PERGAMON

Continental Shelf Research 18 (1998) 1613–1629

CONTINENTAL SHELF RESEARCH

Origin of late Holocene fine-grained sediments on the French Guiana shelf

Parra Mario*, Pujos Michel

Université de Bordeaux 1, Département de Géologie et d'Océanographie, UMR CNRS 5805, Avenue des Facultés, 33 405 Talence Cedex, France

Received 25 June 1997; received in revised form 27 February 1998; accepted 28 April 1998

Abstract

Marine muds deposited on the French Guiana coast mostly originate in the Amazon. Recent sediments are composed of (a) illite and chlorite of Andean origin and (b) kaolinite and smectite, principally from the Amazonian lowlands but also from the Guiana shield. The Sr–Nd isotopic studies confirm that these deposits are the result of the mixing between Andean and lowland materials. The importance of the source material can be estimated.

In the coastal mud prism, the comparative study of clay assemblages and Sr–Nd isotopic compositions during the late Holocene shows two assemblages: (a) grey muds with illite, chlorite and a higher Sr content appear to originate mainly in the Andean environment, (b) beige muds with kaolinite, smectite and a lower Sr content show a decrease of the input in favour of a bigger part of the lowland environment. The most important event is a reduction of the Andean source, derived from a dry phase which occurred in Western Amazonia confirming that regional decreases in rainfall, water discharge and erosion were associated with climatic change. As a result particulate flux from the ocean decreased, which had an influence on the sedimentation on the Guiana coasts. © 1998 Elsevier Science Ltd. All rights reserved

Keywords: Sr–Nd isotopes; Clay minerals; Holocene Amazonian clays; French Guiana shelf muds

1. Introduction

The Amazon river (Fig. 1) currently transports an enormous quantity of suspended matter: $1.1\text{–}1.3 \times 10^9\ \mathrm{T\,yr^{-1}}$ (Meade et al., 1985). About half of this ($6.3 \pm 2 \times 10^8\ \mathrm{T\,y^{-1}}$) is deposited on the shelf near the river mouth (Kuehl et al., 1986);

* Corresponding author. Tel.: 0033 5 56 84 60 00.

0278-4343/98/$ – See front matter
PII: S0278-4343(98)00053-3

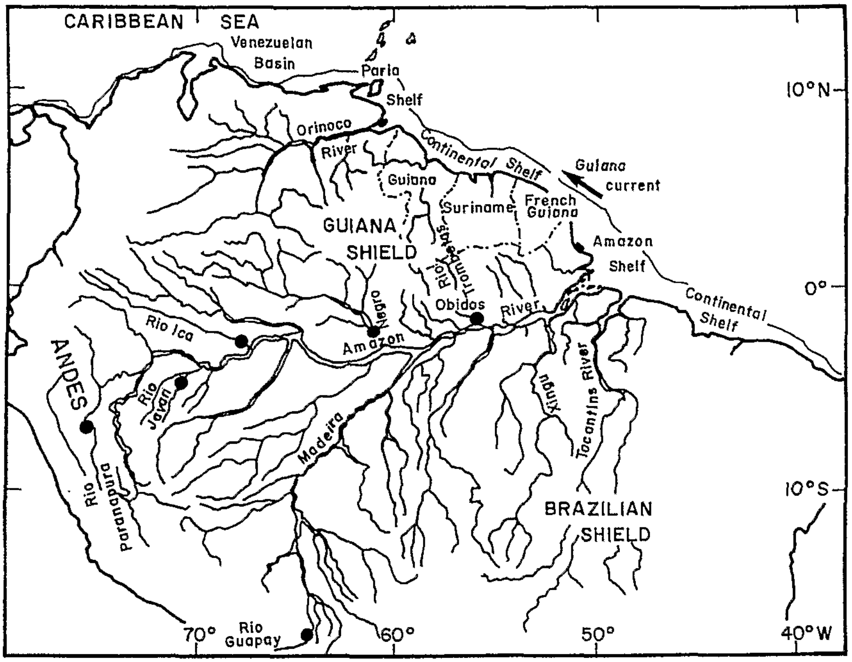

Fig. 1. Amazon basin.

a significant amount (1.5×10^8 T yr^{-1}) is transported towards the northwest by the Guiana Current (Muller-Karger et al., 1988). A small part (1%) of the total amount is deposited on the inner shelf between the Amazon mouth and the Caribbean Sea (Eisma et al., 1991). Intertidal mud-banks (1×10^8 T yr^{-1}) represent another fraction of the Amazonian flux, and migrate in the same northwesterly direction under the action of the Guiana Current, ocean swells and longshore drift (Wells and Coleman, 1981; Froidefond et al., 1988; Pujos and Froidefond, 1995). These muds have built a large coastal sedimentary prism which generally extends to a water depth of 30–40 m, but locally to greater depths (Pujos and Odin, 1986). In French Guiana, cored sediments consist of homogeneous muds, occasionally with interbedded sands and unconformity surfaces. Clay minerals account for 90% of these muds (Pujos et al., 1989); they are generally derived from neighbouring continents, and mostly inherited from the soils in river basins (Chamley, 1989; Weaver, 1989). In this study, the most abundant clay minerals are smectite (S), illite (I), kaolinite (K) and chlorite (Cl), originating principally in the Amazon basin (Gibbs, 1967).

Studies of the basin of two of the major Amazon tributaries, Rio Solimoes and Rio Madeira, show that more than 90% of the suspended matter exported by these rivers comes from Andean deposits (Guyot, 1992; Commission Spécialisée Sciences de la Terre de l'Institut National des Sciences de l'Univers, 1997).

New observations on late Quaternary marine deposits from the continental shelf of Guyana–Surinam indicate that the clay assemblages have changed since

3000 yr BP (Pujos et al., 1996). Since variations in clay assemblages are dependent on the erosional history of the region, they are ultimately linked to climatic changes.

The overall objective of the present study is to understand the effects of climatic changes in the Amazon basin upon French Guiana coastal plain sedimentation. Specific objectives are: (a) to characterize the clay assemblages and the isotopic composition of strontium (Sr) and neodynium (Nd) on recent mud prism; and (b) using the available information on clay minerals and isotopic analysis in the Amazon basin, Andes, lowlands and Guiana shield, to compare the results in the Amazon basin with those obtained along the French Guiana mud prism; (c) to evaluate changes in the depositional environment through time by examining late Holocene muds and to determine the forcing mechanisms controlling fine-grained sediment flux.

