Reports

Storage and Remobilization of Suspended Sediment in the Lower Amazon River of Brazil

Abstract. *In the lower Amazon River, suspended sediment is stored during rising stages of the river and resuspended during falling river stages. The storage and resuspension in the reach are related to the mean slope of the flood wave on the river surface; this slope is smaller during rising river stages than during falling stages. The pattern of storage and resuspension damps out the extreme values of high and low sediment discharge and tends to keep them near the mean value between 3.0 × 10^6 and 3.5 × 10^6 metric tons per day. Mean annual discharge of suspended sediment in the lower Amazon is between 1.1 × 10^9 and 1.3 × 10^9 metric tons per year.*

Seasonal storage and resuspension of river sediments are important considerations in the design of engineering and navigation works and in the prediction of the fate of chemical constituents (including pollutants) that are adsorbed onto fine particles in rivers. Seasonally changing patterns of storage and resuspension have been observed in small (*1*) to large (*2*) rivers. We now have observed them in the world's largest river.

Large quantities of fine-grained sediment are stored and resuspended seasonally in a 750-km reach of the lower Amazon River of Brazil. In a reconnaissance sampling of the Amazon conducted during the high-water season of 1977, we determined that about 10^6 metric tons per day of previously stored sediment were being resuspended in this reach (*3*). During a more intensive sampling program from 1982 through 1984, we collected sufficient data to show the seasonal pattern of storage and remobilization of suspended sediment in this reach of the Amazon and to correlate the changing storage patterns with changes in large-scale river slope.

To collect suspended sediment from the Amazon River and its tributaries, we used a collapsible-bag sampler and a variable-speed hydraulic winch designed for depth-integrated sampling of deep rivers. Typically, depth-integrated samples were collected between the river surface and riverbed by the equal-transit-rate method (*4*) at 5 to 10 verticals equally spaced across the river. The number of sampled verticals depended on the width of the river and the heterogeneity of sediment concentrations in the cross section. The samples collected at all verticals in a given cross section on a given day were then combined to yield a composite sample from which we were able to measure and compute the discharge-weighted concentration of suspended sediment. Water discharges were measured at each cross section at the same time that we sampled the suspended sediment (*5*).

From 1982 to 1984, we sampled the Amazon repeatedly in a 2000-km reach between the mouth of Rio Içá and the town of Óbidos in Brazil. On a typical sampling trip, we collected suspended-sediment samples and measured water discharge at 11 cross sections of the Amazon mainstem and in the downstream reaches (usually within 50 km of the mouths) of seven major tributaries (Fig. 1). On each sampling trip, the cross section farthest upstream was sampled first, and successive mainstem sections and tributaries were then sampled in downstream order.

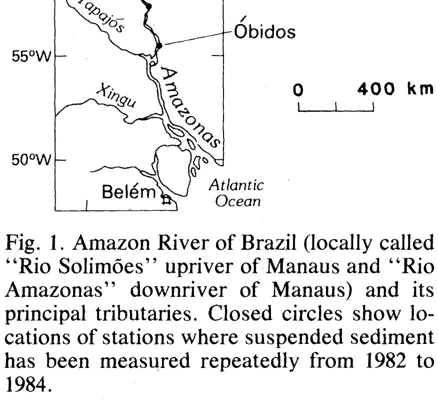

Fig. 1. Amazon River of Brazil (locally called "Rio Solimões" upriver of Manaus and "Rio Amazonas" downriver of Manaus) and its principal tributaries. Closed circles show locations of stations where suspended sediment has been measured repeatedly from 1982 to 1984.

The discharges of suspended sediment in the Içá-Óbidos reach at seven different stages of the hydrograph are shown in Fig. 2. The annual hydrograph of the Amazon mainstem is fairly simple, usually consisting of one major rise and fall plus perhaps one or two secondary rises early in the rainy season (Fig. 3). The graphs of sediment discharge (Fig. 2) show that discharges (represented by the width of the shaded patterns) are substantially greater during the early and middle rising stages (B–D) than they are during peak and falling stages (E–G). This indicates that plots of the relations between sediment discharge and water discharge will form loops rather than simple curves or straight lines. Looped patterns also are typical of other large rivers such as the Mississippi and Orinoco (*2, 6*).

