FRACTION ANALYSES OF MODERN RIVER SAND OF RIOS NEGRO AND SOLIMÕES, BRAZIL, IMPLICATIONS FOR THE ORIGIN OF QUARTZ-RICH SANDSTONES

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ABSTRACT Two fraction analyses of river sand from the Rios Negro and Solimões in Brazil conclusively demonstrate that granitic terrains with low relief and tropical weathering yield first cycle quartz arenites. Implications for clastic sedimentation above paleoerosion surfaces of granitic terrains are discussed and inexpensive future research is proposed.

RESUMO Duas análises fracionais de areia dos rios Negro e Solimões no Brasil demonstram de modo conclusivo que terrenos graníticos com relevo baixo e intemperismo tropical forneceram arenitos quartzosos de primeiro ciclo. São discutidas implicações, tais como sedimentação clástica sobre superfícies de erosão anteriores, e são feitas proposições de pesquisas futuras de baixo custo.

INTRODUCTION This note provides more documentation and analysis of the general differences noted by Franzinelli & Potter (1983) between sands from streams in the Amazon Basin with watersheds in Precambrian rocks versus those with headwaters in the Andes. Franzinelli & Potter (op. cit) found that the Q:F:Rf ratio for the Solimões above Manaus (seven samples) averages 46:8:46 whereas it averages 93:3:4 (twenty-one samples) for tributary watersheds in Precambrian terrains. From this, they inferred the likelihood of first-cycle, quartz-rich, sand production in the low relief, rainforested river watersheds of much of the central part of the Amazon River basin. Gibbs (1969) earlier noted similar contrasts in the 2-20 micron fraction carried in suspension by rivers of the Amazon Basin. Recently, Stallard (1983) reported on pure quartz river sand in juxtaposition with granitic outcrops in the upper reaches of the nearby Rio Orinoco.

We report on the contrasting petrographic analyses from the Solimões River and the Rio Negro in Brazil (Fig. 1). These two petrographic analyses are of interest because they have great contrasts in composition – the pure quartz sand of the Rio Negro is derived from a low-lying granitic craton covered by rain forest, whereas the sand from the Solimões, which passes through the same rain forest, has an Andean source.

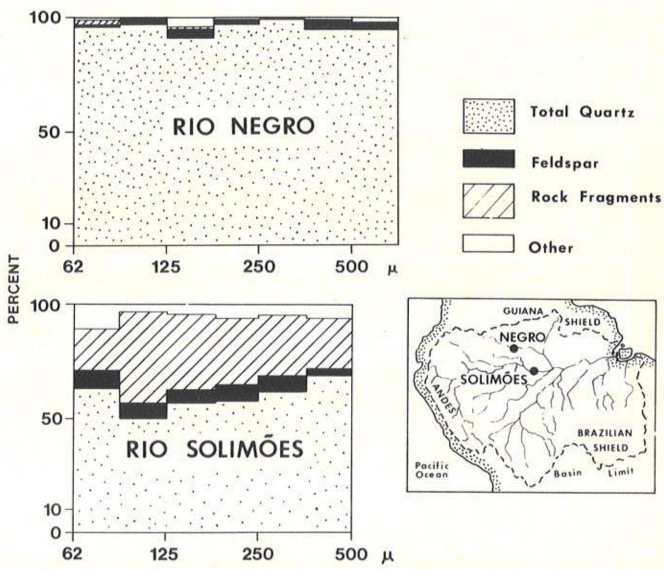

Figure 1 – Fraction analyses of sand from Rios Negro and Solimões and index map. Sand from the Rio Negro is from the riverbed above Ilha Grande and Ilha Jerusalém (see text for exact locations) and sand from the Rio Solimões is from three riverbed samples between 62°51'31" and 62°00'04" W Long.

