Anonymous Referee #2

This manuscript presents a topical report on the oxygen uptake of the sediments in front of the Rhone river delta. The dataset consists primarily of O2 micro-electrode profiles (DOU), obtained both in situ and ex situ, as well as data on the total O2 uptake (TOU) obtained ex situ in whole core incubations. This O2 uptake dataset is further supplemented by porosity, Chl a and organic carbon content data.

There is nothing really wrong with this manuscript. The methods are state-of-the-art in terms of O2 uptake and seem to be well executed (only the application of the Eddy Correlation technique would have been a valuable complement to the current dataset, providing in situ TOU values, but the application of the Eddy technique cannot yet be considered routine). The resulting DOU and DOU dataset is carefully reported (including detailed info on porosity profiles, bottom water temp en O2 concentration, and sediment parameters). As a result this dataset will provided a valuable contribution to the existing global dataset on in situ DOU values.

Still, I can't say that I am terribly excited after having read the manuscript. There is little novelty or creativity in the way the data is interpreted. Some obvious questions concerning organic matter processing in deltas are not touched upon in the discussion. Moreover, the questions that are addressed in the discussion are treated in a rather "light" way, and so overall, the manuscript attains the character of a valuable data report.

Given the high quality of the dataset, I think publication in BG could be possible, but then the discussion and framing of the results should be improved.

Major comments

The text should be carefully screened and improved, because throughout, the manuscript contains improper grammatical constructions and incorrect expressions (a few are indicated below in the detailed comments).

Reply: The text has been read by a native English speaker and modified according to the detailed comments.

The first sentence of the abstract reads: "the biogeochemical fate of the particulate organic inputs from the Rhone river was studied". Equally, the last sentence of the conclusion reads: "coastal sediments off the Rhone act as … a degradation centre for flood deposits". I'm not *convinced this is truly what is this study shows. The question of how much of the mineralization (or the O2 consumption) is due to the input of riverine material on the one hand, and due to local primary production on the other hand, is left unanswered. More importantly, the question is not even posed. So: is the high Chl a and the high org C content in the river mouth stations due to riverine input or locally produced? To me the high Chla would indicate local production (stimulated by riverine nutrient input), but then one would expect a strong seasonal signal in the DOU and TOU (because of seasonality in production). Such seasonality does not appear to be there. This important issue should be further sorted out in the discussion.*

Reply: In most coastal ocean regions located at the river-sea connections, it is known that the primary production is low because of the large turbidity due to particles delivered by the river (Dagg et al., 2004). Thus sediments in large river deltas are mostly constituted by terrestrial particles. In the Rhone river delta, it has been demonstrated using different techniques that the sediment is of terrestrial origin (Radakovitch et al., 1999). Stable carbon isotopes clearly indicate terrigeneous material with $\delta^{13}C$ signatures around -27‰ reflecting the river input signature (Lansard et al., 2009). Moreover, associated with rather low N/C ratios and high lignin content, this material represents a mixture of fine soil organic matter and plant debris (Tesi et al., 2007). The wood fragments (high OC and lignin contents) are retained within the prodelta area, while the soil-derived OM adsorbed onto fine fraction, lignin poor particles, is selectively transported out of the prodelta along the main sediment dispersal system (Tesi et al., 2007). Thus, the contribution of marine organic matter in the sediments of the Rhône River prodelta is not significant.

Chla measured in sediments close to the river mouth is delivered by the river. To strengthen this idea, in our revised manuscript, we added Chlb data, which, in the case of the Rhône River, is linked of terrigeneous material (Alliot et al., 2003). The high OC and Chla contents we observed at the Rhône River mouth were associated with high Chlb and Pheoa contents; offshore stations presenting lower degraded material content and no Chlb. This likely reflects inputs of terrestrial phytodetritus (Christensen, 1962) rather than local primary production stimulated by riverine nutrient inputs. Hence, marine contribution to the sediments of the Rhône River prodelta seems negligible, the benthic degradation system being driven by riverine inputs rather than local primary production. Moreover, the Rhône River mouth is an area of low biomass and primary production (Pujo-Pay et al., 2006) and is characterised by a relatively constant level of

chlorophyll a throughout the year (Lefevre et al., 1997). Although seasonal primary production may control the benthic mineralization further offshore on the shelf (which we do not see in our data, sampled from spring to summer and winter periods), temporal variability of the DOU rates in the prodelta area results from hydrological variability of the Rhône River.
The Chlb data have been added to the discussion in the revised manuscript, and we better emphasize the terrestrial origin of sediments in the Rhône River prodelta.

