A MODEL OF SEDIMENT BIOGEOCHEMISTRY AT THE SEWAGE SLUDGE ACCUMULATION SITE FOR 1983-1989

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ABSTRACT

A deterministic model of sediment biogeochemical processes has been developed for surficial sediments at the sewage sludge accumulation site (0.5 cm at station NY-6). The model predicts that; 1) quasi-steady state can not be confirmed until at least 1990, 2) the decreases in microbiological activity and labile carbon will be much greater from 1986-87 to 1988-89 than they were from 1983-85 to 1986-87, and 3) the increase in redox potential will much be greater from 1986-87 to 1988-89 than it was from 1983-85 to 1986-87.

INTRODUCTION

The model (figure 1) uses inputs of labile carbon loading rates (sewage sludge plus non-sewage), temperature, and dissolved oxygen, together with controlling relationships among variables to calculate the output variables; microbiological activity, standing stock of labile organic carbon and, redox potential. As reported here, the model is configured to represent conditions at 0.5 cm in the sediment where, during at least half the year, dissolved oxygen is directly involved in poising the redox (oxidation-reduction) potential. That is, oxygen is a major terminal electron acceptor and is, therefore, involved in establishing the electron condition of the sediment. The calculated redox potential was forced to fit the patterns observed in 1983-87 by adjusting the empirical coefficients that relate it to the input variables. Since the portion of labile carbon at the sewage sludge depositional site from non-sewage sources is unknown, the model was run at 5 levels of non-sewage carbon input. These ranged from 2 to 50% of the carbon loading originating from non-sewage sources (in the period before cessation; 1983-85). The model was run from 1983 through 1989 in one month intervals.

The factors controlling the redox potential in sediments are; 1) sediment porosity, 2) biological rates of degradation of labile organic carbon in the sediment, and 3) oxygen concentration in the overlying water as it controls rates of oxygen diffusion into the sediment (Walker 1980). Finer sediments, higher bacterial rates and lower oxygen concentration in the water, result in the oxidized zone (or a given redox isopleth) occurring closer to the sediment-water interface. Since this model considers a single site (station NY-6), for the purposes of this first iteration, sediment porosity is considered to be constant.

METHODS

Input

Input variables are temperature, bottom water dissolved oxygen and organic carbon loading. To minimize variation that would obscure major trends, a synthesized temperature regime for 1983 was used for all years. Likewise, there are only two seasonal dissolved oxygen patterns; one for 1983-85 and a second for 1986-89. These two patterns were based on observed oxygen minima of 15 uM (0.47 mg/l) in the summer from 1983 through 1985, and 125 uM in 1986-87. September concentrations were still allowed to drop to 95 uM in the 1986-89 period. Carbon loading was assumed to consist of two components. The sewage component followed the dumping phase-out schedule. The non-sewage component (largely from primary production in the water column) was of constant magnitude for a model run and equal to a percentage (2-50%) of pre-cessation sewage loading.

Relationships

The temperature effect on microbiological activity is modeled as linear in two stages with rates above 7^{o}C being about 25 times those below that temperature. This coincides with abrupt changes in sediment chemistry observed in 1983-85 and 7^{o}C is the temperature at which the facultative anaerobic microbiological community becomes metabolically active. Microbiological activity is also modeled as a function of labile carbon standing stock.

Labile carbon standing stock is calculated as the sum of existing carbon from the previous month (model cycle) and carbon input (sewage sludge plus non-sewage) minus carbon consumed in microbiological processes.

Redox potential is modeled as a function of dissolved oxygen concentration and microbiological activity (porosity being considered constant as mentioned above). The differences in redox potential excursion among carbon levels in the same pre-cessation years must be considered scaling differences at this time. (One solution would be to normalize by 1983-85 values across non-sewage loading levels.)

Output

The model was stepped in one month intervals. At each cycle, the values of microbiological activity, labile carbon standing stock, and redox potential are calculated.