2. Clay minerals in Andean sediments and continental shelf of the northern part of South America

In the Amazon basin, suspended load varies as a function of geology, relief, vegetation and seasons. Concentrations are much higher on the eastern slopes of the Andes during the wet season (600 mg/l versus 75 mg/l in the dry season, see Gibbs, 1967). A wide range of igneous, metamorphic and sedimentary rocks is present in the Andean mountains, and the sedimentary mineralogy is highly varied. Clays are derived by mechanical erosion; more than 95% of the particulate matter in Rio Madeira, a principal tributary of the Amazon, originates in the Andes catchment area (Guyot, 1992). Illite and chlorite are the most abundant minerals (Pujos et al., 1996). In marine muds of the Pacific Colombian shelf region where lowlands are reduced, clay minerals are exclusively composed of illite and chlorite as in Andean sediments (Pujos et al., 1995). In the Brazilian shield and the lowlands from the Amazonian basin, the Xingu and the Negro are the major rivers (Fig. 1). Both essentially transport kaolinite (Irion, 1991). In the lower Amazon basin, the clay assemblages from some known Andean tributaries (illite and chlorite) and from the lowlands (kaolinite and smectite) accumulate, the latter being due to geochemical weathering in a hot and humid climate, and sometimes to crystallization after diagenesis. However, it must be stressed that the Andes is the major contributor of clay minerals to the Amazon (Gibbs, 1967; Guyot, 1992). The resulting clay assemblage, which is dominated by smectite, can be traced from the Amazon mouth to the Lesser Antilles, indicating the extent of the Amazon influence (Eisma and Van der Marel, 1971; Boltenhagen and Marion, 1975; Pujos and Odin, 1986, Pujos et al., 1996).

3. Isotopic studies in the Amazon basin

The isotopic and chemical analyses carried out by Goldstein (1985) focus on the fluvial sediments from three main physiographic regions of Amazonia

(Fig. 1, Table 1):

(1) *The Guiana region.* The Negro and Trombetas rivers drain on a large part of their course the Precambrian Guiana shield. The main mass is composed of granitoid, metamorphic basic and ultrabasic rocks (Gibbs and Barron, 1993).

Table 1
Chemical and isotopic data in the clay muds (Amazon basin, Amazon dispersal system)

Location	$^{87}Sr/^{86}Sr$ $\pm\sigma(10^{-6})$	Sr (μg.g − 1)	1000/Sr	$^{143}Nd/^{144}Nd$ $\pm\sigma(10^{-6})$	$\varepsilon_{Nd}(O)$	Nd (μg.g − 1)
Surficial sediments						
Amazon river tributaries*						
Rio Guapay (Andes)	0.737079 ± 40	111.7	9.0	0.511958 ± 22	− 13.3	51.9
Rio Paranapura (Andes)	0.735527 ± 44	85.4	11.7	0.511956 ± 14	− 13.3	18.6
Rio Ica (Andes + lowlands)	0.710384 ± 22	172.6	5.8	0.512253 ± 20	− 7.5	35.3
Rio Javari (lowlands)	0.719276 ± 24	31.8	31.4	0.512169 ± 32	− 9.1	12.1
Amazon river mouth						
B 8701–0/5 cm	0.725343 ± 10	90.9	10.9	0.512051 ± 18	− 11.5	14.8
5/10 cm	0.726547 ± 12	91.2	11.0	nd	—	nd
French Guiana shelf						
KS 87153 – 0/1 cm	0.727698 ± 13	86.2	11.6	0.512038 ± 11	− 11.6	15.8
USN 8704– 0/5 cm	0.724480 ± 11	99.5	10.6	0.512041 ± 49	− 11.6	23.5
P 11 Cayenne Bank	0.724671 ± 13	98.1	10.2	0.512042 ± 41	− 11.6	34.2
My 17 Mahury estuary	0.724479 ± 14	97.0	10.3	0.512067 ± 30	− 11.1	28.9
CK 04-Oyapock estuary	0.725415 ± 76	90.0	11.1	0.512062 ± 30	− 12.2	27.5
Cored sediments						
KS 90105						
0/2.5 cm	0.726842 ± 23	88.5	11.3	nd	—	nd
50/52.5 cm	0.725405 ± 14	110.0	9.1	nd	—	nd
150/152.5 cm	0.725999 ± 12	100.9	9.9	nd	—	nd
190/192.5 cm	0.725736 ± 68	102.6	9.7	nd	—	nd
250/252.5 cm	0.725363 ± 19	86.8	11.5	nd	—	nd
310/312.5 cm	0.726750 ± 11	89.5	11.1	nd	—	nd
355 cm	0.723855 ± 11	117.7	8.5	nd	—	nd

*Goldstein (1985) nd: not dosed

The fluvial sediments present an original isotopic composition characterized by high $^{87}Sr/^{86}Sr$ ratios (0.7515–0.7686) and low $^{143}Nd/^{144}Nd$ ratios (0.5116–0.5117).

(2) *The lowlands* (llanos). The rio Javari valley cuts across the Neogene alluvia derived mainly from the erosion of the Andean chain.

The isotopic ratios of the lowlands (rio Javari) are low for Sr ($^{87}Sr/^{86}Sr = 0.7193$) and high for Nd ($^{143}Nd/^{144}Nd = 0.5121$).

(3) *The Andes.* The drainage basin of the rio Guapay (Bolivia) component part of southwestern Amazonia, consists of Paleozoic and Mesozoic rocks. Further to the north, that of the rio Paranapura (Peru) essentially consists of Paleozoic rocks.

The $^{87}Sr/^{86}Sr$ (0.7355–0.7370) and $^{143}Nd/^{144}Nd$ (0.5119) isotopic ratios of the sediments from the two rivers are intermediate between those recognized in the rivers of the lowlands and those of the Guiana shield.

The Putamayo, upstream part of the rio Ica, drains the Colombian and the Ecuadorian Andes, and the Andean piedmont before reaching the lowlands. The isotopic ratios of the deposits in the rio Ica are different from those of the two previous rivers $^{87}Sr/^{86}Sr$ ratio = 0.7103 (low) and $^{143}Nd/^{144}Nd$ ratio = 0.5122 (high) are close to those of the lowlands. Sr content is very high (173 $\mu g\,g^{-1}$) characteristic of the Andean area (118 $\mu g\,g^{-1}$ for rio Guapay, 86 $\mu g\,g^{-1}$ for rio Paranapura and only 31 $\mu g\,g^{-1}$ for lrio Javari).

