

Climatic and morphological control of rare earth element distribution in weathering mantles on alkaline rocks

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Abstract

In humid coastal regions and in areas of accentuated relief of SE-Bahia, Brazil, weathering of alkaline rocks resulted in the formation of kaolinitic and lateritic weathering mantles. Under subhumid conditions in the inland region of Bahia, less mature sandy-clayey soil have developed. Rare Earth Element (REE) distribution in the weathering profiles has been investigated in order to establish relationships between climatic and morphological parameters and the enrichment and fractionation of REE. Under tropical humid climate and intensive drainage conditions, REE fractionation is enhanced. Ce is absolutely enriched in laterite layers while the Heavy REE are retained in the saprolite. Moderate drainage due to high groundwater tables lead to minor fractionation and enrichment of REE. Restricted drainage conditions in subhumid climatic zones hamper liberation of REE from primary minerals and impede enrichment and fractionation of these elements. REE distribution is also controlled by poly-phase evolution of the weathering mantle: the positive Ce anomalies in laterite layers are related to stable mineral phases like Mn oxides, which have developed in roots of weathering during former, less humid weathering cycles.

The REE fractionation patterns correspond to the drainage conditions which prevailed during the formation of the weathering products. Thus they may represent a valuable tool for the reconstruction of landscape evolution and the investigation of the paleoenvironment.

1. Introduction

Tropical weathering of alkaline rocks in Brazil results in the formation of extensive weathering mantles. Humid tropical climate and moderate relief favour bauxitisation and lateritisation, representing the end product of lateritic weathering under good drainage conditions. Less intensive drainage with restricted removal of silica, alkali and earth alkali elements may lead to the formation of fersiallitic and bisiallitic, sandy clayey weathering products.

The spatial distribution of bauxites, laterites and fersiallitic soils in Brazil does not

necessarily correspond to the actual climatic conditions. The formation of bauxites in South-Brazil like e.g. in Poços de Caldas, Itatiaia, Passa Quatro and Lages are related to more humid climatic conditions in the past (Melfi and Carvalho, 1983). On the other hand, kaolinitic weathering products with no indications of bauxitisation have developed on alkaline rocks in tropical humid zones like São Sebastião Island near Rio de Janeiro (Kronberg et al., 1987).

Thus the evolution of weathering mantles on alkaline rocks in Brazil in most of the cases represents the result of polyphase and polygenetic weathering processes. Drainage conditions which control the geochemical and mineralogical composition of weathering products are intimately related to climatic and morphological parameters. Thus the interpretation of geochemical and mineralogical patterns in weathering material, especially the investigation of Rare Earth Elements (REE) may yield direct evidence on climatic and morphological control of profile evolution, on paleoclimatic conditions and on landscape evolution.

Regarding the supergene fractionation and enrichment of REE, the until now obtained results still diverge significantly, especially in respect to the behaviour of individual REE like Ce and groups like the Heavy REE (HREE) (Trescases et al., 1987; Bonnot-Courtois, 1981; Braun et al., 1990). The divergence may be due to the fact that investigations of isolated REE occurrences in individual profiles usually lack integration into a more regional or global scale.

This contribution focuses on the interpretation of REE patterns on a regional scale by comparing profiles from various climatic zones and morphological positions. Under consideration of polyphase and polygenetic weathering processes, present REE distribution patterns are related to different phases of landscape and climatic evolution in SE-Bahia State, Brazil. Finally the use of REE patterns as tools for the reconstruction of landscape evolution and weathering history is discussed.

2. Geological and geographical setting

In the study area various intrusions of alkalic silicate rocks of syenitic and nepheline–syenitic composition are hosted in granulitic and gneissic rocks of the Archean basement (Fig. 1). The alkaline rocks have radiometric ages between 430 and 770 ma (Cordani et al., 1974). From NE to SW, the alkaline bodies consist mainly of nepheline–aegirine syenites, syenites and monzonites (Itabuna), sodalite syenites (Sta. Cruz), quartz syenites (Potiragua) and syenites and monzonites (Itarantim). Main mineralogical components are microcline, albite and micropertite, nepheline and sodalite. Mafic minerals are arfvedsonite, aegirine augite and biotite. Apatite, sphene, zircon and allanite represent the most important REE-bearing accessory minerals. The REE fractionation patterns of the alkaline rocks show a distinct dominance of the Light REE (LREE). La/Lu ratios vary between 26 and 352 with a mean value of 183 (Marker, 1991).