Considerable quantities of sediment are contributed by Rio Madeira. At mid-rising stages on the Amazon mainstem, which correspond in time to peak stages on Rio Madeira, the input from the Madeira can double the sediment discharges of the mainstem (Fig. 2, C and D). More than 90 percent of the total suspended sediment discharged by the Amazon mainstem of Brazil is contributed by the combination of Rio Madeira (which drains the Andes of Bolivia) and the drainage basin of the Amazon above Rio Içá (which includes most of the Andes of Peru). These data confirm earlier statements that the overwhelming preponderance of sediment in the Amazon mainstem is derived from the Andes (*7*).

Seasonal changes in the storage and remobilization of suspended sediment in the Amazon mainstem are most apparent in the 750-km reach between Manacapurú and Óbidos. During early and middle rising stages (Fig. 2, A–C) sediment discharges in this reach decrease downriver, indicating that suspended sediment is going into storage. Conversely, at near-peak and falling stages (Fig. 2, E–G) sediment discharges through this reach increase downriver at rates greater than can be attributed to inputs from tributaries, indicating that sediment is being resuspended from storage.

This pattern of storage and suspension can be correlated with the mean slope of the river surface—that is, the slope of

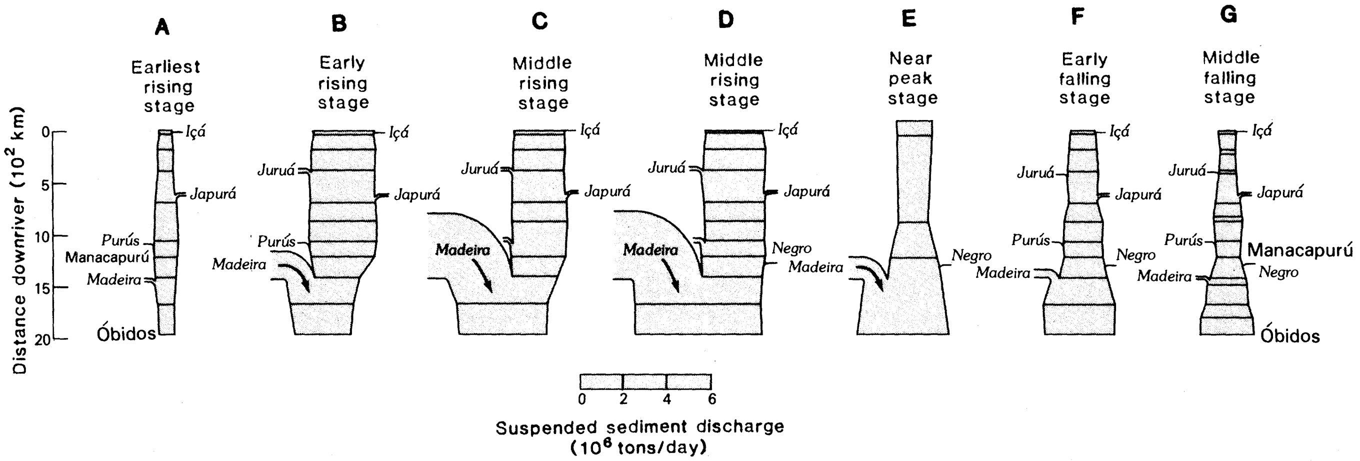

Fig. 2. Suspended-sediment discharges in the Amazon River mainstem and in principal tributaries, as measured in downriver sequences at different river stages. (A) Earliest rising stage, October and November 1983. (B) Early rising stage, November and December 1982. (C) Middle rising stage, March and April 1983. (D) Middle rising stage, February and March 1984. (E) Near-peak (late rising) stage, May and June 1977; data from Meade *et al.* (*8*). (F) Early falling stage, June and July 1983. (G) Middle falling stage, August and September 1982. Thickness of shaded patterns indicates sediment discharge. Horizontal lines drawn through shaded patterns indicate where suspended-sediment discharge was measured. Suspended-sediment discharge was measured but was too small to be portrayed at this scale (that is, $<10^4$ metric tons per day) in Rio Jutaí during all sampling cruises except E; in Rio Negro during cruises A, B, and C; and in Rio Juruá during cruise A. Only two tributaries were sampled during cruise E.