From Goldstein's studies (1985), we can infer:

(a) *The plausibility of the isotopic and chemical measurement of Sr and Nd*: the Andean tributaries cover limited regions of the cordillera. However, if the isotopic and chemical values are not probably representative of the mean of the inputs, they give an idea of the values obtained in the Andean area (Colombia, Ecuador, Bolivia, Peru) and allow us to compare these values with those obtained in the lowlands and the Guiana shield.

(b) *the importance of the sediment input originating in the Guiana shield*: the observations of the author reinforced by those of Gibbs (1967), Baker (1978) and Meade et al. (1979) confirm the low contribution of the Guiana shield to the Amazon. We also observed this low contribution for the rivers draining the Guiana shield to the north and mixing with the Amazonian muds which are transported along the Guianas coast (Pujos et al., 1990; Pujos et al., 1996). Thus:

(1) Sr and Nd isotopic ratios and contents are variable in the Amazonian basin. The petrographic zones of the Andes, Guiana shield and lowlands are very distinctive.

(2) the Andes and the lowlands are the two only regions that provide a significant source of sediments. Possibilities of mixing characterize the downstream part of the Andean tributaries (Rio Ica).

(3) $^{87}Sr/^{86}Sr$ ratios and Sr contents are higher in the Bolivian and Peruvian Andes (> 0.7355 and $> 110\ \mu g\,g^{-1}$) than in the lowlands (0.7192 and 32 $\mu g\,g^{-1}$).

(4) $^{143}Nd/^{144}Nd$ ratios and ε_{Nd} values are lower in the Andes (0.5119 and -13) than in the lowlands (0.5121 and > -9).

4. Clay mineralogy and isotopic studies in French Guiana mud prism

4.1. Methods

4.1.1. Clay mineralogy

Clays were analysed by X-ray diffraction (Philips diffractometer with Cu K_α radiation and a nickel filter – 35 KV and 25 mA). Sediments were decarbonated (0.1 N HCl) as required and then rinsed thoroughly with deionized water.

The clay fraction (< 2 μm) was separated by gravity and centrifuging, and then put on three glass slides for X-ray analysis following the methods described by Holtzapffel (1985). One sample was left untreated; another was saturated with ethylene glycol; and the third was heated to 550°C for 1 h. Identification of the clay minerals is based on their typical reaction to these treatments (Brown, 1961; Thorez, 1975). The relative amount of each mineral is calculated from the ethylene glycol-treated samples. Quantitative determinations were performed using the peak height of characteristic reflection of each class: 17 A for smectites; 10 A for illites, 7.1 and 3.57 A for kaolinites and 7.1 and 3.55 A for chlorites.

4.1.2. Isotopic studies

The clay-rich detrital fraction (< 10 μm) was isolated by decantation and ultracentrifugation after carbonate and organic matter were removed by HCl (0.1 N) and H_2O_2 (10 V), respectively. The detrital residues were washed several times with ultrapure distilled water and centrifuged to eliminate all traces of HCl and H_2O_2.

Sr and Nd were separated by cation and anion-exchange chromatography after sample (10 mg) dissolution at 125°C temperature in HF + $HClO_4$ + HNO_3 mixture. The $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios and concentrations of Sr and Nd were determined on a Finigan Mat 261 Mass Spectrometer. Equipment reproducibility was controlled by measurements of the NIST-987 (0.710206) and La Jolla standards (0.511881). For each sample, 7–12 series of 10 measurements were carried out until we obtained a good standard deviation (2σ). The isotopic ratios have been corrected for mass fractionation by normalizing to $^{88}Sr/^{86}Sr = 8.375209$ and $^{146}Nd/^{144}Nd = 0.7219$. Uncertainties on concentration measurements of Sr and Nd are < 0.1%. Nd results are expressed as:

$$\varepsilon_{Nd}(0) = (((^{143}Nd/^{144}Nd)meas./0.512636) - 1) \times 10^{-4},$$

using the present-day CHUR value of Jacobsen and Wasserburg (1980).

The Sr–Nd chemical and isotopic compositions of regional petrographic formations defined by Goldstein (1985) were utilized as end-members. The composition in percentage is determined using the mixing equation with the $^{87}Sr/^{86}Sr$ ratios and the Sr contents (Langmuir et al., 1978), or the mixing hyperbola (Faure, 1985) integrating the $^{87}Sr/^{86}Sr$ ratios, the ε_{Nd} (0) values and the Sr and Nd contents.

4.2. Surficial sediments

4.2.1. French Guiana

Sediment samples were collected by a variety of sampling devices. Shipboard sampling was performed using a Reineck corer, Ekman and Shipeck grabs (Fig. 2). For many of the mud prism stations, sampling sites were reoccupied during each of the five cruises. The geographical locations (more than 100 stations) and sedimentological data are given in Pujos and Odin, 1986; Jouanneau and Pujos, 1987, 1988; Pujos et al., 1988, 1989, 1996; Pujos, 1991.

4.2.1.1. Clay minerals. In this coastal shelf (tidal zone, mud-banks, between mud-banks, infralittoral zone) illite dominates (33%) but kaolinite (28%) and smectite (26%) are common (Pujos et al., 1996).

Littoral muds are inherited from two distinct regional sources. First, the mechanical erosion of ferralitic soils (local continental source) produces kaolinite. In the same area, in coastal swamps with poor drainage, erosion of muds (underlying peats) may supply smectite.

Second and much more important is the Amazonian source of suspended matter ($1.1–1.3 \times 10^6$ T yr^{-1}, see Meade et al., (1985), which is characterized in part by illite and chlorite from Andean environments. Data on particulate matter, discussed in the introduction, show that only 1% of these muds are deposited on the coasts of the three Guianas (Fig. 1). Since the particulate matter flux from French Guiana rivers is estimated at 1.7×10^6 T yr^{-1} (Prost and Lointier, 1988), it is easy to notice that the local input of kaolinite and smectite would be much diluted by the Amazonian flux. Thus, the identification of clay assemblages provides a reasonable framework for interpreting long-term variations in the regional climate (Pujos et al., 1996).