Within the study area various climatic zones can be differentiated (Fig. 1). Profiles 21, 22 and 23 are located in the humid coastal zone which is characterized by hydrological excess rates. Principal morphological features are rolling hills with

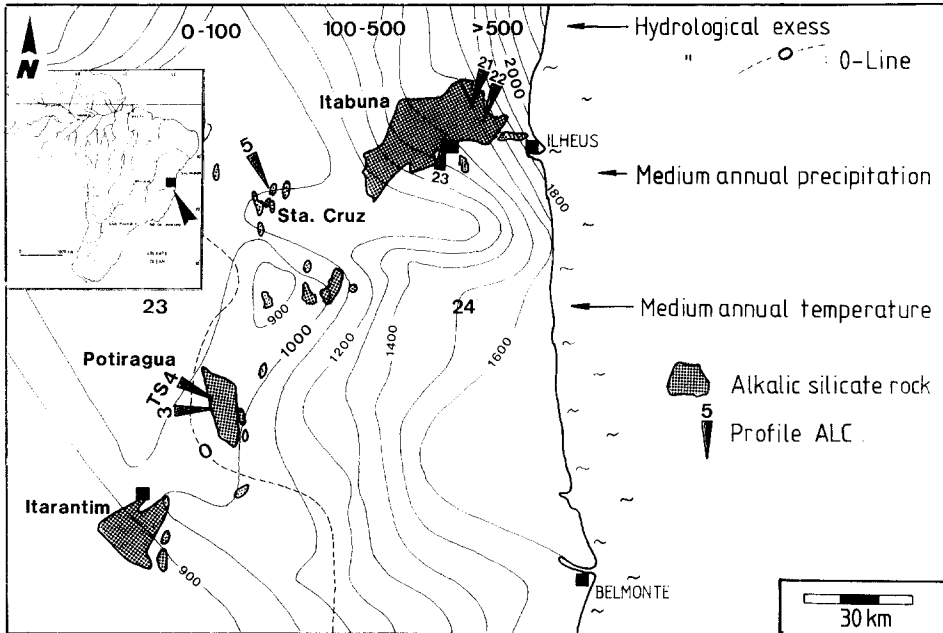


Fig. 1. Sketch map of the study area and climatological parameters.

elevations between 100 and 150 m. In this region tropical rainforest vegetation is almost entirely preserved. Profile 5 and 5A are situated in a climatic zone with annual precipitation of around 1100 mm. The topography is mountainous and patches of tropical rainforest alternate with grassland vegetation. Profile 3 and profile sequence 4 (TS 4) are located in the subhumid climatic zone of the inland region of Bahia. The landscape is characterized by gently rolling mountain plateaus with intramontaneous depressions.

3. The weathering products

3.1. Classification and description of weathering products

The weathering mantle on alkaline rocks in SE-Bahia consists of loose friable reddish-brown latosols (Profile 5, 22) or sandy-clayey soils (Profile 3, TS 4, 21, 23).

In the classification scheme for lateritic weathering products after Schellmann (1982), the majority of the weathering products above alkaline rocks in SE-Bahia has hardly attained the stage of kaolinisation (Fig. 2). With the exception of the uppermost laterite layer of profile 22 and the sandy-clayey soils from profiles 3 and TS 4, which show low maturity, the recent weathering conditions in the more humid regions of SE Bahia lead to kaolinisation. This fact is supported by thermodynamic calculations of the water-mineral equilibrium (Fig. 3). The groundwater composition of profile 22 is in equilibrium conditions with kaolinite in respect to the main rock forming minerals.

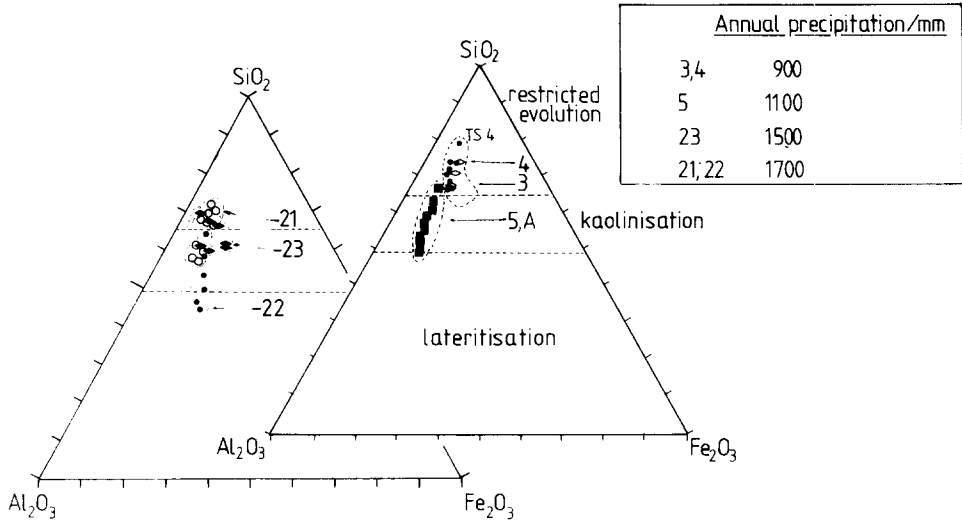


Fig. 2. Classification of weathering products on alkali ne bedrock from SE-Bahia after Schellmann (1982).