There are two major conclusions regarding the O2 consumption in the Rhone prodelta sediments: (1) The absence of seasonality (2) The fact the O2 consumption decreases after a flood event and then goes back up to the pre-flood value. The discussion of both topics is presently rather shallow, and could certainly be deepened and improved.
Absence of seasonality. - Is the present temporal resolution in sampling enough to determine that there is no seasonality?
Reply: We agree that the temporal resolution of the sampling might not be appropriate to investigate yearly seasonality of DOU rates in the study area and instead of using "seasonality" we now use "temporal variations" The title of the paper is thus now: **Temporal variability of carbon recycling in coastal sediments influenced by rivers: assessing the impact of flood inputs in the Rhône River prodelta.** Nevertheless our paper gives insights of inter- and intra-yearly variability. As discussed above, sediments in the Rhône River prodelta clearly derive from the river inputs (shown by previous papers, see above and not re-discussed here). Sampling during contrasted water discharge regimes allow us to link depositional and benthic degradation processes, and to constrain better the factors controlling this temporal variability.

- What about primary production in the Rhone river mouth? (both yearly averages as well as seasonality). Primary production is not included in the discussion at all. There must be data on this…
Reply: As stated above, the Rhône River mouth is an area of low biomass and primary production (Pujo-Pay et al., 2006) and is characterised by a relatively constant level of chlorophyll a throughout the year with no striking seasonal variations (Lefevre et al., 1997). Moreover, Lefevre et al (1997) pointed out that the low primary production at the Rhône River mouth, and in the plume were associated with high dark community consumption rates,

suggesting that bacterial respiration mostly based on terrestrial particles would certainly recycle the little production in the turbid freshwater plume.

- *There is remarkable little seasonal variation in the temperature and bottom water O2 (see table 1). Why is this?*

Reply: The Mediterranean Sea has a bottom temperature of 13.5°C, thus when the shelf is fed by deeper water mixed during winter, the temperature is between 13.5°C and 14°C. In summer, stratification can occur forming a thermocline which separates a bottom layer (minimum temperature ~13.5°C on the shelf) from an upper layer with a mean temperature of about 20°C and surface values reaching maxima around 25°C (Millot, 1990). Nevertheless, in the Rhône coastal region, this stratification occurring during summer warming is counteracted by secondary wind-induced circulation, which frequently breaks stratification and maintains high oxygen levels and roughly constant temperatures in the bottom water of the shelf region (Rabouille et al., 2008).

- *There are a few previous studies that have investigated seasonality in DOU and TOU. Glud et al (2003) made a detailed study of seasonality in Aarhus Bay. One should compare to these studies in the discussion.*

Reply: The benthic degradation system of the Aarhus Bay works in a complete different way than the Rhône River mouth. Driven by local primary production, the Aarhus bay system is characterized by a tight pelagic-benthic coupling and bio-irrigated sediments (Glud et al., 2003). Besides, important variations in temperature and bottom water oxygenation (Glud et al., 2003) are likely to influence benthic degradation rates (Thamdrup et al., 1998). We do not really see the interest of comparing the seasonality in these two different systems, since it basically leads to the conclusion that the two systems are working differently and are driven by different processes.

O2 consumption decrease after a flood event. The O2 consumption is (implicitly) used as a direct one-to-one proxy for mineralization rate. This assumes that sedimentary mineralization (CO2 production) always scales with O2 consumption. However, the question is whether this critical assumption holds in a transient situation as right after a flood deposit. There are (at least) two possible explanations for the O2 consumption decrease after a flood event: (1) It takes time to re-establish the microbial community that performs the mineralization. This would temporarily lead *to a decreased mineralization (i.e. CO2 production) as well as decreased O2 consumption right after the flood. (2) It takes time to re-establish the gradients of reduced products from suboxic/anoxic diagenesis. This could temporarily decrease the O2 consumption right after the flood, but not the mineralization (i.e. CO2 production) Somehow the authors favor the second mechanism. But this choice is only speculative. There is no data to support this conclusion. Based on O2 consumption data alone (i.e. without CO2 production rates or other mineralization data), one cannot rule out the first option. Accordingly, the discussion on p 10793 about transient redox fronts as the cause of the decreased O2 consumption after the flood is speculative. Overall, the discussion of the decreased O2 consumption after the flood should be more thorough.*