PHYSIOGRAPHY AND GEOLOGY OF THE UPPER RIO NEGRO To our knowledge, the first scientific reports on the Upper Rio Negro were prepared by Humboldt & Bonpland (1804), who made many scientific observations in their fascinating report. The upper part of the Rio Negro above Ilha Grande near Vila Tapuruquara (Lat. 00°26'22"S; Long. 65°00'16"W) and Ilha Jerusalém (Lat. 0°16'45"S; Long. 65°29'22"W) has a drainage basin of about 135,000 km^2, belongs to the western portion of the Guyana Shield and drains a pediplane varying between 80 and 160 m above sea level. On this plain there are numerous inselbergs (Fig. 2) whose tops occur at two levels – about 460 and 700 m. They have varied shapes – gentle slopes with exfoliation as well as steep slopes with solution channels which are formed by acids from plants growing at their tops. See Khobzi *et al.* (1980) for a description of the similar physiography of adjacent eastern Colombia. On this pediplane there are vast areas with quartz-rich sand 50 to 100 cm thick and its soils have been described by Klinge (1965; 1967).

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The extreme northeastern part of the watershed of the Upper Rio Negro has some restricted terraces that form the low divide between the Amazon and Orinoco watersheds. This divide is such that it is possible to take a boat between the two watersheds. The Rio Negro and its tributaries are well entrenched in the truncated surface formed on the Guyana Shield. The majority of rivers follow fractures or faults formed by regional tectonism (Fig. 2). Most of the rivers have rapids and falls less than 8 m high.

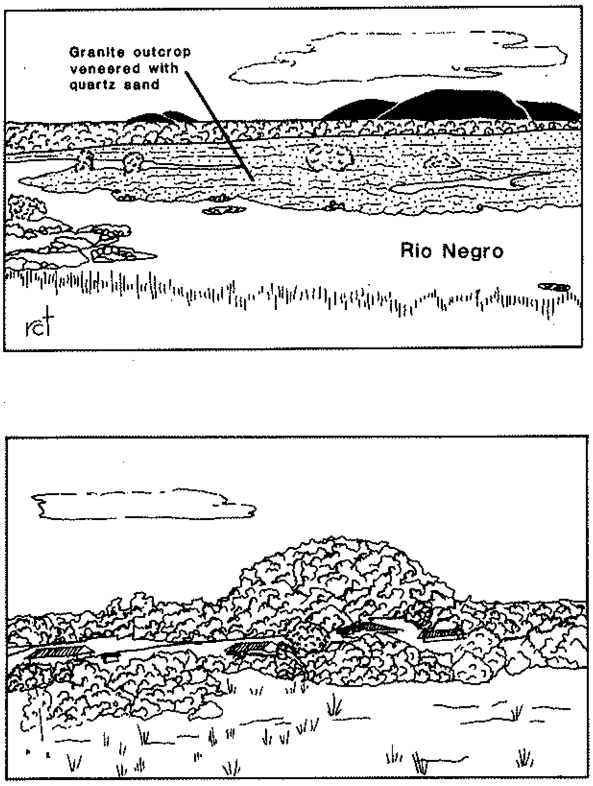

Figure 2 – Glimpses of the physiography of the upper drainage basin of the Rio Negro, Amazonas: Rio Negro during dry season with exposed fractured granite, partially covered with pure white sand, about 3 km above São Gabriel das Cachoeiras (above) and isolated or inselberg rising above well developed Pleistocene pediplain at São Gabriel das Cachoeiras (below).

Porphyroblastic granulites, mostly of granitic composition, but with some adamelites and quartz diorites, form most of the basement; the porphyroblasts of microcline are common and range up to 2 to 5 cm. Microcline occurs also in the matrix with quartz, sodium plagioclase and biotite. The quartz is granulated with strong undulose extinction. Some outcrops of equigranular, granulated granitoid rocks with homogeneous texture occur as well as gneisses of the same composition.

Rainfall varies from 2.5 to 3.5 m with a marked dry season; the temperature varies from 24 to 26°C (climatic type *f* of Koppen). The vegetation is dominantly that of a tropical rain forest. See DNPM (1976) for more complete details.