Latosol profiles consist of a reddish-brown kaolinite and goethite rich upper horizon, containing minute, blackish-brown concretions in its topmost portion and concretionary fissures in its lower part, grading towards depth into a yellowish brown–red saprolite with preservation of rock structures. In inclined hillslope position (profile 5), the saprolite is extremely thin (< 30 cm) with sharp contact towards the underlying sodalite syenite bedrock. In hilltop position (profile 5A)

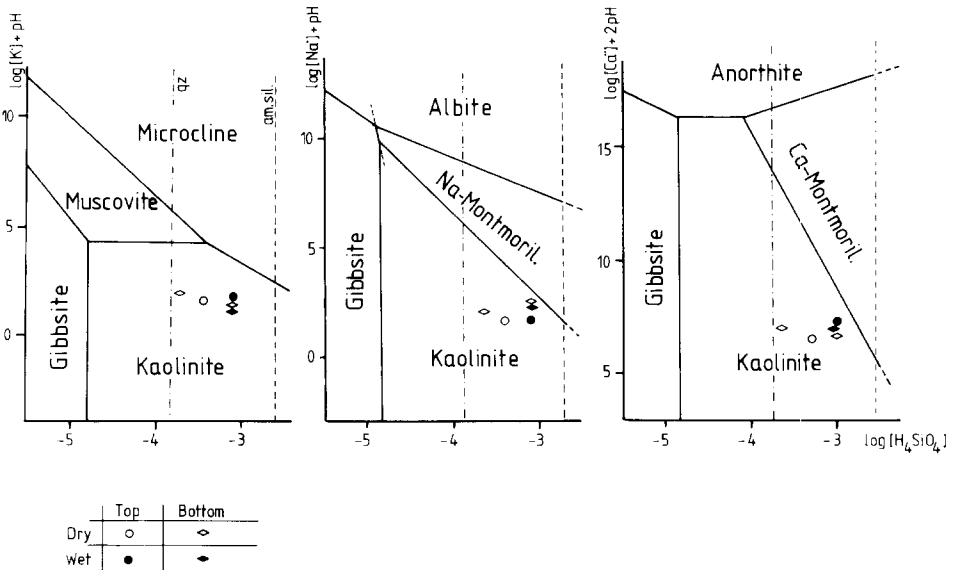


Fig. 3. Groundwater composition in the area of profile 22 and stability fields of primary and secondary minerals. top = hillslope, bottom = hillfoot, wet = after rain, dry = before rain.

and along gentle hillslopes close to the groundwater table (profile 22), the saprolites are thick and may contain boulders of unweathered bedrock. Here the transition to the underlying bedrock is gradual.

The relatively thin soil profiles consist of yellowish grey-brown sandy–clayey soil horizons with thicknesses less than 3 m. The material is friable, containing minute blackish brown nodular concretions in upper parts of the horizon (TS 4). In profile 3, 21 and 23, the soil horizons are underlain by a rather hard and compact saprolite which grades towards depth into fresh bedrock. Along toposequence TS 4, the hilltop profiles consist of a 20–40 cm thick indurated, blackish brown, spongy-cellular crust, grading towards depth into a sandy–clayey horizon and a thin saprolite. Along the hillslope, the profile consists of a sandy–clayey top horizon with nodular blackish brown concretions, grading towards depth into a yellowish brown saprolite.

Locally the lowermost portion of the saprolite is highly indurated resulting from cementation by secondary silica. This portion of the saprolite has the appearance and consistency of white sandstone. Here the contact to the fresh bedrock is rather sharp.

Thicknesses of the individual profile layers, pH values and bedrock composition are shown in Fig. 4.

3.2. Geochemical and mineralogical evolution

The weathering products show different stages of depletion of alkalis and Si. In sequence Ca is the first element to be depleted, followed by Mg, Na and K (Fig. 4).

