



Universidade de Brasília
Instituto de Geociências
Programa de Pós-graduação em Geologia

COMPORTAMENTO DOS ELEMENTOS TERRAS RARAS E DOS ISÓTOPOS DE Nd e Sr EM PERFIS LATERÍTICOS NO BRASIL CENTRAL

**BEHAVIOR OF RARE EARTH ELEMENTS, Nd
AND Sr ISOTOPES IN LATERITIC PROFILES IN
CENTRAL BRAZIL.**

CAROLINE ARAUJO FREITAS

Dissertação de Mestrado Nº 502

Orientadora: Prof^ª. Dr^ª. Adriana Maria Coimbra Horbe

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Dissertação apresentada ao Programa de Pós-Graduação em Geologia – Instituto de Geociências – IG da Universidade de Brasília – UnB como requisito parcial obrigatório para a obtenção do título de Mestre em Geologia.

Área de concentração: Geoquímica

Orientador: Prof^a. Dr^a. Adriana Maria Coimbra Horbe

Comissão Examinadora:

Prof. Dr. Claudio Gerheim Porto (UFRJ)

Prof. Dr Rômulo Simões Angélica – (Suplente Externo/UFPA)

Prof. Dr. Jérémie Garnier (IG/UnB)

Prof. Dr. Elton Luiz Dantas (Suplente IG/UnB)

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RESUMO

Análises de amostras de dois perfis lateríticos, formados a partir de um filito e um arenito, por meio de DRX e ICP e informações sobre suas características texturais foram correlacionadas para investigar os efeitos do intemperismo/lateritização na mobilização e redistribuição de elementos, fracionamentos dos ETR e dos isótopos de Nd e Sr. Ambos os perfis lateríticos são estruturados em saprólito, mosqueado e crosta ferruginosa. A crosta formada a partir do filito (perfil 1) é colunar, com três fácies associadas (brechóide, pisolítica e oolítica) e a formada a partir do arenito (perfil 2) é vermiforme e descontínua lateralmente, além de sobreposta por um latossolo. A análise de componentes principais e associações minerais revelou a evolução contínua da lateritização de forma semelhante nos dois perfis, com diferenças associadas as fases minerais particulares de cada rocha mãe. O progresso do intemperismo promoveu a lixiviação em ambos os perfis de SiO_2 , MgO , K_2O , CaO , Na_2O , Ba e Rb devido ao intemperismo de fases primárias como muscovita no perfil 1 e microclínio no perfil 2, em detrimento da concentração de P_2O_4 , As, Cu, Pb, V e Zn associados a formação de goethita + hematita e caulinita. No perfil 2, a hidratação da hematita resultou na remobilização do Fe e na menor concentração dos traços associados aos óxidos de Fe no latossolo. A normalização em relação ao condrito de Taylor e McLennan (1985) revelou que os ETRL são empobrecidos no filito e no arenito e a normalização em relação as rochas mães indicou que o enriquecimento desses elementos no intemperismo. Os ETRP são controlados no perfil 1 pela muscovita e lixiviados com o avanço do intemperismo que associado ao enriquecimento dos ETRL resultando no fracionamento dos ETRL/ETRP. Zircão, rutilo e anatásio no perfil 2 que contém ETRP em sua estrutura, concentram esses elementos no latossolo. O intemperismo da muscovita – illita, principais fases portadoras de K no perfil 1, reflete na menor razão Rb/Sr e $^{87}\text{Sr}/^{86}\text{Sr}$ para o topo do perfil, enquanto no perfil 2 está associado ao decréscimo do microclínio, que por ter menor concentração de K comparado a muscovita reflete na menor razão Rb/Sr e assinatura isotópica menos radiogênia do perfil 2 comparado ao perfil 1. As razões Sm/Nd e $\epsilon\text{Nd}(0)$ não foram fracionadas durante o intemperismo e junto com as razões Hf/Ta, Zr/Nb e Th/Nb reforçam a origem in-situ dos perfis. Razões $\epsilon\text{Nd}(0)$ e $^{87}\text{Sr}/^{86}\text{Sr}$ similares na amostra total e fração argila demonstram que não há diferenças isotópica associadas a fração granulométrica.