the flood wave averaged over the 750-km reach. The key observation is that the mean water-surface slope between Manacapurú and Óbidos is greater during falling stages than during early and middle rising stages. This observation is contrary to the usual expectation that, as a flood wave moves progressively down a large river, the slopes on the front of the wave during rising stages will be steeper than the slopes on the back of the wave during falling stages. In the lower Amazon, however, the expected pattern is distorted by three large tributaries—Rios Madeira, Tapajós, and Xingu—that reach their peak discharges 2 months earlier than the Amazon mainstem at Manacapurú. At the time of their peak stages in April, these three tributaries together may be contributing as much as 40 percent of the total water discharged by the Amazon to the ocean. This causes the annual peak stage at Óbidos to precede the peak at Manacapurú (Fig. 3), and it causes the mean water-surface slopes in the Manacapurú-Óbidos reach to be greater on falling stages than on rising stages.

The slopes of the Amazon are not known with precision because the elevations along the river have been determined only by an aneroid barometer. No comprehensive spirit leveling or geodetic-satellite measurements have been carried out along the Amazon to relate local elevations to mean sea level or some other common datum. However, if we assume that the barometric measurements are approximately correct and that the river gages at Manacapurú and Óbidos share a common datum, we can discuss at least relative differences in stage if not absolute differences in elevation.

Curves of daily mean stage at two points on the Amazon mainstem—Rio Solimões at Manacapurú and the Amazon River at Óbidos—are shown in Fig. 3. The mean slopes of the Manacapurú-Óbidos reach (indicated by the vertical distances between the two curves) are smaller during early and middle rising stages (A, B, and C) than at peak or falling stages (E, F, and G). An intermediate slope recorded during the sampling, D, represents a period when the Manacapurú-Óbidos reach was showing neither net storage nor net resuspension of sediment.

The mean water-surface slopes in the Manacapurú-Óbidos reach (Fig. 3) were calculated by assuming a common datum for the Manacapurú and Óbidos gages and dividing the vertical distance between stage readings by the river distance of 750 km between the two gauges. The scale is approximate at best because we lack precise measurements of the elevations of the gauges. Nonetheless, the principle holds regardless of the absolute difference between gauge heights. When the slopes are smaller than some transitional value (1.25×10^{-5} on our approximate scale), suspended sediment is stored in the Manacapurú-Óbidos reach. When the slopes exceed this transitional value, sediment is resuspended.

With this seasonal pattern of storage and resuspension, the lower river behaves as a kind of sedimentary capacitor that damps out the extremes in the discharges of sediment past Óbidos. At times when sediment discharges in the upper Amazon of Brazil are large (Fig.. 2, B and C), the lower river stores sedi-

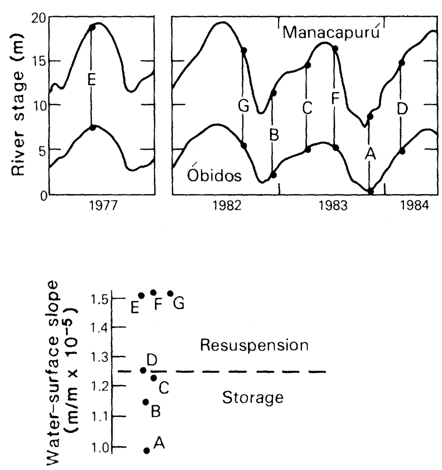

Fig. 3. (Top) Stages of Amazon River mainstem at Manacapurú (upper curve) and Óbidos (lower curve), Brazil, based on daily measurements, 1977 and 1982 through 1984; closed circles show dates of sampling of suspended sediment portrayed in Fig. 2. (Bottom) Mean water-surface slopes of Amazon River mainstem between Manacapurú and Óbidos during the different periods when sediment data were collected. Letters A–G correspond to those in Fig. 2. Daily stage data provided by Companhia de Pesquisas de Recursos Minerais.

ment, at rates of about 10^6 metric tons per day. At times when sediment discharges in the upper river are smaller (Fig. 2, E–G), the lower river resuspends sediment, again at rates of about 10^6 tons per day. This pattern tends to regulate the flow of suspended sediment to the Atlantic Ocean by keeping daily sediment discharges near the average value for large segments of the year.