RESULTS

Figures 2-6 represent the model output at each of the five levels of non-sewage carbon loading; 2-50%. The following points are observed. The model is stable in the period 1983-85 but all response variables change from one year to the next between 1985 and 1989. The redox potential calculated by the model generally follows the 1983-87 patterns at station NY-6 presented in the October 1987 quarterly progress report (figure 7). (This should not be a surprise since it was the criterion used to establish relational factor values.) Specifically the model represents data from NY-6 well in the following areas:

1) the decline in redox potential follows closely bottom water warming in spring;

2) in 1983-85, the redox potential remains low for a period of months;

3) the minimum redox potentials in 1986 and 1987 are higher than in 1983-85;

4) the secondary decline in redox potential in 1983 is successfully modeled;

5) redox potential reaches a minimum for one month in 1986 and 1987 then increases.

The calculations of the model were extended two years into the future. Labile carbon concentrations and microbiological activity are predicted by the model to be much lower in 1988 and 1989 than in 1986 and 1987. This is compared with only slightly lower levels in 1986 and 1987 relative to 1983-85. Redox potential follows a similar but opposite trend. In 1988 and 1989, at all levels of non-sewage carbon, redox potential is predicted to reach maxima about 50 mv higher than in 1983-87. There are differences in redox potential predicted as a function of non-sewage carbon loading levels. Summer minima are calculated to be only slightly lower than winter maxima at low non-sewage carbon loadings (2%) while considerable within year variation is predicted at high non-sewage percentages (50%).

The BOD_{13} data are not yet readily available. When they are, the pattern of BOD_{13} at station NY-6 will be an independent test of the model.

There are three notable departures from values observed at station NY-6 in the model as currently constituted:

1) In the model, the redox potential recovery after the initial decline in 1986 and 1987 is slower than was observed at station NY-6.

2) The redox potential minimum in 1987 is higher than 1986 (the reverse of that observed).

3) The periods of depressed redox potential are shorter and occur earlier in the year in 1984 and 1985 than was observed at NY-6.

These departures many be the result of using 1983 temperature and dissolved oxygen (adjusted to minima of 125 uM) data for all years. Similarly, the abrupt changes in the response variables that have not been observed in nature, can be addressed, for example, by including a microbial succession component.

DISCUSSION AND CONCLUSIONS

This first iteration of the model has given reasonable and some interesting results:

1) The continuous decline in labile carbon and microbiological activity predicted by the model from 1985 through 1989 implies that quasi-steady state can not be confirmed by measurement at station NY-6 until at least 1990.

2) While some recovery is detectable in 1986 and 1987, much larger changes are predicted for 1988 and 1989 in microbiological activity, labile carbon, and redox potential.

3) The increase in redox potential in the upper sediment stratum, following cessation, is predicted by the model to be greater than was predicted a priori (100 mv).

The seasonal cycling of the redox potential in 1988-89, at the lower labile carbon concentrations (2-9%), is predicted to be very weak. By comparing the values calculated in the model with redox potentials at station NY-11, when they are available, it may be possible to estimate the percent non-sewage labile carbon loading.

Since gradually decreasing levels of seabed oxygen consumption were confirmed after cessation was initiated (though not at NY-6; Phoel 1987) and since the model predicts a larger decrease in microbiological activity in 1988-89 than 1986-87 as compared with 1983-85, it may be inferred that a corresponding large decrease in seabed oxygen consumption will be observed in 1988-89. The within year variation in microbiological activity is large and multi-functional. That this variation occurs even in the model may help to explain why a decrease in seabed oxygen consumption was not detectable at station NY-6 in 1986-87 as compared to pre-cessation values.

The higher redox potential minima in 1986-87 for short periods (one month) compared to 1983-85, imply that the extirpation of benthic fauna may be less pronounced in 1986-87 than in previous years and based on the consistently high redox potentials predicted for 1988-89, may not occur at all under post cessation conditions (for all levels of carbon loading simulated).