Reply: We agree with the reviewer that with the current data set, we do not have argument to clearly identify the processes involved in the return to stationary conditions after the June 2008 flood event. What we actually observed is:

- Sediments located offshore on the continental shelf seem to be unaffected by the flood: their DOU rates remained constant over our sampling cruises.
- The June 2008 flood generated an immediate decrease in DOU rates in the prodelta. This restricted zone corresponds to the major deposition area of the Rhône River inputs (Lansard et al., 2009;Lansard et al., 2007;Ulses et al., 2008;Radakovitch et al., 1999).
- 6 months after this flood event, the benthic degradation system of the prodelta has reached back the values observed in low discharge rates conditions, which can therefore be considered as stationary ones (i.e. continuous sediment deposition).

In the discussion, we describe the mechanisms involved in this return to stationary conditions. As stated by the referee, they imply in particular the re-establishment of both the microbial community (migration, growth, selection), and the redox gradients. The DOU rates measurements at initial and final time do not allow us to define which process dominated. From our data set, we extrapolated the time constants of diffusion (years) versus reaction (days) processes. This provides the order of magnitude of the time scale of each process, and highlights that diffusion only can not explain our 6 months recovery time-scale. Since the previous discussion might not have been cautious enough, **this part of the discussion has been rephrased** in the revised manuscript.

In addition, redox potentials have been measured in the June 2008 deposit and have been added to the revised manuscript. Combined with the sediment description of Fig.11, they give insight of the redox front during the flood. The redox potential profile in the June 2008 flood deposit presents positive values from the surface until 10 cm depth. Then anoxic processes settle down with values more and more negative until the 28-30 cm level. In the underlying ochre mud (30-32 cm), the redox potential rises again, reflecting thus the location of the old sediment-water interface. Below this former interface, the dark muds with strong H_2S smell are reduced twice more than the bottom part of the flood deposit: this likely reflects the anoxic processes taking place in the sedimentary column under normal discharge rates conditions. Therefore, the discussion of the revised manuscript now describes the potential processes involved (relying to this redox potential profile), but focuses more on the time scales of each based on literature data, while cautiously avoiding to state about dominant mechanisms.

The dataset offers more topics for discussion than currently addressed: (1) An average TOU/DOU ratio of 1.2 is reported, but no further discussion is given what could cause the DOU to differ from the TOU, nor is any comparison made with TOU/DOU ratios in other coastal environments. Is there any information on bioturbation (eg 210Pb) or bio-irrigation rates, or info on the benthos at the sites (as a proxy for the intensity bio-irrigation and bioturbation)?

Reply: TOU/DOU ratios were 1.2 +/- 0.4 and not significantly different from unity except for stations J and I, less influenced by the Rhône River inputs. These values are in agreement with values recorded previously in the same area by Lansard et al. (2008, 2009). These authors already discussed these TOU/DOU values and their implications for the benthic ecosystem. They also compared them to similar environments: they pointed out that most of the sediment oxygen demand off the Rhône River mouth is driven by diffusive processes and largely influenced by the Rhône River inputs. Moreover, in a coastal station located near our study area (Gulf of Fos), Rabouille et al (2003) found similar TOU/DOU ratios (close to unity) and discussed extensively the controlling mechanisms involved. Few mixing rates determined from 210Pb measurements in the Rhône River prodelta are available, and values of bioturbation coefficients Db range from 0.22 to 12.7 $cm^2 y^{-1}$, consistently with similar coastal environments (Duport et al., 2007;Schmidt et al., 2007), but falls in the lower range of the set of values recorded by Teal et al. (2008) for Temperate North Atlantic systems. Moreover, (Rosenberg et al., 2003) reported lower apparent redox potential discontinuity (aRPD) and Benthic Habitat Quality (BHQ) index in the prodelta than further offshore in the self. The prodeltaic sediments correspond thus to an early successional stage II characterized by moderate macrofauna abundance, biomass and species diversity (Nilsson and Rosenberg, 2000). Therefore, as stated by Lansard et al. (2008), sediments in the Rhône River prodelta are likely to present relative low benthic macrofauna activities, consistent with the TOU/DOU ratios close to 1.