4.2.1.2. Isotopic studies. The isotopic analysis has been carried out on five samples representative of different entities from the French Guiana littoral prism (Fig. 2): (a) submerged banks (87153 and 8704, respectively, in front of the Oyapock river and Cayenne), (b) Cayenne bank (P 11), and (c) Mahury (My 17) and Oyapock (CK 04) estuaries. The sample B 8701 located in the Amazon mouth is also analyzed.

The isotopic and chemical compositions (Sr and Nd) of the clayey phases can be grouped into two distinct geographical zones (Table 1).

The Oyapock region. The $^{87}Sr/^{86}Sr$ ratios (0.7254–0.7276) of the muds from the littoral prism (KS 87153, KS 90105) and the Oyapock estuary (CK 04) are comparable to those of the Amazon muds (0.7253–0.7265), into relation with the proximity of the mouth.

The Cayenne region. The muds of the littoral prism (USN 8704), Cayenne bank (P 11) and Mahury estuary (My 17) have $^{87}Sr/^{86}Sr$ isotopic ratios lower (0.7244–0.7246) than the previous, probably linked to the greater distance from the mouth.

4.2.2. The Amazon mouth

Their study appear to be complementary to that of the Guiana shelf muds to understand the mineralogical and isotopic relationships existing between the Amazonian basin and the Guiana shelf (Figs. 1 and 2).

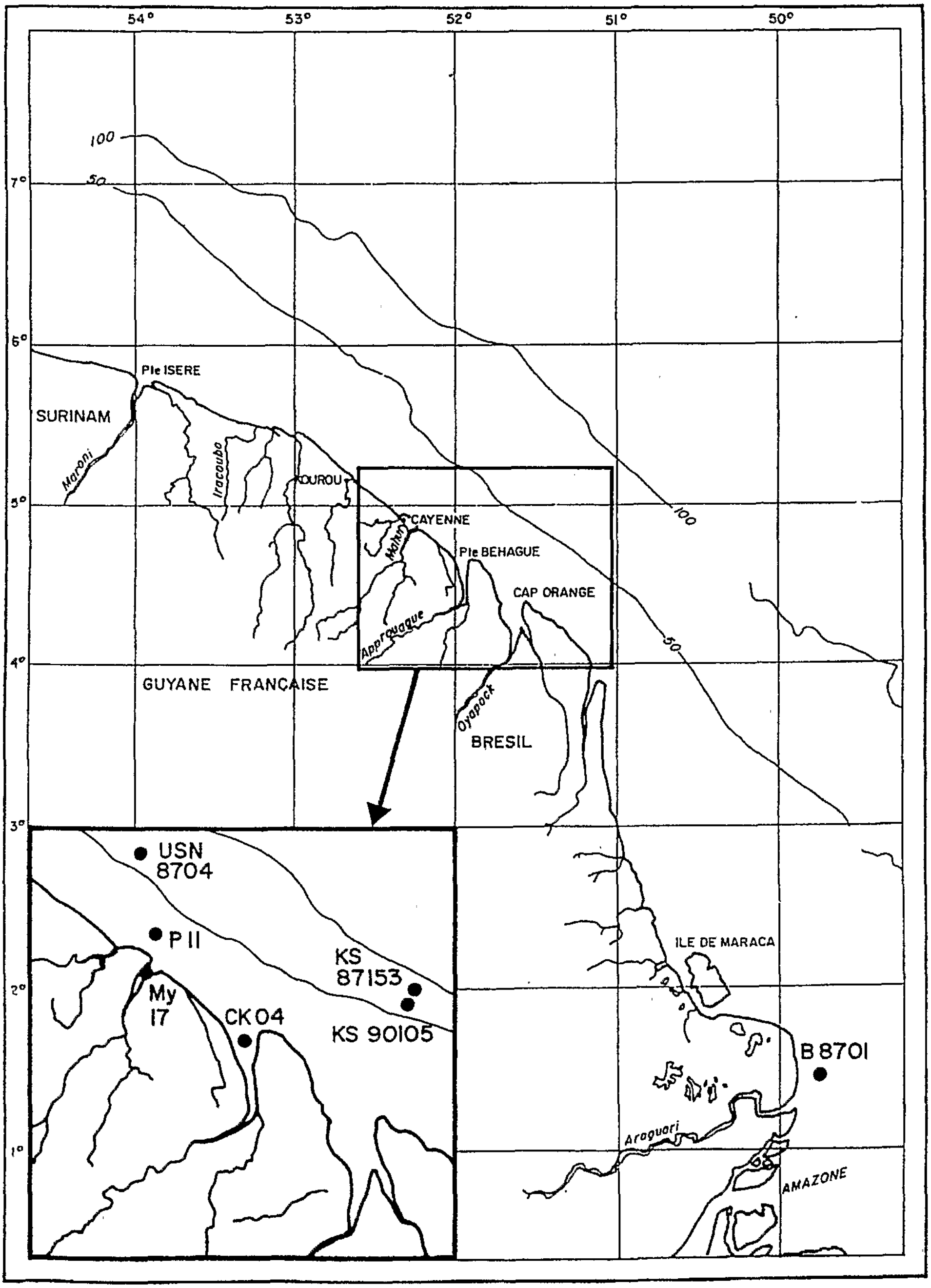

Fig. 2. Part of the region influenced by the Amazon dispersal system. Sample locations.

Clay mineral assemblages show the predominance of smectites (35%) and the good representation of illites (25%) and kaolinites (31%) (Pujos et al., 1996).

Two isotopic measurements were carried out in this zone. Sr and Nd ratios are, respectively, $^{87}Sr/^{86}Sr = 0.7253–0.7265$ and $^{143}Nd/^{144}Nd = 0.5120$ (Table 1), values which are intermediate between Andean ($^{87}Sr/^{86}Sr = 0.7355–0.7370$; $^{143}Nd/^{144}Nd = 0.5119$) and lowland materials ($^{87}Sr/^{86}Sr = 0.7103–0.7192$) and $^{143}Nd/^{144}Nd = 0.5121–0.5122$) (Goldstein, 1985).