Future refinements of the model will be:

1) configuring the model for deeper (than 0.5 cm) sediment strata (involving sulfur, nitrogen and reduced carbon compounds as the main redox determining species);

2) the inclusion of temperature and oxygen field data for 1984-1987;

3) inclusion of estimates of the proportion of non-sewage labile carbon (dependant upon getting laboratory analyses done);

4) adjustment for changes in porosity if grain size is found to have changed;

5) inclusion of storm effects;

6) the calculation of benthic macrofauna response.

LITERATURE CITED

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Walker, J. C. G. 1980. The Oxygen Cycle. In, The Handbook of Environmental Chemistry, Vol 1, Part A, The Natural Environmental and Biogeochemical Cycles,(O. Hutzinger, Ed.), Springer-Verlag, NY.

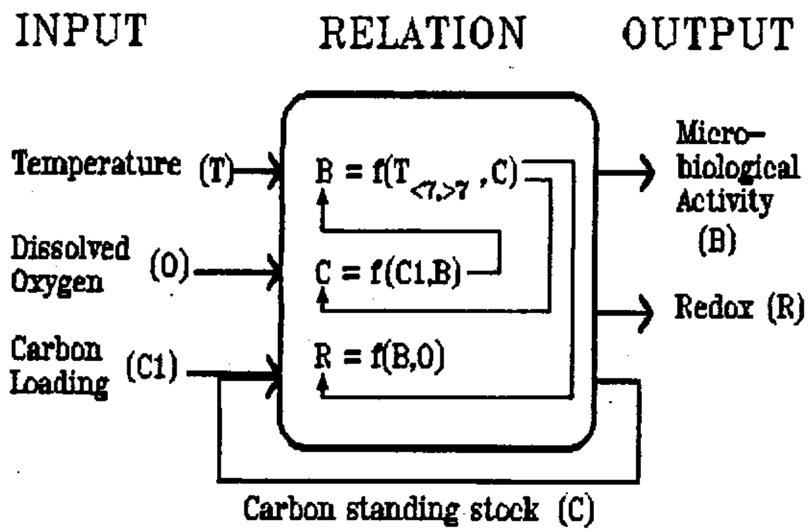

Figure 1. Schematic diagram of sediment biogeochemistry model.