Since TOU/DOU ratios and the processes they reflect have already been discussed in previous studies, we do not think that further discussing these aspects would represent a valuable contribution to the paper, especially since we do not bring new features or more arguments than the previous authors.

(2) One recent topic of attention is the small-scale variability in DOU and OPD, as recently demonstrated in the deep sea (see Glud et al L&O 2009). Figure 10 hints that such variability is also present here (some profiles show a homogeneous consumption, while other profile at the same site show a peak consumption at the oxic-anoxic interface). How much variability is there in the DOUOPD relation here (a DOU versus OPD plot might be useful)?

Reply: As suggested by the referee, we plotted our DOU versus OPD. Previous studies suggested that in homogeneous sediments both are related as $OPD = 2\phi Ds\frac{[O_2]_{bw}}{DOU}$ (Cai and Sayles, 1996), where ϕ stands for porosity, Ds for the diffusion oxygen coefficient in the sediment and $[O_2]_{bw}$ for the oxygen concentration in bottom waters. We observe a good agreement between this relation and our data (cf. Figure 1). This likely indicates steady-state O_2 distribution, uniform distribution of organic material and negligible irrigation in the Rhône River prodelta sediments, as have been observed in other shelf and continental margin sediments (Cai and Sayles, 1996). The Rhône River prodelta would therefore be a diffusive system, with benthic mineralization driven by microbial processes rather than macrofauna activity. As stated earlier, this last point has already been evidenced and discussed in Lansard et al. (2008, 2009), in particular, based on TOU/DOU ratios, and our dataset does not provide significant breakthrough or further argument on this issue. We therefore chose to focus on the originality of our dataset, namely the temporal evolution of the oxygen demand in these sediments especially during a flood period.

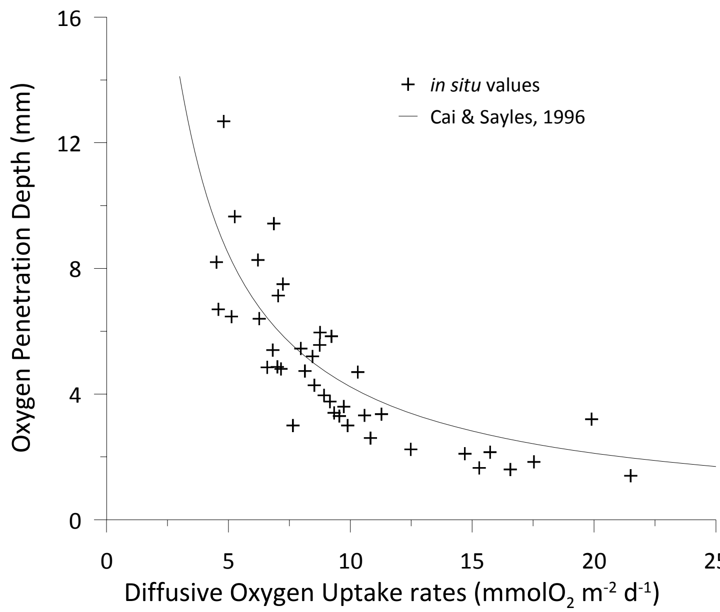

Figure 1. The O_2 penetration depth, OPD, plotted as a function of the DOU rates calculated from our in situ O_2. The solid line indicates the relation as predicted from OPD = $2\phi Ds([O_2]_{bw}/DOU)$, (Cai and Sayles 1996)

Section 4.1 discusses that ex situ DOU values are lower than in situ values for the stations in the river mouth displaying high activity (large DOU and small OPD). However, this discussion is rather unsatisfying. After a quite long and winding discussion, a boundary layer effect is hypothesized to be cause of the discrepancy. However, no further arguments are given to support this hypothesis. Firstly, the thickness of the diffusive boundary layer could be deduced from the upper part O2 profile (at least for some "nice" profiles). Secondly, one could vary the stirring rate of the lab incubators to examine boundary layer effects on DOU (this has been done in the past).