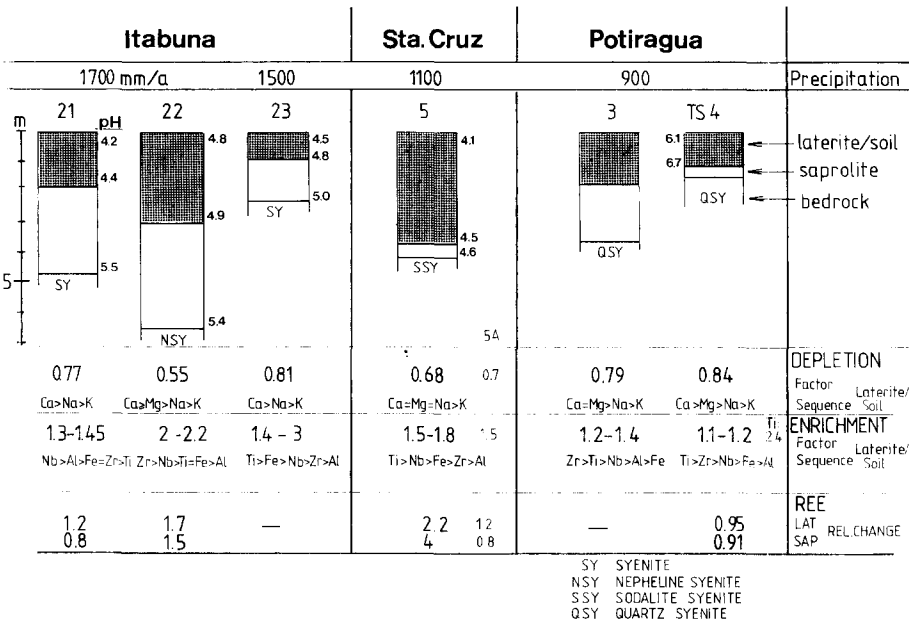


Fig. 4. Geochemical, pedological and climatological parameters of weathering of alkaline rocks in SE-Bahia.

This corresponds to the sequence of mineral dissolution: calcite, followed by mafic minerals, feldspathoids, albite and finally microcline.

The depletion factor was calculated as the sum of alkali + earth alkali + Si contents in the latosol or soil horizon divided by the contents of these elements in the corresponding fresh bedrocks of the profiles. It can be regarded as an indicator for drainage conditions and profile maturity (“Depletion Factor” in Fig. 4). The most advanced depletion is observed in the well drained latosol profiles 5 and 22 with factors of 0.68 and 0.55, indicating that the laterite only preserves 68% respectively 55% of the primary alkali- and Si concentration of the bedrock. Correspondingly the factors of residual enrichment of the less mobile elements, calculated from the mean enrichment factors of Fe, Nb, Ti, Zr and — with restriction of TS 4 — also of Al in the latosol or soil horizon in relation to bedrock, are highest in profiles 5 and 22 (“Enrichment Factor” in Fig. 4). The enrichment sequence of these elements indicate that most of the heavy minerals like ilmenite, rutile, sphene (Ti) and zircon (Zr) are rather stable. Fe in general shows residual behaviour whereas Al is partly mobilized, especially in TS 4. This fact has been proven by mass balance calculations (Marker, 1991).

Less intensive drainage in profile 21 and 23 of Itabuna is related to the morphological position of these profiles, which are located in lowland areas with a high groundwater table.

Low maturity in function of climatically controlled drainage deficiencies characterize the sandy–clayey soils of Potiragua. Precipitation of secondary silica due to seasonal Si-supersaturation in weathering solutions can locally be observed. Clay mineral lessiviation from the eluvial top horizon to the illuvial bottom horizon of the profiles of TS 4 is common. Depletion factors between 0.79 and 0.84 reveal that 79% to 84% of the rock forming feldspar minerals and feldspathoids have not been hydrolyzed.

3.3. REE distribution

3.3.1. Enrichment and fractionation relative to bedrock

The relative enrichment of REE in the weathering products in relation to bedrock is most pronounced in the well drained profiles 5 and 22 (Table 1, Figs. 5 and 6). High REE concentrations and positive Ce anomalies can be found in the laterite layers where REE are mainly bound to manganiferous concretions, fissure fillings (profile 22) and pisolites (profile 5) (Figs. 5 and 6). In profile 5, REE are locally concentrated in the thin saprolite zone bound to vermiculite and hydrobiotite (Fig. 5A) (Marker, 1991).

The fractionation patterns normalized to bedrock indicate that the laterite layers preserve distinct enrichment of the LREE La–Gd, whereas the HREE are depleted. The REE fractionation in the saprolites has a contrary trend with relative enrichment of the HREE and absence of positive Ce anomalies. The exceptional Ce anomaly in the saprolite of profile 5 is of local importance. In the saprolite zone of the neighbouring profile 5A, situated in hilltop position, a distinct negative Ce anomaly can be identified (Fig. 5B).

Table 1
Contents of Rare Earth Elements (in ppm) of weathering products and related bedrocks (numbers with 9...)