On the graphic representation $^{87}Sr/^{86}Sr$ versus 1000/Sr, the values of French Guiana shelf and Amazon mouth muds are plotted in the mixing triangle of three petrographic end-members (Fig. 3): Paleozoic and Mesozoic rocks in the Bolivian and Peruvian Andes, Neogene formations in the lowlands and Precambrian and Paleozoic rocks in the Columbian and Ecuadorian Andes (Instituto Codazzi, 1989). On the graphic representation ε_{Nd} (O) versus $^{87}Sr/^{86}Sr$, values are plotted between three mixing hyperbola (Fig. 4).

The graphic position of the Sr–Nd isotopic and chemical values of Amazon mouth and French Guiana shelf muds (Figs. 3 and 4) confirm that these deposits are the result of the mixing between Andean and lowland materials. The importance of the source materials can be estimated through the two graphic representations.

4.3. *Cored sediments*

Samples of KS 90105 were taken with a Kullenberg corer in the French Guiana coastal mud prism at a depth of 38 m (Fig. 2). The location was chosen on the basis of

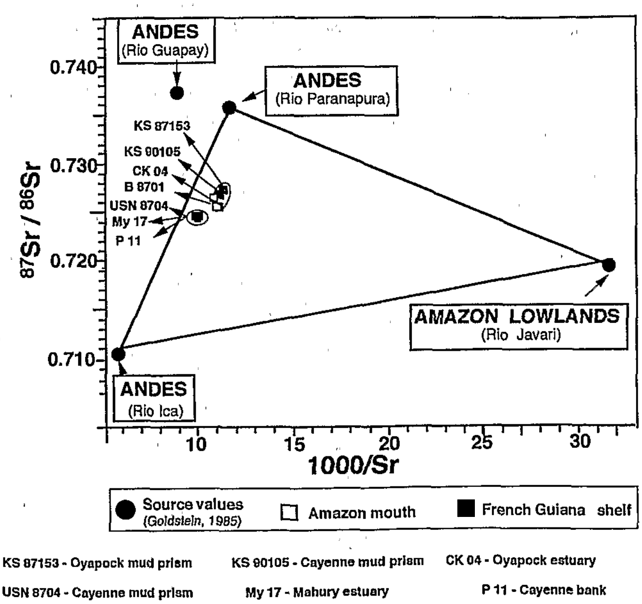

Fig. 3. Plot of $^{87}Sr:^{86}Sr$ versus 1000/Sr content in the surficial muds from the Amazonian mouth and the French Guiana shelf.

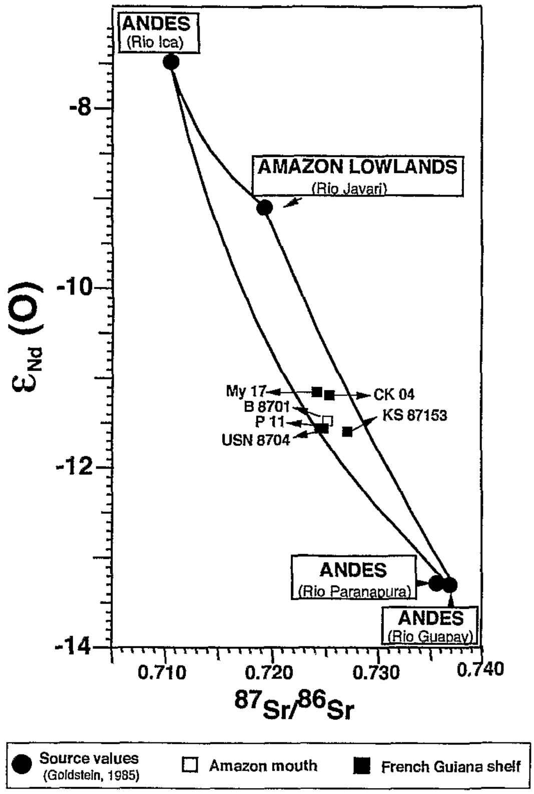

Fig. 4. Plot of $^{87}Sr:^{86}Sr$ versus ε_{Nd} (O) in the surficial muds from the Amazonian mouth and the French Guiana shelf.

acoustic reflectors recognized in 3.5 kHz seismic profiles (Frappa and Pujos, 1994). On this core, 3.5 m in length, it has been possible to identify grey muds (on the base and the upper part) and beige muds (near the base) separated by characteristic unconformity, reworked beach rocks and coastal relict cheniers (Fig. 5).

Both mineralogic and isotopic compositions of the clay fraction are highly variable.

4.3.1. Clay minerals

The beige lithic muds are characterized by predominant smectite (37%) and kaolinite (27%) contents. The ratios S/I (1.4), K/I (1.1) and K/I + Cl (0.85) are high (Table 2). The abundance of kaolinite indicates an Amazonian lowland source (Gibbs, 1967). In these sediments, smectite is always abundant and dominant, reflecting the clay mineral composition of the soil formed under humid climatic conditions. The result of a higher smectite–kaolinite content (between >3000 yr and 1860 yr BP) could be attributed to a reduction of the Andean source and consequently to an increased Amazonian lowland source.

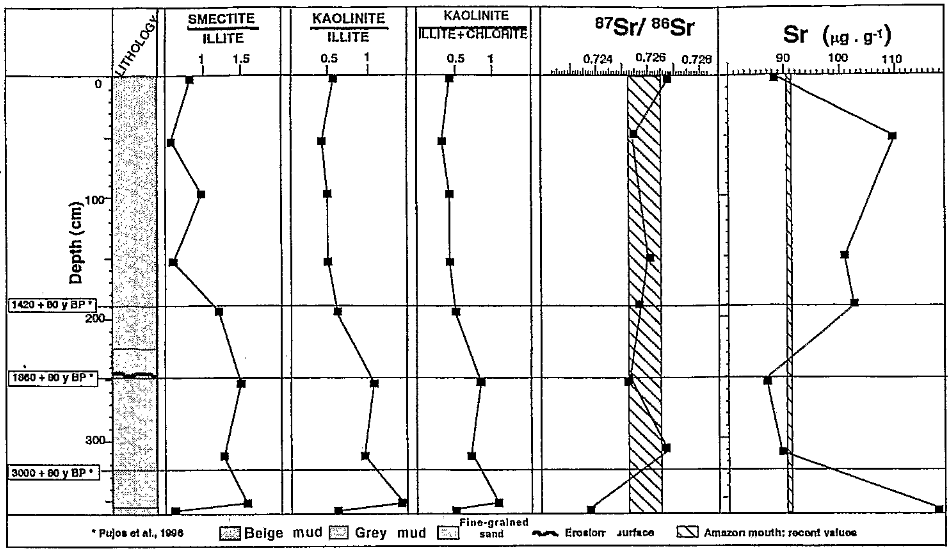

Fig. 5. Lithology, mineralogy, Sr chemical and isotopic composition, radiocarbon dates of sediments from core 90105.