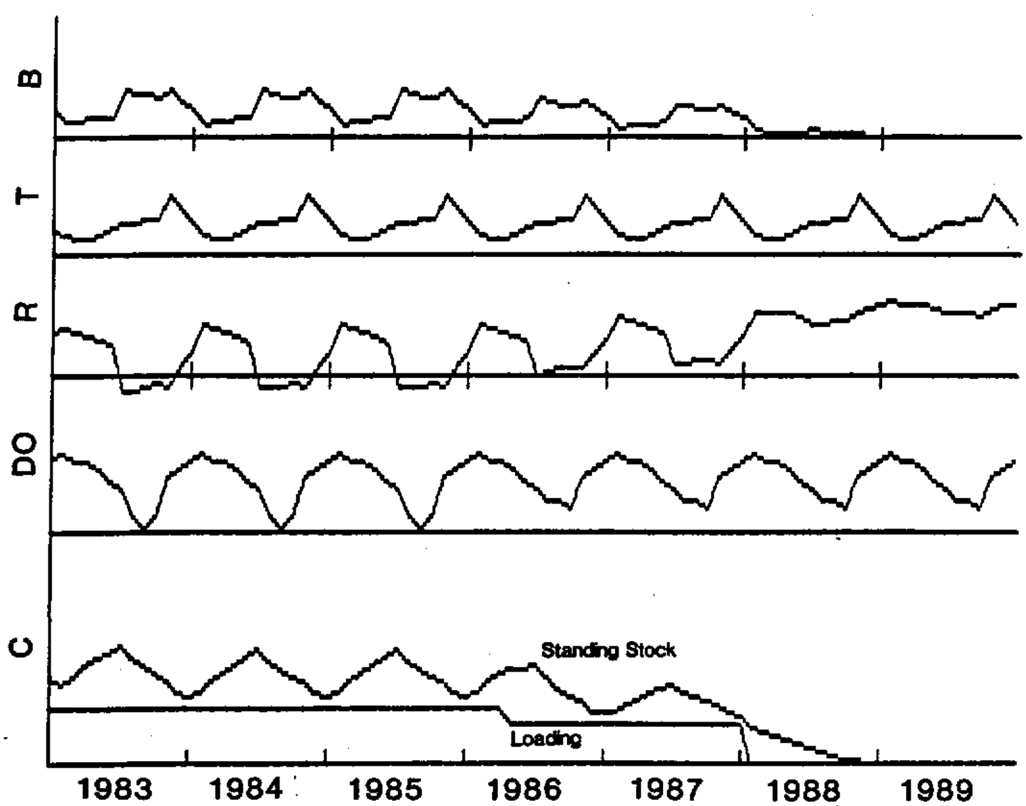

Figure 2. Sediment biogeochemistry model with labile carbon from non-sewage sources equal to 2% of pre-cessation sewage sludge labile carbon loading. (B = microbiological activity, T = temperature, R = redox potential, DO = dissolved oxygen, C = carbon)

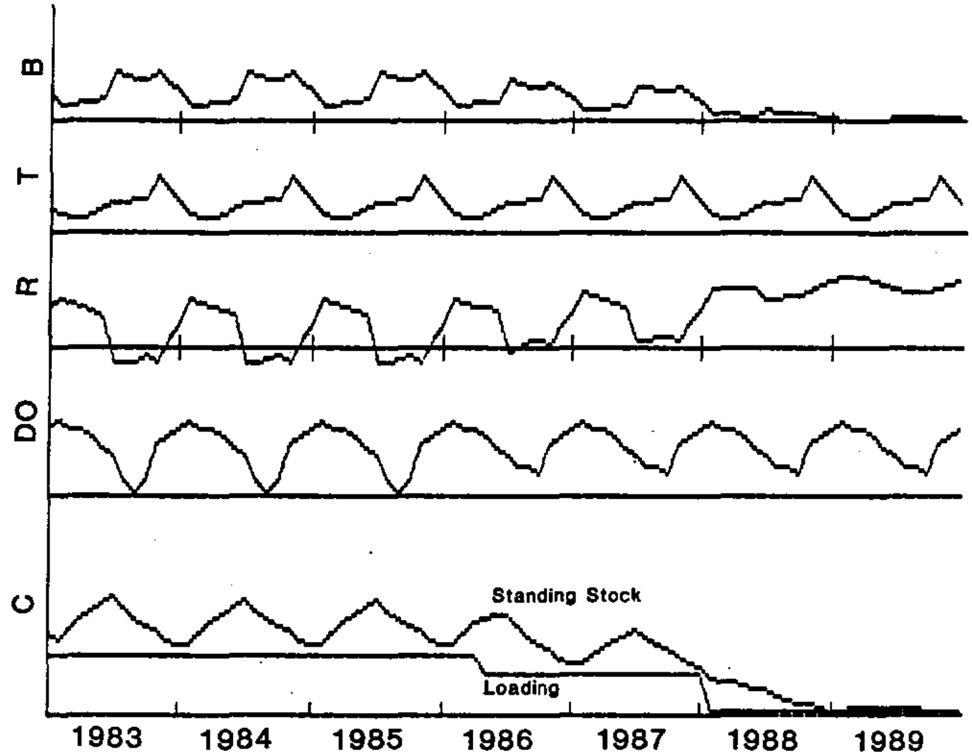

Figure 3. Sediment biogeochemistry model with labile carbon from non-sewage sources equal to <u>9% of pre-cessation</u> sewage sludge labile carbon loading. (B = microbiological activity, T = temperature, R = redox potential, DO = dissolved oxygen, C = carbon)

