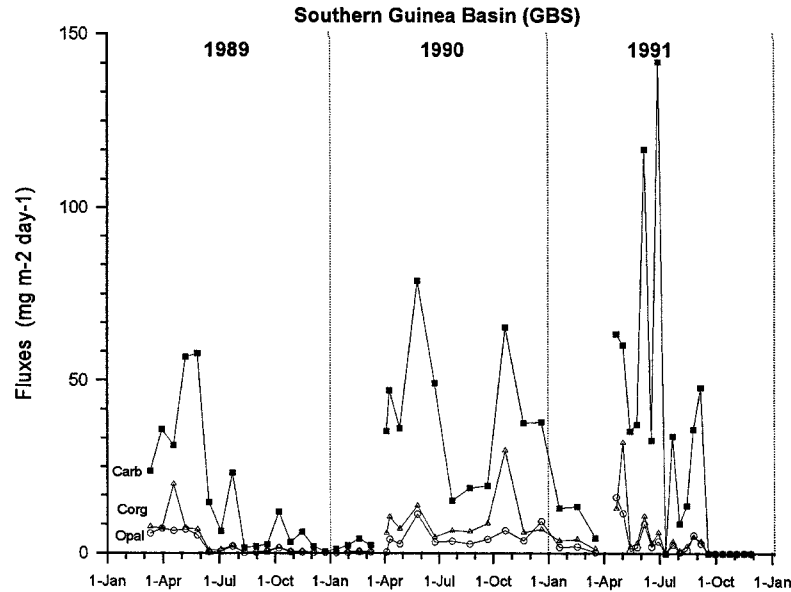


**Figure 10.4** Seasonal total and lithogenic fluxes in the southern Guinea Basin (GBS). (a) upper traps (597–1068 m). (b) lower traps (3382 m).



**Figure 10.5** Seasonal carbonate, opal and organic carbon fluxes at GBS (upper traps: 597–1068 m).

a decreasing influence of the ITCZ in spring. The relatively low summer carbon fluxes revealed C/N ratios between 8.0 and 9.1 and  $\delta^{13}\text{C}_{\text{org}}$  ratios of -21.4 to -21.8‰ suggesting a predominantly marine planktonic origin.

Spring sedimentation and primary production at the GBS site was also influenced by a thermal ridge at 2–3°S which is a permanent feature of the equatorial warm season (Voituriez and Herbland, 1977). This season is characterized by nutrient depletion in the surface layer (TTS) and primary production which is primarily controlled by the nitracline depth in relation to optimal light conditions. The occurrence of a deep chlorophyll maximum and the intensive biological production result in carbon export as measured with the traps.

### 10.5.1.3 Annual fluxes and year-to-variations

Annual fluxes, their composition and some ratios as well as the interannual variability given in percent of the annual average are listed in Table 10.2. The composition of the fluxes during the three year sampling period did not differ significantly. On an annual basis, the northern and southern sites were relatively similar with respect to composition and ratios except biogenic opal and lithogenic materials which constituted higher proportions (10.8 and 17.8% on average) at GBN. However, the absolute fluxes showed significant year-to-year variation,