Stallard & Edmund (1983) provide much data on the relations between river water chemistry, physiography and source rocks for the Amazon Basin including the Upper Rio Negro.

PETROLOGY OF THE TWO FRACTION ANALYSES

The fraction analyses from the Rio Negro and from the Solimões are totally different for each size grade of the sand fraction from 62 to 707 microns (Tab. 1 and Fig. 2) – the sand of the Solimçoes averages about 6 percent feldspar and 27 percent rock fragments, whereas feldspar in the Rio Negro sand averages between 2 to 3 percent and rock fragments but 2.6 percent feldspar. Plagioclase forms about 17 percent of the feldspar in the Solimões, and some of it is zoned, but is virtually absent in Rio Negro sand. Contrasts in rock fragments are equally great – those of the Solimões include many low rank, fine grained, foliated, quartz-mica-feldspar schists, and some volcanics, whereas rock fragments in the Rio Negro are chiefly ferrocretes derived from lateritic crusts. Composite quartz, size grade by size grade, is always more abundant in the Solimões than in the Rio Negro, and averages 8 percent in the Solimões fraction analysis but only 2 percent in the Rio Negro. It tends to be most abundant in the larger size fractions and notably so in the 500-700 micron fraction of the Rio Negro. Fewer composite quartz grains in the Rio Negro than in Solimões sand reflect more intense weathering in the low relief watershed of the Rio Negro, where acid solutions not only remove feldspar byt also weaken the

Table 1 – petrographic summary of fraction analyses

Size Fraction Microns *Rio Negro*	Q:F:RF:0 *	Percent Composite Quartz	F_K/F_T **
500-707	95:3:0:2	11	1.00
354-500	95:4:1:0	3	0.95
250-354	99:1:0:0	1	1.00
188-250	97:2:1:0	2	0.83
125-188	91:4:1:4	3	1.00
88-125	97:3:0:0	1	1.00
62- 88	96:1:2:1	2	1.00
Rio Solimões			
354-500	69:3:22:6	12	0.83
250-354	62:7:27:4	10	0.95
188-250	58:7:29:6	9	0.82
125-188	57:6:33:4	18	0.63
88-125	50:7:40:3	3	0.58
62- 88	62:9:17:11	4	0.86

* Q:F:R:0 Quartz: Feldspar: Rock fragments: Other (chert, mica, heavy minerals)