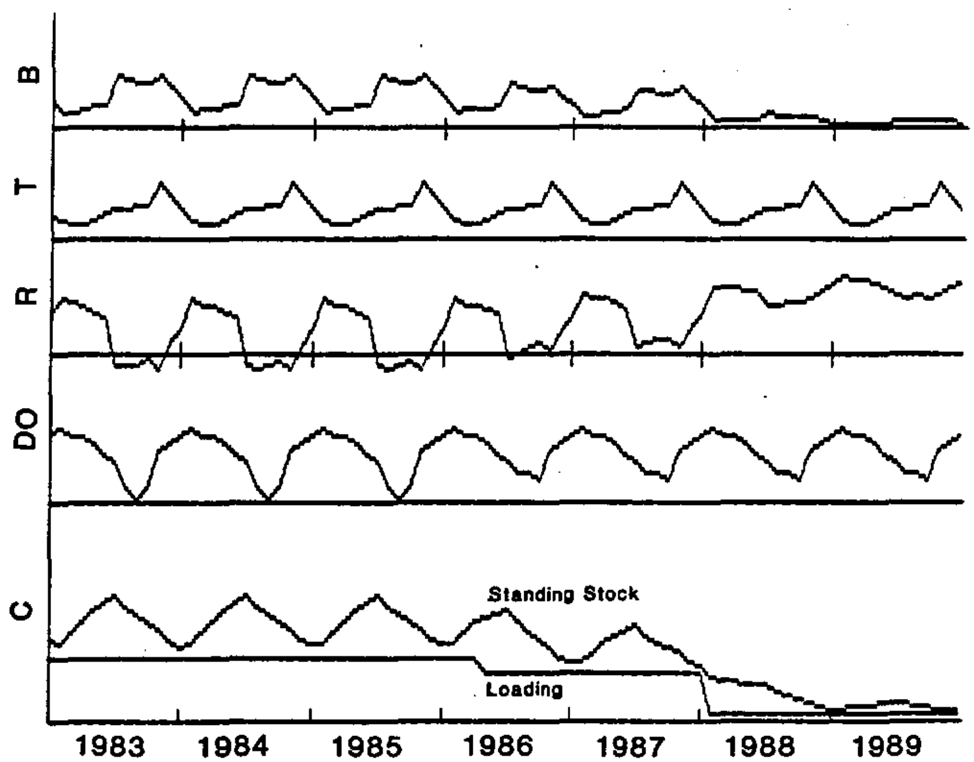

Figure 4. Sediment biogeochemistry model with labile carbon from non-sewage sources equal to <u>17% of pre-cessation</u> sewage sludge labile carbon loading. (B = microbiological activity, T = temperature, R = redox potential, DO = dissolved oxygen, C = carbon)