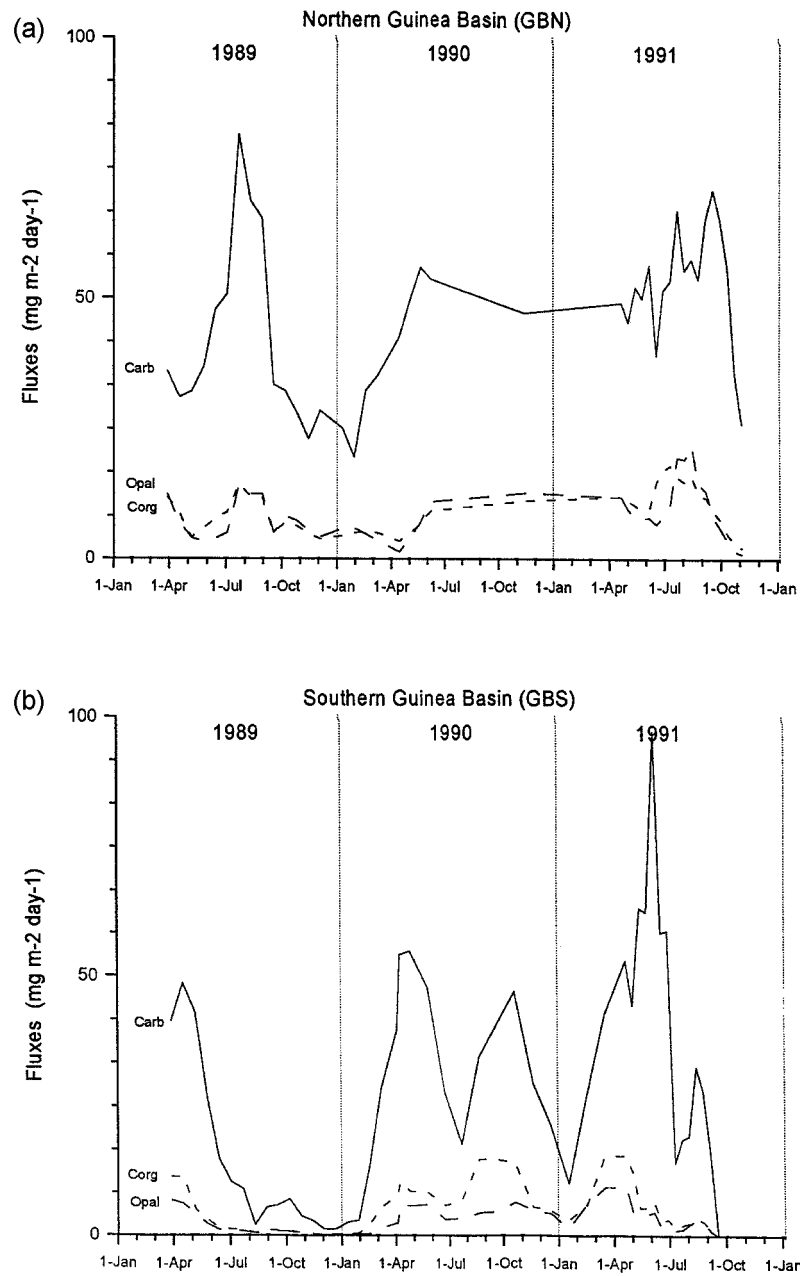
particularly in the upper traps. The recorded variation for the total fluxes was 25% at the GBN site and as much as 76% at the GBS site. These values are comparable to the interannual variability given by Lyle et al. (1992) for the northeastern Pacific. The annual values at GBN were largely determined by the magnitude of the summer sedimentation event occurring during equatorial upwelling. In contrast, annual fluxes at GBS were much more influenced by spring sedimentation representing the TTS.

Bishop et al. (1977) determined flux values through the 388 m water depth for a site nearby to GBN and found  $11.3 \text{ g C m}^{-2} \text{ y}^{-1}$ ,  $11 \text{ g CaCO}_3 \text{ m}^{-2} \text{ y}^{-1}$  and  $3.4 \text{ g biogenic opal m}^{-2} \text{ y}^{-1}$ . Our annual averages were  $2.5 \text{ g C m}^{-2} \text{ y}^{-1}$ ,  $13.1 \text{ g CaCO}_3 \text{ m}^{-2} \text{ y}^{-1}$  and  $2.6 \text{ g biogenic opal m}^{-2} \text{ y}^{-1}$ . This comparison may suggest significant regeneration of organic carbon between 400 m and 853–953 m water depth. Considering some interannual variability, the carbonate and biogenic opal fluxes show similar values. However, one has to keep in mind that different sampling techniques (traps versus pumps) were used to estimate annual flux values.

#### **10.5.1.4 Comparison between the northern (GBN) and southern sites( GBS)**

We will compare the longer records of biogenic fluxes from the upper traps with respect to the timing and magnitude of the spring and summer sedimentation events which correspond to the TTS and equatorial upwelling, respectively. For this comparison, we used the 3-point average fluxes of carbonate, biogenic opal and organic carbon depicted in Figure 10.6. Spring sedimentation events were found both north and south of the equator. However, the spring sedimentation event appeared to be more pronounced further south where thermal ridging during the TTS occurs (Voituriez and Herbland, 1981). During the three-year sampling period, the magnitude of the spring carbonate, opal and  $C_{\text{org}}$  peak increased at GBS (Figure 10.6b). This may indicate a shallowing of the south equatorial thermal ridge centered at  $2\text{--}3^\circ\text{S}$  in spring in conjunction with nutrient injection into the photic layer and increased biological production. Organic carbon and biogenic opal flux maxima seem to precede the carbonate maxima by approximately one to two months.