** Potash feldspar over total feldspar

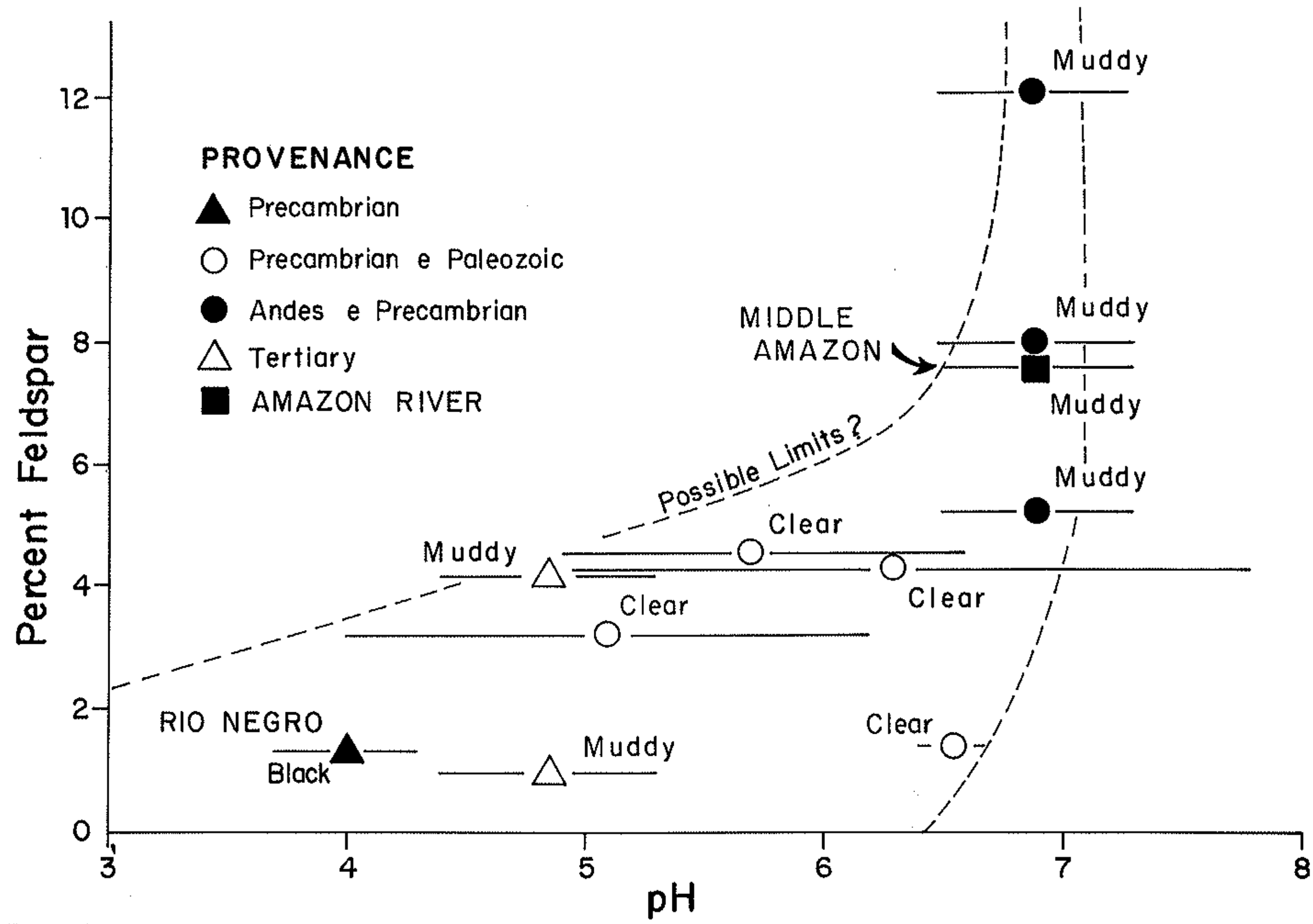

Figure 3 – Plot of total feldspar content of river sand against range and mean of river water pH. Feldspar composition from Franzinelli & Potter 1983, and pH values from Schmidt (1972, Table 2), Ungemack (1972, Tables 2 and 3) and Sioli (1975, Table 18.1). An essential similar graph would result if total cation concentration (TZ) where used rather than pH or if the ZTR index (total percent of the heavy minerals zircon, tourmaline and rutile) were substituted for total feldspar content.

contacts between the welded, individual crystals of composite quartz so that it disintegrates into smaller fragments of silt. Rounding of quartz, however, is but little different between the two sands, because angular grains predominate in both. Finally, each size grade in the fraction analysis of the Solimões is petrographically a lithic arenite, whereas all but one of the size grades of the Rio Negro are quartz arenites. Thus what emerges is striking documentation of a mineralogically pure, quartz-rich sand derived from a pediplane cut on Precambrian granitic rocks and now covered by rain forest.

Water chemistry and feldspar content of the rivers of the Amazon Basin, as noted by Franzinelli & Potter (1982, Tab. 1), hep explain these contrasts. As shown by Figure 3, there is good nonlinear correlation between pH of river water, feldspar content of river sand, and source area. However, it is the mineralogy and composition of soil water that is probably the controlling factor. Where feldspar and rock fragments are present, as in unstable Andean soils, reaction with rainwater leads to a rise of pH whereas reaction of rainwater with quartz-rich materials and humic material in soils, as in the Upper Rio Negro, does not raise pH. Moreover, Rio Negro sands are almost totally devoid of plagioclase (Tab. 1), because it is less stable than potash feldspar (Garrels & Christ 1965, Fig. 10.6; Stallard & Edmund 1983, Table 1). The Rio Negro has the lowest pH (Fig. 3); its waters are organic-rich and black colored – so that feldspar of all kinds, but especially plagioclase, is not common in it even though the river bed has many granitic outcrops.