Sample	REEtot	La	Ce	Nd	Sm	Eu	Gd	Dy	Ho	Er	Yb	Lu
<i>Profile 4A''</i>												
421	258	38.9	167.1	34.9	5.6	2.1	3.5	3	0.6	1.3	1.1	0.14
422	305	58.5	164.9	55	8.6	3.3	5.5	4.6	0.8	1.9	1.5	0.19
423	338	67.7	174.2	64.4	10.3	3.7	6.7	5.5	1	2.3	1.8	0.22
424	396	75.8	202.7	78.3	12.4	4.6	8.2	7.1	1.3	3.2	2.4	0.29
425	352	71	168.7	78.2	12.7	4.6	7.5	5.4	0.9	1.8	1.2	0.15
947/8	297	55.5	119	73.8	13.6	5	9.6	9.7	1.8	4.8	3.9	0.50
<i>Profile 5</i>												
51	412	112	219	55.6	7.7	2.56	4.86	3.69	0.62	1.86	2.62	0.42
53	261	75.5	147.3	26	3.3	1.08	2.84	1.88	0.27	0.75	1.34	0.22
54	255	80.2	129.2	31.8	3.8	1.31	3.2	2.34	0.39	0.89	1.53	0.26
55	558	111.4	382.2	47.7	4.7	1.88	4.84	2.56	0.37	1.03	1.19	0.14
956	141	42.35	66.1	24	2.5	1.18	1.86	1.5	0.25	0.61	0.74	0.12
<i>Profile 5A</i>												
352	559	161.7	268	91.8	12.8	3.6	7.2	6	1.2	3.3	3.2	0.4
354	322	97	154.8	49.6	6.5	1.9	3.9	3.3	0.7	1.8	1.8	0.25
356	255	90.8	105	43	5.4	1.5	3	2.6	0.5	1.5	1.3	0.18
358	182	68.6	68.3	32.8	4.1	1.3	2.3	2	0.4	1.1	1	0.13
360	319	110	133.2	54.7	6.8	2	4.1	3.3	0.7	1.9	1.7	0.22
9300	314	93	156.8	43.7	5.9	1.53	4.2	3.5	0.76	2.15	1.8	0.37
<i>Profile 21</i>												
211	273	60.8	158.6	37.1	5.3	1.15	3.45	2.86	0.51	1.46	1.6	0.24
212	378	64.9	254	42.3	5.7	1.24	3.75	2.8	0.53	1.35	1.51	0.24
214	515	120.1	261.6	94.2	13.3	2.57	7.66	6.44	1.27	3.42	3.42	0.59
215	512	115.8	256.2	98.2	13.9	2.56	8.12	6.85	1.37	3.79	4.1	0.72
217	346	94.1	142.2	79.2	11	2.03	5.98	4.98	0.99	2.64	2.8	0.42
219	226	57.1	104.5	46.6	6.5	1.07	3.45	2.8	0.53	1.49	1.58	0.25
9221	354	91.3	179.3	59.8	7.9	1.6	4.8	3.9	0.8	2.1	2.1	0.34
<i>Profile 22</i>												
221	829	185.6	462.9	132.6	18.5	4.9	10.85	7.18	1.3	2.99	2.02	0.27
222	1318	263.5	727.8	242.1	34.4	9.03	19.14	11.86	2.13	4.56	2.99	0.4
223	925	199	488.6	174.3	25	6.57	13.4	9.1	1.72	3.94	2.93	0.4
224	1267	268.3	657.7	247.4	36.6	9.64	19.94	13.84	2.59	6.06	4.51	0.59
225	862	184.1	362.2	216.7	33.9	10.59	19.45	15.63	3.24	8.21	6.74	0.97
226	969	198.4	420.8	235.8	37.1	11.54	22.86	18.98	3.89	10.04	8.04	1.15
229	458	100.3	175.7	117.7	19.6	6.3	12.29	11.25	2.33	6.3	5.22	0.77
92200	592	133.2	238.9	154.9	23.4	7.2	13.05	10.1	1.96	4.91	4.01	0.56

The fractionation trends of REE from profiles 5 and 22 can also be detected in profile 21 (Fig. 7). Here the divergence between REE patterns of the soil layer, enriched in LREE, and the saprolite, enriched in HREE, is less pronounced but still evident. Local high REE concentrations are bound to weathered mafic minerals (pyroxenes), whereas the bulk of the REE are bound to illite and smectite.

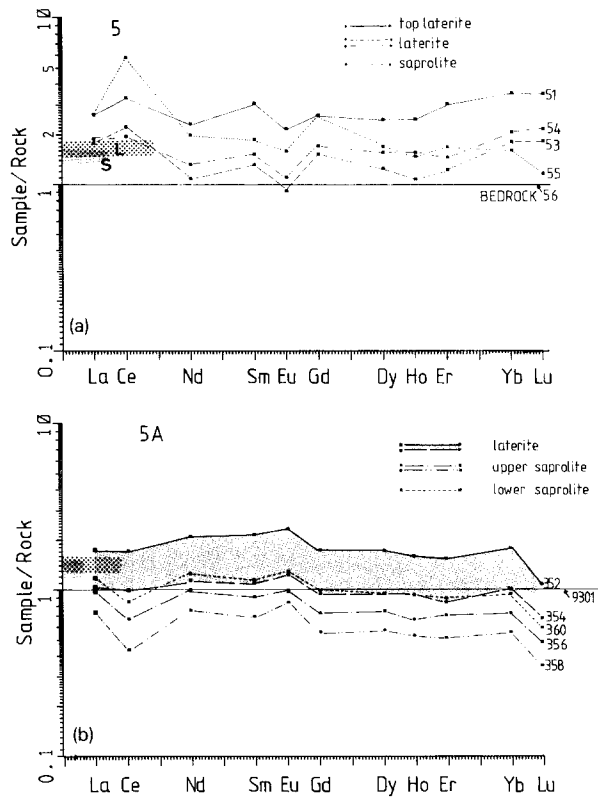


Fig. 5. (a) Fractionation of REE in profile 5 normalized to bedrock; L and S see text. (b) Fractionation of REE in profile 5A normalized to bedrock; L and S see text.