Spring sedimentation at GBN is at least partly influenced by land-derived material supplied by the NE trades (Wefer and Fischer, 1993). Dust plumes which also contain lithogenic materials and pollen grains may be washed out within the southern boundary of the ITCZ and supply equatorial surface waters with micro- and macronutrients (Schütz, 1980; this volume, Chapter 3). We presume that these processes influence biological production north of the equator (GBN) during the nutrient-limited TTS in spring. The  $\delta^{13}\text{C}_{\text{org}}$  and C/N data indicate that the highest land-derived contribution occurred in 1989, associated with highest organic carbon and biogenic opal fluxes. The ITCZ was farthest south almost approaching the GBS position.



**Figure 10.6** Three-point average carbonate, opal and  $C_{\text{org}}$  fluxes to the upper traps in the (a) northern (GBN) and (b) southern Guinea Basin (GBS).

Equatorial divergence generally occurring in summer in response to the intensification of the zonal winds in the western Atlantic (Houghton, 1989) was clearly documented by high fluxes of organic carbon, carbonate and biogenic opal at the northern site, particularly during 1989 (Figure 10.6a). Organic carbon flux peaks slightly preceded biogenic opal fluxes. Further south, at the GBS station, equatorial upwelling during summer was not evident in 1989 (Wefer and Fischer, 1993) but was probably reflected in the fall of 1990 by a considerable peak in the fluxes of carbonate and organic carbon. In summer of 1991, a carbonate sedimentation peak was present which was also observed further north. These findings provide evidence of a regionally variable extension of the equatorial upwelling band which affected sedimentation at both investigation sites in 1991, and probably also in 1990.

## 10.6 SUMMARY AND CONCLUSIONS

In this study we compared two three-year lithogenic and biogenic flux records from the eastern equatorial upwelling area. One site (GBN) was located at  $1^{\circ}48'N$  which is roughly the southernmost penetration of the ITCZ during spring; the other site was located at about  $2^{\circ}S$  (GBS) in the vicinity of a thermal ridge at  $2-3^{\circ}S$  occurring during the warm season. We inferred from this comparison:

1. Equatorial upwelling during the boreal summer was clearly documented by high fluxes at the northern site (GBN) and weakly at GBS, particularly in 1989. However, in 1991, and probably also in 1990, sedimentation due to equatorial upwelling was recorded at both sites suggesting a regionally variable extension of the equatorial upwelling band.
2. The ITCZ appears to have reached the southernmost position in spring 1989. Dust fallout at the southernmost boundary of the ITCZ then obviously contributed to sedimentation both north and south of the equator. The southern boundary of the ITCZ, however, generally did not reach the GBS site.
3. Production and sedimentation during the warm spring season due to thermal doming at  $2-3^{\circ}S$  was preferably expressed at the site south of the equator (GBS); increasing spring sedimentation was observed from 1989 to 1991.
4. Annual fluxes at GBN were largely determined by the summer flux magnitude; at GBS, annual fluxes were dominated by spring sedimentation during the TTS. Interannual flux variations were substantial, reaching 25% at GBN and as much as 76% at GBS.

The flux patterns indicated substantial seasonal and interannual variation in the eastern equatorial upwelling area. We also found important differences between both trap sites although they were located close to each other. The study area appeared to be highly variable, both spatially and temporally, with respect to surface water properties, atmospheric circulation (e.g., ITCZ movements), and the

resulting downward fluxes. Detailed studies covering the eastern (10°W) and western equatorial Atlantic (30°W) with N-S transects are currently underway and will increase our knowledge of sedimentation in the equatorial upwelling area. Long-term records and reconstructions of sea surface temperatures using stable isotopes of calcareous planktonic shells will provide information on the intensity of upwelling, year-to-year variations and occasionally occurring anomalies: e.g., El Niño-like responses (Hisard, 1980) in the eastern tropical Atlantic.

## 10.7 ACKNOWLEDGMENTS

We are grateful to the officers and crew of the research vessel *Meteor* for competent assistance in the deployments and recoveries of the moorings. We also thank G. Krause (AWI, Bremerhaven) and S. Catewicz for processing the current meter data. This research was funded by the Deutsche Forschungsgemeinschaft (Sonderforschungsbereich 261 at Bremen University, Contribution 88).

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