IMPLICATIONS What general implications can be drawn from these petrographic contrasts? First, granite subject to tropical weathering and low relief does, indeed, yield sand of quartz arenite composition as summarized in Figure 4. This conclusion is far from new; see Krynine (1942), who early deduced it, and Millot (1964, Fig. 5; 1970), who inferred it from the study of the clay mineralogy of ancient deposits. Thus the sand in the upper Rio Negro drainage basin fully confirms their earlier inferences. Millot (1964, 1970) perceptively called the deeply weathered landscape *le paysage de tectonique null ou paysage geochimique.*

Secondly, how important is a low relief granitic source with tropical climate for the origin of most quartz arenites? This question is relevant because Suttner *et al.* (1981) tentatively concluded that first-cycle quartz arenites could

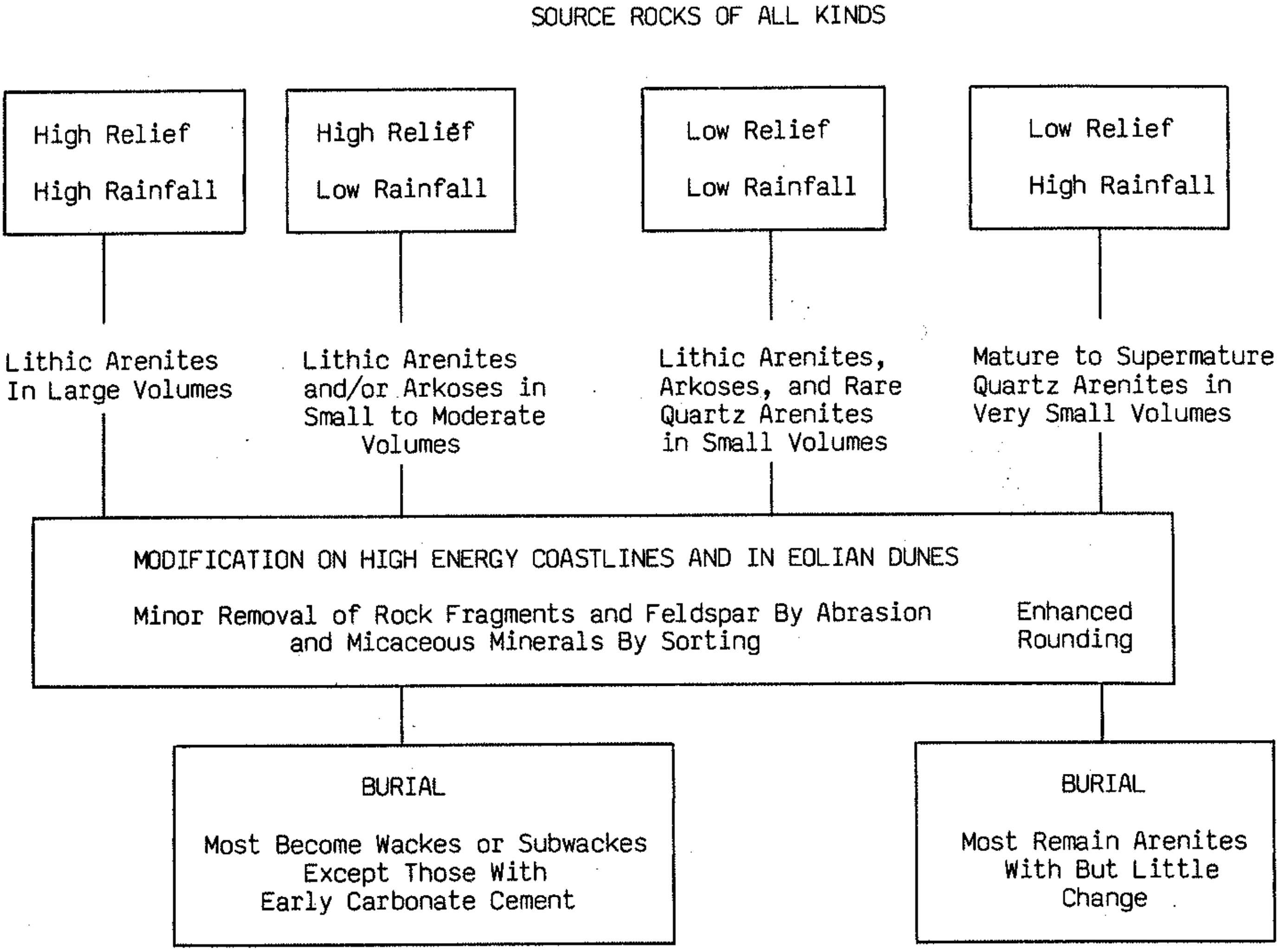

Figure 4 – Flow diagram for the origin of pure quartz arenites and other sandstones

not form under average conditions in the geologic past. However, in non-glacial periods, tropical weathering extended far north and south of its present limits, so that much more of many old cratons were subject to tropical weathering than today. (Dury 1971, Feininger 1971). Nonetheless, the probably low volume of sand produced from the weathering of an ancient peneplain cut on granitic basement suggests that most quartz arenites must be recycled. The low rounding, possible solution pits and ferruginous fracture fillings (Franzinelli & Potter 1983, Fig. 4) should help distinguish a first cycle quartz arenite produced by tropical weathering from the better rounded, many-cycled quartz arenites. But still puzzling is the problem of large volumes of quartz arenite – do these require elimination of feldspar and rock fragments by abrasion in the environment of deposition?