Table 2
Clay mineralogy of sediments from core KS 90105. Md = mean values

KS 90105 level in cm	S %	I %	K %	Cl %	S/I	K/I	K/I + Cl
0–2.5	30	36	21	13	0.8	0.6	0.4
50–52.5	26	41	18	15	0.6	0.4	0.3
97.5–100	32	36	19	13	0.9	0.5	0.4
150–152	26	40	20	14	0.65	0.5	0.4
190–192	37	32	21	10	1.2	0.65	0.5
250–252	38	25	27	10	1.5	1.1	0.8
310–312.5	36	28	26	10	1.25	0.9	0.7
350–352.5	37	23	33	7	1.6	1.4	1.1
355	24	37	25	14	0.65	0.65	0.5
Md (green muds)	27	37	20	14	0.7	0.5	0.4
Md (beige muds)	37	25	28	9	1.5	1.1	0.8

The grey muds. On the upper part of the core (above the erosional contact and the sand layer) but also in the thin undermost layer, the clay assemblage is characterized by the higher illite (37–26%) and chlorite (14–10%) content. The ratios S/I (0.7), K/I (0.45) and K/I + Cl (0.4) are very low (Table 2). This clay assemblage resembles that of the French Guiana surface sediment: dominant smectite, increase of illite and chlorite, low ratios of S/I, K/I, K/I + Cl. It reflects an increased Andean flux.

4.3.2. Isotopic studies

Seven measurements were carried out on this core (Fig. 5).

$^{87}Sr/^{86}Sr$ ratio: almost all the clay sediments present an isotopic ratio with values contained for the most part in the margin of the results obtained for the recent Amazon mouth muds (0.7253–0.7265) or slightly different (0.7267 and 0.7268). In the undermost part of the core the ratio is low (0.7238).

Sr content: the variable values allows us to individualize from the base to the top (Table 1, Fig. 5):

(a) The top of grey-muds layer, where the high Sr value (118 $\mu g\, g^{-1}$) is comparable to those of the Andean tributaries (rios Guapay and Ica and to a lesser extent rio Paranapura).

(b) Beige muds where Sr values (87 and 90 $\mu g\, g^{-1}$) are slightly lower than those of the recent muds sampled at the Amazon mouth.

(c) Grey muds, separated from the previous by the decimetric erosional contact of reworked sands previously cited, where high Sr values (103, 101 and 110 $\mu g\, g^{-1}$) are comparable to those of Andean tributaries.

(d) Grey muds where Sr value (89 $\mu g\, g^{-1}$) is close to those of the recent muds from the Amazon mouth.

These variations result from complex mixtures of essentially two main end-members (Fig. 6): Bolivian/Peruvian Andes (Guapay,Paranapura) and Ecuadorian/Colombian Andes (Ica) specifically identified as sources for the material found in the Guiana mud prism. Grey muds are interpreted by binary mass balance mixtures of Andean inputs whereas the beige muds result from a sedimentary change with an increase in the lowland contribution.

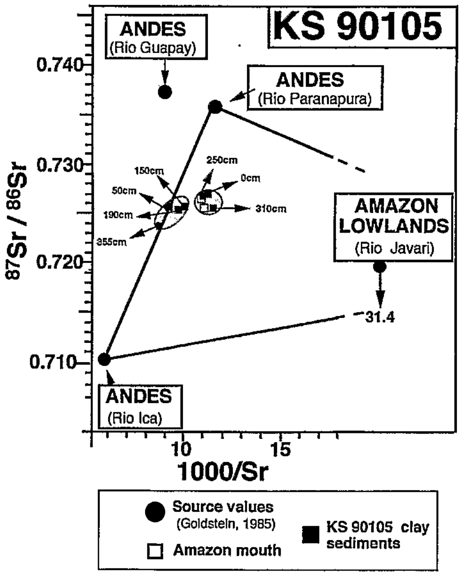

Fig. 6. Plot of $^{87}Sr:^{86}Sr$ versus 1000/Sr content in the KS 90105 clay sediments.

Table 3
Clay material contribution in surficial and cored sediments (Amazon mouth, French Guiana shelf)

Location	Detrital clay contribution Paranapura %	Ica %	Javari %
Surficial sediments			
Amazon mouth			
B 8701–0/5 cm	70	15	15
–5/10 cm	70	15	15
French Guiana shelf			
KS 87153–0/1 cm	70	15	15
CK 04–Oyapock estuary	70	15	15
USN 8704–0/5 cm	65	25	10
P. 11–Cayenne Bank	65	25	10
M.17—Mahury estuary	65	25	10
Cored sediments			
KS 90105			
0/2.5 cm	70	15	15
50/52.5 cm	75	25	0
150/152.5 cm	65	20	5
190/192.5 cm	65	20	5
250/252.5 cm	70	15	15
310/312.5 cm	70	15	15
355 cm	70	30	0

This contribution of the Amazonian inputs to the ocean can be evaluated as percentages calculated from previous isotopic results on the Andes (Paranapura, Ica) and the lowlands (Javari). The results presented in Table 3 are obtained from the mixing equation of Langmuir et al. (1978). They are all the more credible since they appear to be close to those calculated on the base of the mixing equation of Faure (1985). In surficial deposits of the Amazon mouth and the French Guiana shelf, the Andean input is high (80–85%). In late Holocene deposits, if the Andean predominance is constantly obvious, variations appear between grey and beige muds. In the latter (at the base of the core and up to a recent period), about all of the input is of Andean origin (95 à 100%).

The comparative study of clay minerals and isotopic compositions in the core KS 90105 shows two assemblages:

(a) on the undermost grey muds, illite, chlorite and a higher Sr content appear to originate mainly in the Andean environment. The high flux of Andean particulate matter would seem to decrease on the uppermost layer characterized by the lowest Sr content.