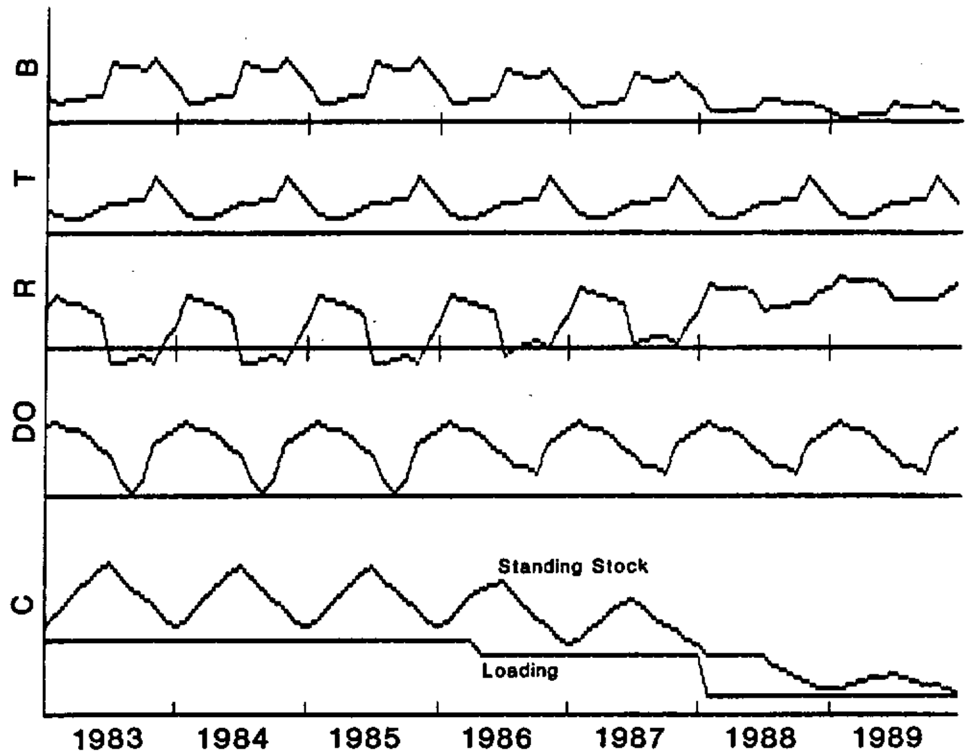

Figure 5. Sediment biogeochemistry model with labile carbon from non-sewage sources equal to **29% of pre-cessation** sewage sludge labile carbon loading. (B - microbiological activity, T - temperature, R - redox potential, DO - dissolved oxygen, C - carbon)

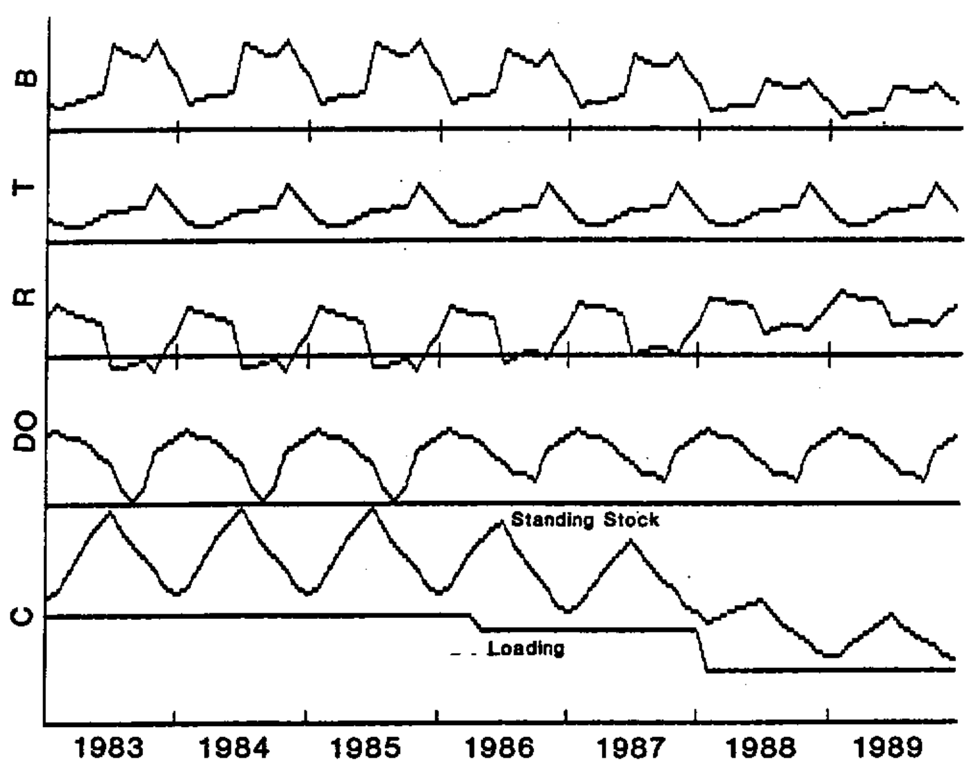

Figure 6. Sediment biogeochemistry model with labile carbon from non-sewage sources equal to **50% of pre-cessation** sewage sludge labile carbon loading. (B - microbiological activity, T - temperature, R - redox potential, DO - dissolved oxygen, C - carbon)