Finally, the amount of arkose and subarkose above granitic basement – residual arkose – and the relief of the unconformity always deserves attention as a guide to paleoclimate. Pause but a moment and think of the Rio Negro's drainage basin as it is today, but with a temperate, semiarid, or arid climate. Under these conditions, river water would be far less acid and there would be but partial solution of feldspar and partial destruction of rock fragments and composite quartz so that streams would be rich in these components – quite the opposite of what exists today. A good summary of how granitic and granite-like rocks weather is given by Twidale (1982), who also believes this to be true. Clearly what are needed, however, are more actual studies of sand, clay and water composition of the streams draining granitic terrains in different climates. In such studies, small headwater streams rather than large ones should be studied – perhaps four basins each for good statistical replication? Brazil and other countries of South America are rich in localities for such studies. Suttner *et al.* (1981) have made a first approach to this in the United States where climatic contrasts are less. The next step appears to be carefully relating river or soil water chemistry to feldspar and rock fragment content and their varieties.

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REFERENCES

DNPM – DEPARTAMENTO NACIONAL DA PRODUÇÃO MINERAL – 1976 – *Pedologia.* In Projeto Radambrasil; Folha Na. 19 Pico da Neblina; geologia, geomorfologia, pedologia, vegetação e uso potencial da terra. Rio de Janeiro. v. 1, p. 193-265. (Levantamento de Recursos Naturais, v. 11).

DURY, G. H. – 1971 – Relict deep weathering and duricrusting in relation to paleo environments of middle latitudes. *Geog. Jour.,* 137:511-522.

FEININGER, T. – 1971 – *Chemical weathering and glacial erosion of crystalline rocks and the origin of till.* Washington (USGS Prof. Paper 750-C).

FRANZINELLI, E. & POTTER, P. E. – 1982 – Caracterização petrográfica e textural de sedimentos arenosos recentes dos rios da Bacia Amazônica. In: SIMPÓSIO DE GEOLOGIA AMAZÔNICA, 1, Belém, 1982. *Anais...* Belém, SBG, v. 1, p. 89-99.