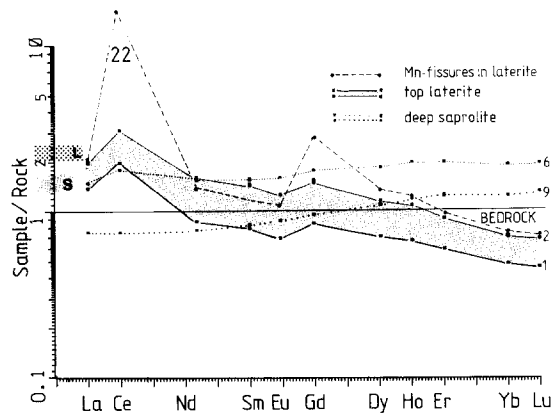


Fig. 6. Fractionation of REE in profile 22 normalized to bedrock; L and S see text.

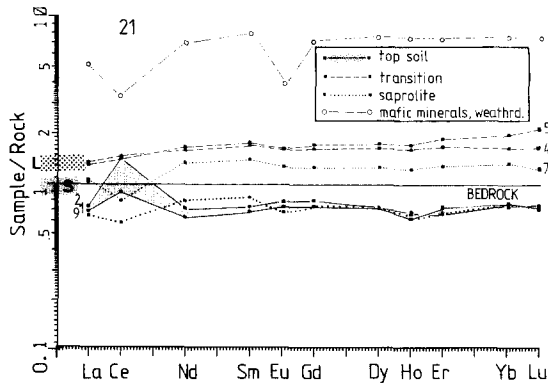


Fig. 7. Fractionation of REE in profile 21 normalized to bedrock; L and S see text.

Under conditions of restricted drainage in profile 4A'', representing TS 4, only Ce shows slight enrichment relative to bedrock whereas all other REE are depleted (Fig. 8). In the sandy-clayey soils of Potiragua, smectite-rich illuvial bottom horizons are significantly less depleted than the eluvial top horizons, where REE are impoverished due to clay mineral leaching. In this environment REE are mainly bound to smectite and thus follow the distribution of this mineral. The positive Ce anomaly is related to the occurrence of manganiferous pisolites.

Fractionation trends of Eu and Gd are exempt of further interpretations and conclusions since they show erratic and non interpretable trends, which also may be due to analytical problems.

3.3.2. Absolute enrichment

The absolute enrichment of individual REE has been determined by using the Fe content as internal standard. Factors of maximum residual enrichment were established as mean values for the laterite or soil horizons (L in Figs. 5–8) and for the saprolite horizons (S in Figs. 5–8) of the individual profiles. This means that values of the individual REE above/below the limits of maximum residual enrichment,

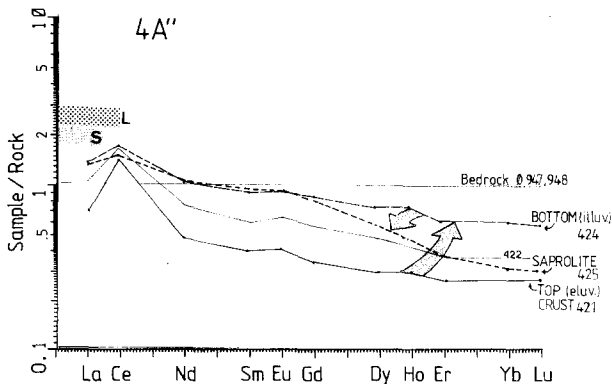


Fig. 8. Fractionation of REE in profile 4A'' normalized to bedrock; L and S see text.

represented by the dotted respectively the shaded bars, indicate absolute supply/depletion of this element in laterite or soil respectively saprolite. Because of Fe mobilisation in profiles of TS 4 (4A''), Ti has been considered the less mobile element and thus was used as internal standard.

In profile 5, all REE are absolutely enriched in the top laterite layer, partly depleted in the intermediate laterite layer and show an absolute gain in the saprolite. In the saprolite of profile 5A, REE are depleted.

In profile 22, Ce shows slight absolute enrichment in the laterite whereas Er–Lu reveal slight absolute gain in the saprolite. The rest of the REE is depleted.

In profile 21, all REE are depleted in the soil layer with exception of Ce, which shows residual behaviour. In the saprolite Ce is absolutely depleted whereas the rest of the REE, especially the HREE Er–Lu, are absolutely enriched.

In profile 4 the bulk of REE is depleted with increasing intensity towards the HREE and highest depletion in the eluvial horizon. Absolute depletion of Ce in the upper soil layers may be an artefact caused by the use of Ti as internal standard. It is assumed that Ce is also residually enriched in the upper soil layers as in the case of profile 21.

4. Discussion of results and conclusions

The here presented results show a distinct climatic and morphological control of the evolution of weathering profiles as well as of fractionation and enrichment/depletion of REE.