On the basis of these measurements and taking into account the spacing of the measurements relative to an average annual hydrograph, we estimate the average discharge of suspended sediment past Óbidos to be between 3.0 and 3.5×10^6 metric tons per day. Therefore, the mean annual discharge of suspended sediment of the Amazon River at Óbidos is between 1.1 and 1.3×10^9 metric tons per year. This exceeds our previous estimate (*8*) by several hundred million tons per year and also agrees more closely with the measurements of sediment accumulation and transport on the continental shelf adjacent to the mouth of the Amazon (*9*).

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Monoclonal Antibody–Directed Radioimmunoassay Detects Cytochrome P-450 in Human Placenta and Lymphocytes

Abstract. *A multiplicity of cytochromes P-450 is responsible for the detoxification and activation of xenobiotics such as drugs and carcinogens. Individual differences in sensitivity to these agents may reside in the cytochrome P-450 phenotype. A monoclonal antibody–directed radioimmunoassay was developed that detects epitope-specific cytochromes P-450 in human placentas and peripheral lymphocytes. Placentas from women who smoked cigarettes contained greater amounts of cytochrome P-450 with the monoclonal antibody–specific epitope than placentas from nonsmokers. The amount of this cytochrome P-450 in human peripheral lymphocytes increased after treatment of the mitogenized lymphocytes with the cytochrome P-450 inducer benz[a]anthracene.*

The cytochromes P-450 are major enzymes for the metabolism of xenobiotics, such as drugs and carcinogens, as well as for certain classes of endobiotics, including steroids and prostaglandins (*1*). The cytochrome P-450–dependent metabolism of xenobiotics can lead to their detoxification or to their activation to toxic, mutagenic, or carcinogenic metabolites. The metabolic pathway depends in part on the phenotype or distribution of cytochrome P-450 isozymes in a tissue. The multiplicity of cytochromes P-450, the inability to measure directly their content in tissue, and their overlapping substrate- and product-specificity have hindered progress in elucidating the relation of the cytochrome P-450 phenotype to differences among individuals in the metabolism of drugs and carcinogens.

Monoclonal antibodies (MAb's) are useful for analysis of isozymic systems such as the cytochromes P-450. MAb's are chemically defined, homogeneous reagents that have epitope specificity and are easily and reproducibly obtained in large quantities (*2*). We have prepared and characterized panels of MAb's to several animal cytochromes P-450 (*3*). Use of the MAb's that inhibit catalytic activity has enabled us to identify immunochemically the cytochromes P-450 responsible for the metabolism of the carcinogen benzopyrene as measured by aryl hydrocarbon hydroxylase (AHH) and those responsible for the deethylation of the drug ethoxycoumarin as measured by ethoxycoumarin deethylase (ECD). In particular, we have used MAb 1-7-1, prepared to a highly purified rat liver cytochrome P-450 inducible by 3-methylcholanthrene, to measure the contribution of MAb-specific cytochrome P-450 to the total AHH and ECD activities in animal (*4*) and human (*5, 6*) tissues. We have also shown the specificity of MAb 1-7-1 for individual cytochromes P-450 in immunopurification studies (*7*). This MAb has been useful in the radioim-

Table 1. Stability of AHH and measurements by radioimmunoassay (RIA) of cytochrome P-450 in human placenta and rat liver.

Treatment	Human placenta		Rat liver	
	AAH*	RIA†	AHH*	RIA†
None	61.2 (100)	100	2550.0 (100)	100
4°C for 48 hours	47.7 (78)	99	790.5 (31)	100
21°C for 24 hours	31.2 (51)	97	459.0 (18)	99

*Picomoles of 3-hydroxybenzo[*a*]pyrene per milligram of protein per minute; numbers in parentheses are percent of control. †Percent of maximum binding with 30 μg of placental microsomes or 0.3 μg of rat liver microsomes.