(b) conversely, in beige muds, kaolinite, smectite and a lower Sr content show a decrease of the input in favour of a biggest part of the lowland environments.

5. Discussion and conclusions

Earlier research on late Quarternary deposits from northern South America has indicated the existence of successive dry and wet climatic phases. Mean water levels in the lower part of valleys and in lakes from the Amazonian basin (Absy, 1979; Van der Hammen, 1986) and the Andes (Mourguiart and Roux, 1990) can fall drastically during the dry periods (e.g. several tens of metres in lake Titicaca; see Mourguiart and Roux, 1990). Today, the South American inter-tropical region is a zone of conspicuous climatic variability, particularly with regard to wind and rain (Kousky et al., 1984).

Hydrological data in the Amazon basin in 1982, 1983 and 1984 show a decrease in rainfall (25%), water discharge (17%) and mechanical erosion (53%) in 1983, characterizing a dry period (Pujos et al., 1996). As a result, the particulate flux from the Andes, which today accounts for an important part of the Amazonian input, especially during the wet season (Gibbs, 1967; Guyot, 1992), decreases notably. Quaternary deposits from Lake Dos Carajas also record low detrital fluxes during dry phases (Sifeddine, 1991; Absy et al., 1991). In the ocean, several workers have shown that, from the Amazon mouth to the Caribbean Sea, erosion-sedimentation cycles depend on the importance of the particulate input from the Andes (Augustinus et al., 1989; Eisma et al., 1991; Allison, 1993). They suggested that many long-term climatic events happened in the late Holocene.

In French Guiana, coastal marine muds mostly originate in the Amazon. Importance in the accretion of the sedimentary prism, clay minerals and Sr–Nd isotope contents are derived from climatic changes in Amazonia.

The recent sediments are characterized by: (a) illites and chlorites, a higher Sr content of Andean origin; and (b) kaolinite and smectite dominant, a lower Sr content, could be attributed to a reduction of the Andean source and consequently, an increased Amazonian lowland source.

In the coastal mud prism the two different clay mineral and isotopic compositions of the fine-grained sediments are controlled by climatic changes: (a) > 3000–1500 yr BP. Kaolinite, smectite and a lower Sr content as a result of a dry phase in western Amazonia. The consequence in rainfall, water discharge and mechanical erosion affects the reduction in the Andean flux and the sedimentation on the Guiana coast; and (b) the renewal of Andean erosion at about 1500 yr BP is recorded in the marine sediments by an increase of illite, chlorite and Sr content. The likeliest cause of this is a return to a normal (moister) climate in western Amazonia with especially an increased supply in particulate matter. The effect in the French Guiana coast is seen in a high flux of Amazonian muds and rapid accretion of the sedimentary prism.

The results of this study on the largest river drainage basin on Earth illustrates the importance of the clay mineral and Sr isotopic ratios and contents in reconstructing: (a) the origin of sediments; and (b) the past Amazonian climate which affects during the late Holocene the Amazonian input to the ocean and influences sedimentation on the northern Atlantic shelf of South America.

Acknowledgements

We thank M. Loubet for access to the Finningan Mat 61 Mass Spectrometer at the Laboratoire de Géochimie Isotopique (Toulouse, France), M. Arnold, Laboratoire des Faibles Radioactivités of Gif-sur-Yvette for AMS ^{14}C and A. Conçalves for correcting the manuscript.

References

Absy, M.L., 1979. A palynological study of Holocene sediments in the Amazon basin. Unpublished Ph.D. thesis, University of Amsterdam, 86 p.

Absy, M.L., Cleef, A., Fournier, M., Martin, L., Servant, M., Sifeddine, A., Ferreira Dasilva, M., Soubies, F., Suguio, K., Turcq, B., Van Der Hammen T., 1991. Mise en évidence de quatre zones d'ouverture de la forêt dense dans le Sud-Est de l'Amazonie au cours des 60.000 dernières années. Première comparaison avec d'autres régions tropicales. Comptes Rendus des Séances de l'Académie des Sciences, Paris 312(2), 653–678.

Allison, M.A., 1993. Mechanisms of coastal progradation and muddy strata formation adjacent to the Amazon river. Unpublished Ph.D. thesis, State University of New York at Stony Brook, 9406858, 322 p.

Augustinus, P.G., Hazelhoff, L., Kroon, A., 1989. The cheniers coast of Surinam: modern and geological development. Marine Geology 90, 219–229.

Baker, V.R., 1978. Adjustment of fluvial systems to climate and source terrain in tropical and subtropical environments. In: Miall, A.D. (Ed.), Fluvial Sedimentology, Canadian Society Letters of Geological Memoirs 5, 211–230.

Boltenhagen, C., Marion, J., 1975. Géochimie minérale et argiles in: Orgon II, Atlantique Nord-Est et Brésil, éditions du CNRS, 89–103.

Brown, G., 1961. The X-ray identification and crystal structures of clay minerals. London (Mineralogical Society), 544 p.

Chamley, H., 1989. Clay Sedimentation. Springer, Berlin, 623 p.

Commission Spécialisée Sciences de la Terre de l'Institut National Sciences de l'Univers, 1997. Prospective Sciences de la Terre, CNRS ed. Paris, 54 p.

Eisma, D., Augustinus, P.G., Alexander, C., 1991. Recent and subrecent changes in the dispersal of Amazon mud. Netherlands Journal of Sea Research 28(3), 181–192.

Eisma, D., Van Der Marel, H.W., 1971. Marine muds along the Guyana coast and their origin from the Amazon basin. Contributions to Mineralogy and Petrology 31, 321–334.

Faure, G., 1985. Principly of Isotope Geology. Wiley, New York, 589 p.

Frappa, M., Pujos, M., 1994. Late Quaternary evolution of the French Guiana continental shelf-evidence from 3,5 kHz data. Marine Geology 121, 231–245.

Froidefond, J.M., Pujos, M., Andre, X., 1988. Migration of mud banks and changing coastline in French Guiana. Marine Geology 84, 19–30.

Gibbs, R.J., 1967. The geochemistry of the Amazon river system. Pt 1. The factors that control the salinity and the composition and concentration of the suspended solids. Geological Society of America Bulletin 78, 1203–1232.

Gibbs, R.J., 1977. Clay mineral segregation in the marine environment. Journal of Sedimentary Petrology 47, 237–243.