FRANZINELLI, E. & POTTER, P. E. – 1983 – Petrology, chemistry and texture of modern river sands, Amazon River System. *J. Geol.,* 91:23-39.

GARRELS, R. M. & CHRIST, C.L. – 1965 – *Solutions, minerals, and equilibria.* New York, Harper and Row, 450 p.

GIBBS, R.J. – 1967 – The geochemistry of the Amazon River system: part 1: The factors that control the salinity and composition and concentration of suspended loads. *Geol. Soc. Amer. Bull.,* 78:1203-1232.

HUMBOLDT, A & BONPLAND, A. – 1804 – *Personal narrative of the travels to the equinoctial regions of the new continent during the years 1799-1804,* v. 5, Book VIII (English translation of French text, published in London in 1821). Ch. 23 New York, AMS Press, Inc., 865 p.

KHOBZI, J.; KROONENBERG, S.; FAIVRE, P.; WEEDA, A. – 1980 – Aspectos geomorfológicos de la Amazonia y Orinoquia columbianas. *Revista CIAF,* 5: 97-126.

KLINGE, H. – 1965 – Podzol soils in the Amazon Basin. *Jour Soil Sci.,* 16:95-103.

KLINGE, H. – 1967 – Podzol soils: A source of black water rivers in Amazonia. In: CONGRESSO PANAMERICANO DE INGENERIA DE MINAS Y GEOLOGIA, 1, Santiago, 1967. *Annales...* Santiago. v. 2.

KRYNINE, P. D. – 1942 – Differential sedimentation and its products during one complete cycle. In: CONGRESSO PANAMERICANO DE INGENERÍA de MINAS Y GEOLOGIA, 1, Santiago, 1942. *Annales...* Santiago. v. 2, p. 537-561.

MILLOT, G. – 1964 – *Geologie des argiles; alterations, sedimentologie, geochimie.* Paris, Masson, 499 p.

MILLOT, G. – 1970 - *Geology of clays; weathering sedimentology, geochemistry.* New York, *Springer-Verlag,* 429 p.

SCHMIDT, G. W. – 1972 – Amounts of suspended solids and dissolved substances in the middle reaches of the Amazon over the course of one year (August, 1969 – July, 1970). *Amazoniana,* 3:208-223.

SIOLI, H. – 1975 – Tropical river: the Amazon. In: WHITTON, B.A., ed., *River ecology:* studies in ecology, 2. Berkeley and Los Angeles, Univ. California Press, p. 461-488.

STALLARD, R. F. & EDMOND, J. M. – 1983 – Geochemistry of the Amazon: the influence of geology and weathering environment on the dissolved load. *Jour. Geophysical Research,* 88:9671-9688.

STALLARD, R. F. – 1983 – Low temperature geochemistry. In: CROSS, P., ed., *The Smilodon:* Princeton University, p. 2-3. (Department of Geological Geophysical Sciences, 13.)

SUTTNER, L. J.; BASU, A.; MACK, G.H. – 1981 – Climate and the origin of quartz arenites. *Jour Sed. Petrol.,* 51: 1235-1246.

TWIDALE, C.R. – 1982 – *Granite landforms.* Amsterdam, Elsevier 372 p.

UNGEMACK, H. – 1972 – Die Ionenfracht des Rio Negro Staat Amazonas, Brasillien. *Amazoniana,* 3:175-185.

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... se se considerar a história do globo, a aparição do homem assume para os biólogos a mesma significação dos grandes cataclismas na escala do tempo geológico, das "Revoluções" de Cuvier, no decurso dos quais a fauna e a flora do mundo inteiro se transformam radicalmente em sua composição e em seu equilíbrio.

Jean Dorst, 1973, *Antes que a Natureza Morra,* São Paulo, Blücher, p. 1