Reply: Thanks to the referee's comment, we checked the DBL thickness: there were no significant differences between ex situ and in situ measurements. We therefore performed further statistical tests (signed rank test, $p<0.05$) that confirmed the discrepancy between our in situ and ex situ DOU rates and indicated that it was likely due to the high variance of our in situ fluxes. This suggests that the ex situ DOU rates measured on small diameter cores were not able to capture the small scale spatial heterogeneity of the sediment. The discrete core sampling, the core selection by the operator (in order to get an interface as plane as possible) added to the intrinsic spatial heterogeneity of the sediment could result to an under-representation of the small scale spatial heterogeneity (Lansard et al., 2008;Devol and Christensen, 1993). Therefore, it would lead to a reduction of the variance of ex situ DOU rates by excluding some of the processes that can potentially generate this small-scale spatial variability such as hot-spots of organic matter (Rabouille et al., 2003). This comparison of in situ vs. ex situ DOU rates has thus been rewritten and reoriented in the revised manuscript: differences were discussed and interpreted in terms of spatial variability of the system.

Figure captions and elsewhere (P10785). The porosity is not "calculated" but fitted to expression (2). Because of the freedom inherent in this fitting procedure (one can adapt the parameter m), one should expect a rather good agreement between data and fitted profiles. Accordingly, the correspondence between "measured" and "calculated" profiles is not as surprising.

Reply: We agree with the referee that the term "calculated" was not appropriated. As stated by the referee, the *m* coefficient was tuned so that porosity derived from formation factor fit the measured porosity profiles. We did not interpret the concordance between measured and derived porosity as a "surprising" achievement but rather as a confirmation of the reliability of our estimations. Indeed,

1) the resolution of our measured porosity profile (≥ 2mm) is lower than the one of the formation factor
2) small-scale spatial variability on the sampling site could lead to wrong porosity assessment
3) *m* coefficients were 2.2 ± 0.4. This is in the lower range of *m* values reported for coastal sediments constituted by high porosity ($\phi > 0.7$) muds ($m \sim 2.5 – 3$).

Text has thus been changed in the revised manuscript. "The porosity derived from F^{-1} factor through the power law $F^{-1} = \varphi^{-m}$ were fitted to the measured values. As displayed in Figure 3, correlation with the fitted profiles (plain curves) and the measured porosity profiles (dots) were good, indicating the reliability of our porosity estimations. Indeed, in average r^2 is 0.9939 ranging between 0.9795 and 0.9997."

Detailed comments

I would suggest to split section 4.2 into separate sections - spatial variability in O2 uptake - seasonality in O2 uptake - effect of flood deposits on O2 uptake

Reply: As suggested by the referee, the section 4.2 has been split into separate sections: spatial variability in O2 uptake – Temporal variability in oxygen uptake – effect of flood deposits on O2 uptake.

P10790 An input of 3.5x10ˆ6 tons of and 80x10ˆ3 tons of org C provides an OC content of 2.29% in the deposit (solid sed density = 2.5 g cm-3; porosity = 0.8). However, the data in figure 11 shows only an OC content of ~1% in the deposit. Where does this discrepancy come from?

Reply: Instantaneous flood discharge rates and Suspended Particulate Matter (SPM) measurements were performed in June 2008 at the Arles station. Integrated over time, they give an accurate estimation of the total particulate material discharged. Incorporating this new data, we re-assessed the amount of particulate material discharged, which gives a total input of the Rhône River during our sampling period (10 days) of 4.9 10^6 tons of sediments. With 7.9 10^4 tons of OC delivered it leads to a potential OC content in the flood deposit of 1.6%. This value is still higher than the 1.05% OC content we observe in our flood deposit at a single station.

Nevertheless, several aspects have to be taken into consideration. First, this calculation assumes that the particulate inputs of the river have been integrated over time. Therefore this average of 1.6 % OC content in the flood deposit would only be valid under several conditions:

1) Homogeneous and continuous inputs over time

2) Homogeneous and continuous disposal of the inputs over space

The evolution during the flood of the OC content of the particulate matter delivered by the Rhône River is highly variable, with values ranging from 1 to 4.5 %. The major part of the flood inputs occurred during the flood peak that delivered 2.3 10^6 tons of sediments poor in OC. Indeed, 50% of the total particulate inputs were delivered in 2 days with a mean OC content in the SPM of 1%, the rest being deposited over 8 days with OC contents between 1 and 4.5 % (these data are to be published in an article in preparation). It is therefore likely that this high amount of poor material discharged constitutes the flood deposit we observed at our sampling station.

