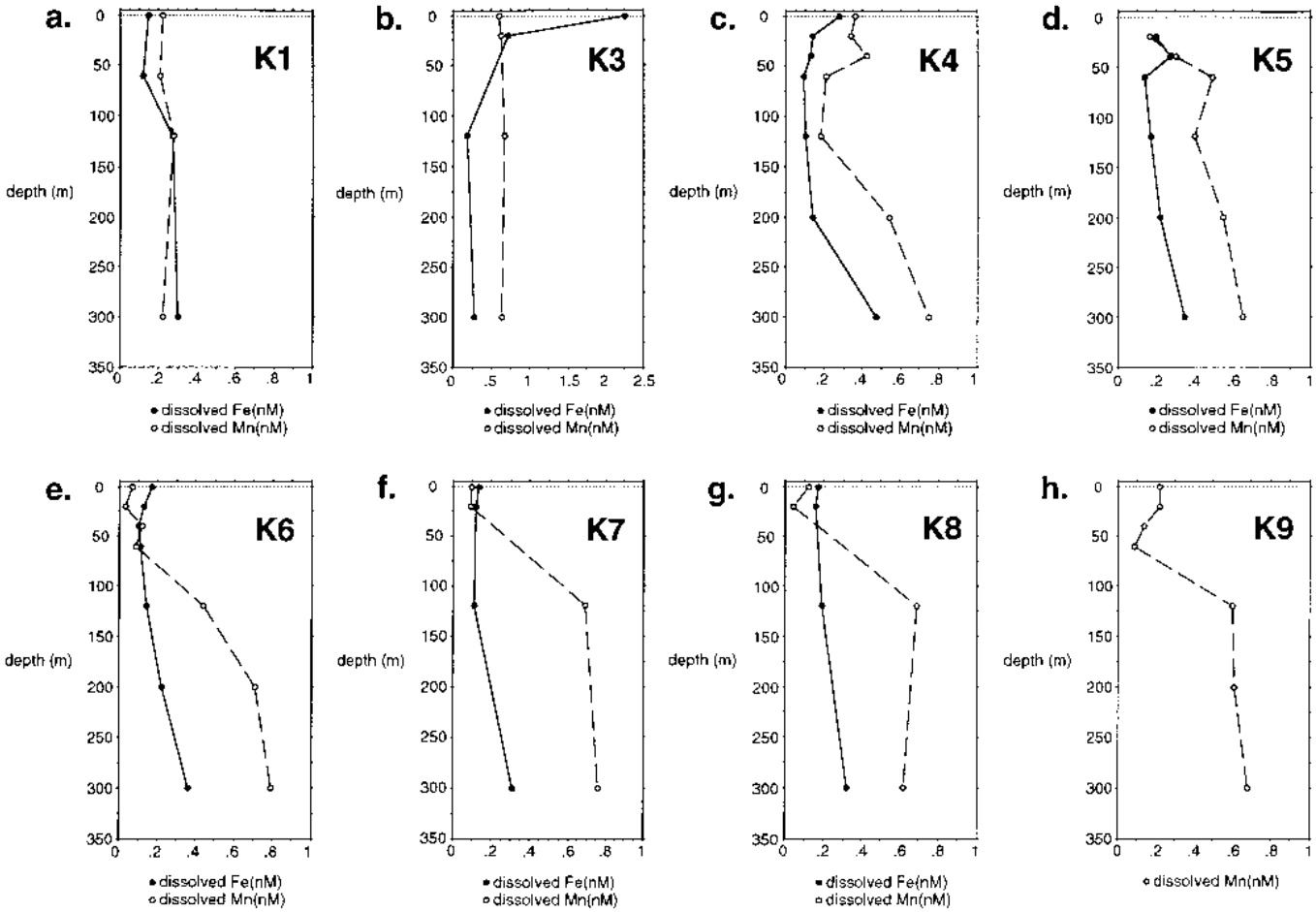

Figure 2. Vertical concentration profiles of dissolved iron (Fe) and manganese (Mn) in the water column at stations (*A*) K1, (*B*) K3, (*C*) K4, (*D*) K5, (*E*) K6, (*F*) K7, (*G*) K8, and (*H*) K9 (Mn only).

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