4.1. Enrichment and fractionation of REE

The most significant features of REE behaviour in the weathering profiles are polarisation of LREE and HREE in laterites/soils and saprolites and the Ce anomalies.

– *Polarisation of LREE and HREE*: During tropical weathering and mineral dissolution, REE are subject to mobilisation and migration. Under slightly acid and oxidizing conditions in upper parts of the weathering profiles, REE are mobilized and transported downward, where the HREE become enriched in the saprolite due to decreasing hydroxide solubility from Gd to Lu with increasing alkaline pH (Nesbitt, 1979). The adsorption of REE to clay minerals like smectite is enhanced with decreasing ionic radii from Gd to Lu (Bonnot-Courtois and Jaffrezic-Renault, 1982). The LREE are removed with exception of Ce, which due to its spontaneous oxidation to Ce^{4+} forms stable compounds in the laterite/soil layers. This process explains the negative Ce anomaly in the saprolite, since this element is retained in the laterite.

– *Ce anomalies*: In weathering profiles of SE-Bahia Ce anomalies can be related to two different processes which may overlap each other.

(i) In the laterite/soil layers, Ce is principally bound to manganiferous, X-ray amorphous concretionary minerals. These concretions are inherited from an earlier phase of profile evolution. During this phase high saturation of solutions in respect to

Mn and Si had favoured the precipitation of non-stoichiometric Mn oxides in lower parts of the weathering mantle (Formoso et al., 1989; Boulangé et al., 1990). Under these conditions Ce can be scavenged by Mn oxides and after oxidation fixed as tetravalent Ce (Rankin and Childs, 1976; Kühnel, 1989; Marker et al., 1991). The stability of Ce^{4+} compounds such as Mn oxides or minute cerianite crystals favoured absolute enrichment of Ce in the weathering products. In consequence of the downward progression of the weathering front, these stable minerals subsequently reached the upper profile parts (laterite/soil layers) as a result of profile truncation during a later phase of profile evolution: during this process stable Ce-bearing concretions from lower profile portions became residually enriched in surface-near profile layers of lateritic respectively kaolinitic composition without being dissolved.

(ii) During weathering of Ce-bearing primary minerals, Ce forms rather immobile compounds and becomes subject to residual enrichment in function of its spontaneous oxidation. Thus it remains residually enriched in the upper part of the profile, causing a negative Ce anomaly in the saprolite. Ce may be fixed to vermiculite and hydrobiotite, as reported by Duddy (1980). Anomalously high Ce contents of almost 3000 ppm Ce_2O_3 in weathered biotites from profiles 5 and 22 confirm this observation (Marker, 1991).

4.2. Polyphase evolution of the weathering mantle and REE distribution

The relationship between profile evolution and weathering history on one side and REE distribution and fractionation on the other side may be interpreted as follows:

The weathering products above alkaline rocks in the humid coastal region of SE-Bahia (profiles 21 and 22) and in Sta. Cruz (profile 5) contain remnants of a former less humid climatic period. These remnants are represented by manganiferous concretions (Mn–Fe–Si pisolites and veinlets). They have developed in the roots of weathering during an ancient weathering cycle (Phase 1). Similar observations have been made by Sigolo et al. (1987), Trescases et al. (1987) and Formoso et al. (1989) in South Brazil. As described above under (i), the oxide minerals which formed these concretions scavenged and accumulated REE, in particular Ce.

Climatic changes and less humid conditions in the past are discussed by Conceição et al. (1974), who investigated weathering profiles on granulites in the region of Ilheus, Bahia.

In the formerly even less humid inland regions of Potiragua, the exposure of Mn–Fe–Si rich saprolite zones which was favoured by profile truncation, resulted in the formation of Mn–Fe–Si duricrust cappings. Geomorphological instability caused further profile erosion and the bulk of the eroded material was transported to the coastal plains where important heavy mineral beach placers have developed. The erosional event may also be related to sea level changes during Late Tertiary, as proposed by Gillson (1981).

With the beginning of Pleistocene, climatic conditions became more humid in the coastal regions. Kaolinisation and subordinately lateritisation are the dominating weathering processes which prevailed until today (Phase 2). The weathering front progressed further downward in the truncated weathering profiles, resulting in the

formation of predominantly kaolinitic–goethitic weathering products. Because of permanently wet conditions in the coastal region, conditions for bauxitisation were never attained (Bardossy and Aleva, 1990).

In the inland regions of Potiragua, restricted weathering conditions in subhumid climate prevailed until recent times. Smectite formation and clay lessiviation are the recent soil forming processes. Degradation of former silica hardcrusts can be observed.

During this phase polarization and fractionation of LREE and HREE took place, being controlled by the prevailing drainage conditions and physico-chemical parameters of weathering as described above.