Gibbs, A.K., Barron, C.N., 1993. The Geology of the Guiana Shield, Oxford University Press, New York, 246 p.

Goldstein, S.L., 1985. Isotopic studies of continental and marine sediments and igneous rocks of the Aleutian Island arc. Unpublished Ph.D. thesis, Colombia University.

Guyot, J.L., 1992. Hydrogéochimie des fleuves de l'Amazonie brésilienne. Unpublished Ph.D. thesis, Bordeaux I, 362 p.

Holtzapffel, T., 1985. Les minéraux argileux, préparations, analyses diffractométriques et détermination. Soc. Géol. du Nord, 12, 136 p.

Instituto Codazzi, A., 1989. Atlas basico de Colombia. Division de difusion geographica, 446p.

Irion, G., 1991. Minerals in rivers. In: Degons (Ed.), Biogeochemistry of Major World Rivers. Kempe et Richey 12, 265–281

Jacobsen, S.B., Wasserburg, G.J., 1980. Sm–Nd isotopic evolution of chondrites. Earth and Planetary Science Letters 61, 97–111.

Jouanneau, J.M., Pujos, M., 1987. Suspended matter and bottom deposits in the Mahury estuarine system (French Guiana) environmental consequences. Netherlands Sea Research 21 (3), 191–202.

Jouanneau, J.M., Pujos, M., 1988. Suspended matter and bottom deposits in the Maroni estuarine system (French Guiana). Netherlands Sea Research 22 (2), 99–108.

Kousky, V.E., Kagano, M.T., Kousky, V.F., Cavalcanti, I., 1984. A review of the Southern oscillation oceanic-atmospheric circulation changes and related rainfall anomalies. Tellus 36A, 490–504.

Kuehl, S.A., Nittrouer, C.A., De Master, D.J., 1986. Distribution of sedimentary structures in the Amazon subaqueous delta. Continental Shelf Research 6 (1/2), 311

Langmuir, C.H., Vocke, R.D., Hanson, G.N., Hart, S., 1978. A general mixing equation with application to icelandic basalts. Earth and Planetary Science Letters 37, 380–392.

Meade, R.H., Dunne, T., Richey, J.E., Santos, U., and Salati, E., 1985. Storage and remobiliztion of suspended sediment in the lower Amazon River of Brazil. Science 228, 488–490.

Meade, R.H., Nordin, C.F., Curtis, W.F., Rodrigues, F.M.C., Do Vale, C.M., Edmond, J.M., 1979. Sediment load in the Amazon river. Nature 278, 161–163.

Mourguiart, P., Roux, M., 1990. Une approche nouvelle du problème posé par les reconstitutions des paléo-niveaux lacustres: utilisation d'une fonction de transfert basée sur la faune d'ostracodes. Géodynamique 5, 2.

Muller Karger, F., McClain, C., Richardson, P., 1988. The dispersal of the Amazon's water. Nature 333, 56–59.

Prost, M.T., Lointier, M., 1988. Coastal sedimentation and local rivers supply in French Guiana: comparisons with the Amazon. In: Chapman conference, A.G.U., pp. 182–186.

Pujos, M., 1991. Rapport de la mission Guyante II. Rapport Institut de Géologie du Bassin d'Aquitaine, 32 p.

Pujos, M., Bobier, C., Chagnaud, M., Fourcassies, C., Froidefond, J.M., Gouleau, D., Guillaume, P., Jouanneau, J.M., Parra, M., Pons, J.C., Pujos, A., De Resseguier, A., Viguier, C., 1989. Les caractères de la sédimentation fine sur le littoral de la Guyane Française (région de Cayenne): nature, origine et périodicité de l'envasement. *Rapport CORDET*, 87001/88310, 77 p.

Pujos, M., Froidefond, J.M., 1995. Water masses and suspended matter circulation on the French Guiana continental shelf. Continental Shelf Research. 15 (9), 1157–1171.

Pujos, M., Griboulard, R., Latouche, C., Meidinger, P., 1995. Analyse morphotectonique récente sur la plate-forme continentale Pacifique de la Colombie. Oceanologica Acta 18(1), 1–18.

Pujos, M., Jouanneau, J.M., Pawilowski, Cl., 1988. Premiers résultats d'analyses des échantillons d'eau et de sédiments prélevés dans l'Oyapock (Guyane). Bulletin de Institut de Géologie du Bassin d'Aquitaine 44, 71–79.

Pujos, M., Latouche, C., Maillet, N., 1996. Late quaternary paleoceanography of the French Guiana shelf: clay-mineral evidence. Oceanologica Acta 19 (5), 477–487

Pujos, M., Odin, G.S., 1986. La sédimentation au Quaternaire terminal sur la plate-forme continentale de la Guyane Française. Océanologica Acta, 9 (4), 363–382.

Pujos, M., Parra, M., Pons, J.C., Jouanneau, J.M., 1990. Forçage amazonien sur la plate-forme continentale de la Guyane Française: mythe ou réalité d'une sédimentation allochtone. Symposium International PIGC 274/ORSTOM, Cayenne, 1990, vol. des résumés, pp. 149–151.

Pujos, M., Pascual, A., 1992. Los paleoambientes costeros de la plataforma continental de Guyana y Surinam en el Cuaternario terminal, in: VIII Congreso Latino- americano de Geologia, Salamanca, 2, 161–165.

Sifeddine, A., 1991. La sédimentation en région tropicale humide (Carajas, Amazonia, Brésil). Relation avec les modifications de l'environnement climatique au cours des 60.000 dernières années. Unpublished Ph.D. thesis, Muséum National d'Histoire Naturelle, Paris, 119 p.

Thorez, J., 1975. Phyllosilicates and clay Minerals. In: Lelotte (Ed.), A Laboratory Handbook for their X-Ray Analysis, Dison, Belgique 90 p.
Van Der Hammen, T., 1986. Fluctuaciones holocenicas del nivel de inundaciones en la cuenca del Bajo Magdalena-Cauca-San Jorge (Colombia). Geologia norandina 10, 12–18.
Weaver, C.E., 1989. Clays, muds and shales. Development in Sedimentology 44, Elsevier, Amsterdam, 818 p.
Wells, J.T., Coleman, J.M., 1981. Physical processes and fine-grained sediment dynamics, coast of Surinam, South America. Journal of Sedimentary Petrology 51(4), 1053–1068.