In addition to this temporal variability of the riverine inputs during the flood, one must consider the spatial heterogeneity of these inputs. Indeed, the deposition of flood material is not spatially homogeneous. Tesi et al. (2007) highlighted that terrigeneous material has different hydrodynamical behaviour depending on its nature and in particular its OC content (see above): the rest of the flood material more variable in OC content and delivered at lower discharge rates may have been spread all over the prodelta and further in the continental shelf, and may probably been diluted in the first low OC content deposit. As displayed in the manuscript in Table 1. (P. 10802), the OC content of surface sediment in June 2008 in the Rhône River prodelta is not homogeneous, ranging from 0.8 (station F) to 1.8 (station B). The following Table 1 shows the deposit thickness on different stations during the June 2008 cruise: it is highly variable and really heterogeneous among the prodelta, consistently with previous studies (Ulses et al, 2008). The OC content of our sediment core represents an instantaneous snapshot, uncoupled from the integrated and "average" value of particulate material discharged over the whole flood period. A correspondence with the integrated OC content of the discharged material and our sediment deposit would therefore only be a coincidence, and the discrepancy we observe is completely normal.

Table 1. Deposit thickness at different sampling sites during the June 2008 flood.

Station	Longitude	Latitude	Depth	Date	Deposit thickness
Z	4°39.038E	43°09.925N	22	06/08/2008	>50
ZL45	4°52.881E	43°18.855N	47	06/08/2008	13
A	4°51.108E	43°18.591N	32	06/08/2008	40
AK20	4°51.107E	43°18.737N	22	06/08/2008	44

The origin/source/authors of the discharge and SPM data in Figure 2 is not mentioned.

Reply: Discharge and SPM data have been achieved in the courtesy of the CNR in the frame of the EXTREMA ANR project. This has been added in the revised manuscript.

The legends of Figures 3 and 6 are too small to be readable

Reply: Given the amount of charts, and data on them, it is unfortunately not possible to increase the size of the legend, without loosing information. Nevertheless, they are readable, especially in the digital version.

P10777 L3 Organic carbon is not a chemical element Title and P10778L14. "carbon recycling" "organic carbon recycling". More careful terminology needed. Organic carbon is not "recycled", but mineralized or decomposed to CO2 (recycling implies the transformation of one form of organic matter into another).

Reply: These comments have been taken into consideration into the revised manuscript.

P10778 "Brought insights on" -> "provided insight into" (there are more examples in the text of incorrect use of expressions)

Reply: As previously stated, the revised manuscript has been carefully scanned for improper expressions.

P10782 L2 delete "steady state" P10782 L3 "Conservation of overlying water…" bad expression

Reply: Expressions have been changed in the revised manuscript: "The oxygenation of the overlying water has been maintained using a soft bubbling system."

P10785 "normal to flood condition" bad English

Reply: "This station also displays a large change in grain size between April 2007 (normal discharge rates conditions) and June 2008 (flood conditions); mean ∅ = 6.7 – 37.4 µm; **Erreur ! Source du renvoi introuvable.**."

In station A the porosity drastically decreases right after the flood (to 0.6), but the grain size is really small. So this is not due to a sandy deposited, but due to unconsolidated mud.

Reply: The porosity of 0.6 in station A was observed in December 2008. This is probably due to the flood deposit that occurred in November 2008, and which grain size is unknown. In comparison, the flood deposit in June 2008 has a higher porosity corresponding to an "unconsolidated mud".

10791 "impoverished bio-avialable compounds" what is meant by this

Reply: This data (Buscail, R., pers. Communication) has been clarified directly in the discussion of the revised manuscript. These "bio-available compounds" corresponds to the sum of lipids, proteins and carbohydrates present in the sediment, and thus potentially available for organisms.

P10793 Units of O2 consumption rate: mmol O2 L-1 h-1. Is this per bulk volume of sediment or per volume of pore water?

Reply: Per unit volume of bulk sediment

P10793 L Wrong units: 30ˆ2/10-5 = 9x10ˆ7 s (which gives 1041 days or 2.8 years)

Reply: We did not include the result in seconds, but rather the result in days directly, because we believe that it is more explicit to the reader.

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