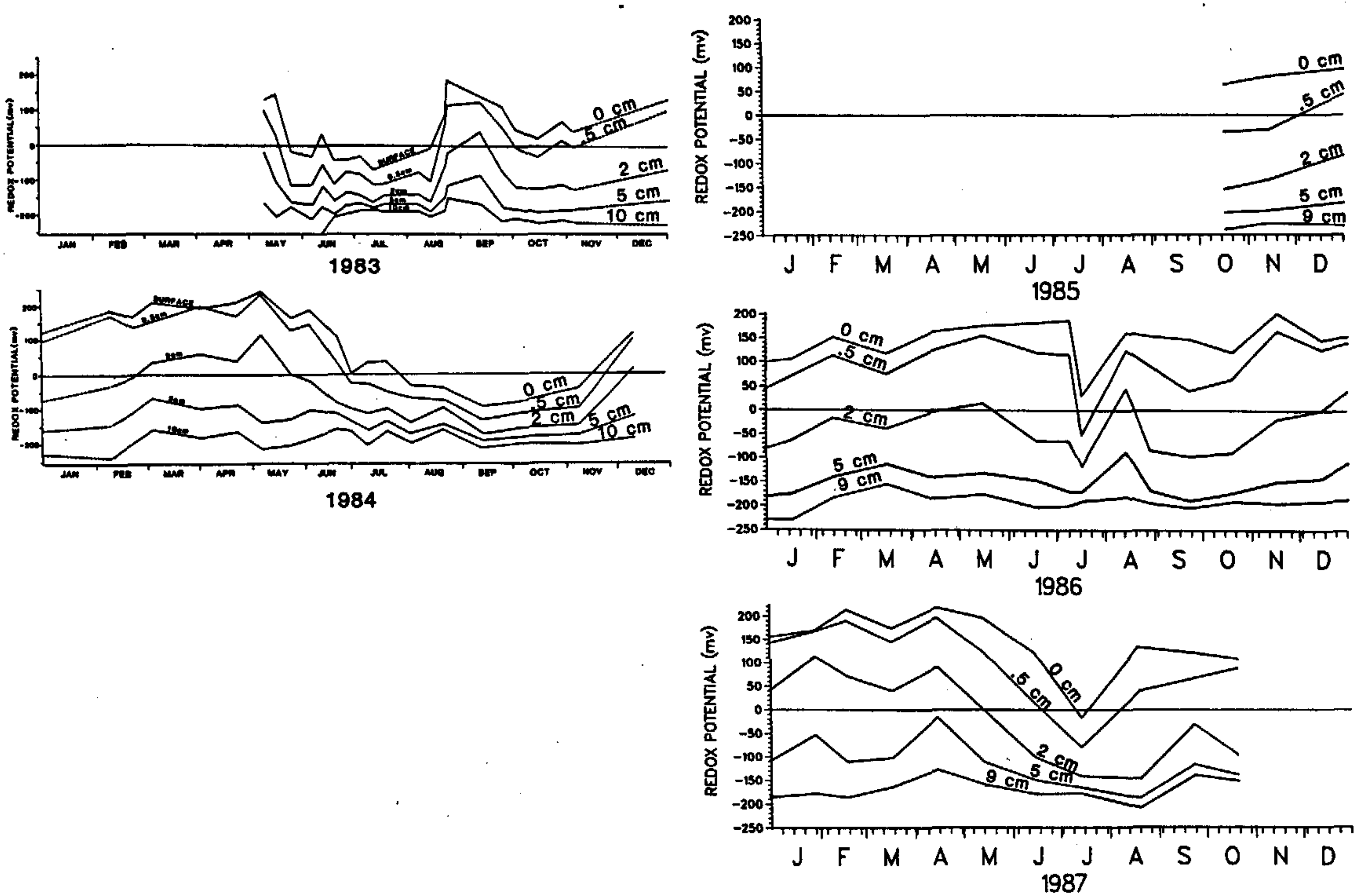

Figure 7. Sediment redox potential at station NY-6: 1983-1987