4.3. Generalized pattern of REE distribution

As an attempt to establish a generalized pattern which relates drainage conditions and REE behaviour, the following scheme is presented (Fig. 9):

– Intensive drainage conditions favour enhanced polarization, fractionation and enrichment of REE in a way, that LREE are more intensively depleted in the saprolite and HREE are more strongly depleted in the laterite (B in Fig. 9). Ce shows considerable positive anomalies in the laterite and HREE are significantly enriched in the saprolite. These features are related to the physico-chemical conditions of well drained profiles: silicate hydrolysis is enhanced, thus liberating considerable amounts of REE to the supergene cycle. Residual enrichment of already existing Ce-bearing

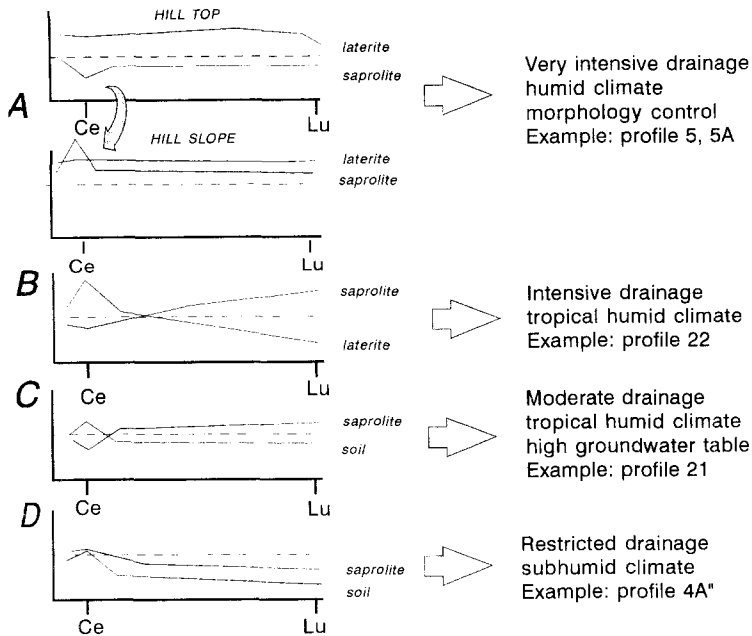


Fig. 9. Relationship between REE fractionation patterns and climatological and morphological parameters.

minerals like Mn oxides is favoured by intensive leaching of alkalis and Si, thus causing positive Ce anomalies in laterite layers. Due to intensive drainage and absence of suitable geochemical barriers like carbonate horizons which could trap La (Fortin, 1989), most LREE are essentially depleted. HREE are intensively leached downward in the profile, retained and absolutely enriched in saprolite zones of low level profiles, where alkaline conditions prevail and smectite is present.

– Less intensive drainage due to permanently elevated groundwater table and/or less humid climate is reflected in weaker fractionation trends and lower enrichment factors of REE (C in Fig. 9).

– Under restricted drainage conditions silicate hydrolysis is impeded and REE liberation, mobilisation and fractionation are limited. Ce remains in the weathering products as stable Ce^{4+} compound whereas the remaining REE, mainly the HREE, are depleted. This depletion is due to the fact that clay minerals which preferentially fix HREE, are subject to lessivage (D in Fig. 9). Furthermore precipitation of secondary silica in soil and saprolite has a dilution effect on all REE, thus explaining relative Ce depletion.

– Morphological control on REE behaviour is documented in profiles 5 and 5A (A in Fig. 9). The considerable enrichment of Ce in saprolites of the hill slope (profile 5) is related to its strong depletion in hill top position (profile 5A). Here Ce shows depletion along the entire profile. In this case intensive drainage along the hilltop and -slope is believed to be responsible for Ce mobilisation and transportation in form of Ce^{3+} in ground- and porewaters under less oxidizing or even reducing conditions. These processes have been observed by Braun et al. (1990) in lateritic profiles. The possibility of long lateral Ce transport has already been discussed by Marker et al. (1991). Remobilisation of Ce from surface near laterite layers under oxidizing conditions is more difficult to explain. However, Beauvais et al. (1987) discuss the dissolution of stable MnO_4 (pyrolusite) and mobilisation of Mn under supergene conditions. The strong depletion of Ce in the laterite layer of profile 5A thus may be explained by dissolution of stable manganese scavenger minerals and subsequent transport of Ce in colloidal solution.

Concluding, REE distributions may yield valuable indications for profile evolution and paleoenvironment. It is evident that tropical weathering leads to considerable modification of REE fractionation patterns. With increasing weathering intensity and drainage conditions, REE fractionation becomes more pronounced. Important supergene REE concentrations can only be expected in regions with intensive lateritic weathering, existence of geochemical barriers and abundance of scavenger minerals in weathering profiles.

In SE-Bahia the bulk of the REE is retained in the weathering products whereas LREE show tendencies of removal from the weathering mantles and transport to the sea. This result is confirmed by observations of Goldstein and Jacobsen (1988), who stated that river and sea waters in the tropics have negative REE anomalies.

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