Palavras-chave: Lateritização; DRX (Difração de Raios-X); ICP (Espectrometria de Emissão Óptica com Plasma Indutivamente Acoplado) rocha sedimentar

ABSTRACT

Analysis of samples from two lateritic profiles, formed from phyllite and sandstone, through XRD and ICP, and information about their textural characteristics were correlated to investigate the effects of weathering/lateritization on the mobilization and redistribution of elements, fractionation of REEs, and Nd and Sr isotopes. Both lateritic profiles are structured into saprolite, mottled zone, and ferruginous crust. The crust formed from phyllite (profile 1) is columnar, with three associated facies (brecciated, pisolithic, and oolitic), and the one formed from sandstone (profile 2) is vermicular and laterally discontinuous, overlain by a latosol. Principal component analysis and mineral associations revealed a similar continuous evolution of lateritization in both profiles, with differences associated with the particular mineral phases of each parent rock. Weathering progress led to leaching in both profiles of SiO₂, MgO, K₂O, CaO, Na₂O, Ba, and Rb due to the weathering of primary phases such as muscovite in profile 1 and microcline in profile 2, while P₂O₄, As, Cu, Pb, V, and Zn concentrations were reduced due to the formation of goethite + hematite and kaolinite. In profile 2, hematite hydration resulted in Fe remobilization and lower concentrations of trace elements associated with Fe oxides in the latosol. Normalization to Taylor and McLennan's (1985) chondrite revealed depletion of REEs in phyllite and sandstone, while normalization to parent rocks indicated enrichment of these elements during weathering. REE partitioning is controlled in profile 1 by muscovite and leached with weathering progression, resulting in fractionation of REEs/RELPS. Zircon, rutile, and anatase in profile 2, containing RELPS in their structure, concentrate these elements in the latosol. Weathering of muscovite-illite, the main K-bearing phases in profile 1, leads to lower Rb/Sr and ⁸⁷Sr/⁸⁶Sr ratios at the profile top, while in profile 2, it is associated with the decrease of microcline, which, having a lower K concentration compared to muscovite, reflects in lower Rb/Sr ratio and less radiogenic isotopic signature of profile 2 compared to profile 1. Sm/Nd ratios and εNd(0) were not fractionated during weathering, and along with Hf/Ta, Zr/Nb, and Th/Nb ratios, they support the in-situ origin of the profiles. Similar εNd(0) and ⁸⁷Sr/⁸⁶Sr ratios in the total sample and clay fraction demonstrate no isotopic differences associated with grain size fraction.

Keywords: Lateritization; XRD (X-ray Diffraction); ICP (Inductively Coupled Plasma Optical Emission Spectrometry), sedimentary rock.

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CAPÍTULO 1

INTRODUÇÃO

1 INTRODUÇÃO

O presente estudo tem como motivação investigar os impactos do intemperismo na mineralogia e distribuição dos elementos, especialmente terras raras (ETR) e os isótopos radioativos de Nd e Sr, em amostras coletadas em dois perfis lateríticos desenvolvido a partir de um filito e um arenito. Pretende-se com os resultados contribuir com o debate, ainda em aberto, sobre o comportamento do Sm-Nd, do Sr e dos seus isótopos durante intemperismo e lateritização (Nesbitt, 1979, Nahon et al., 1982; Nesbitt e Wilson, 1992; Braun et al., 1998; Nesbitt e Markovics, 1997; Hill et al., 2000; Aubert et al., 2001; Patino et al., 2003; Ma et al., 2007; Babechuck et al. 2015; Huang et. al. 2021).

Apesar das rochas sedimentares correspondem a 70% da superfície terrestre (Amiotte-Suchet et al., 2003; Ma et. al. 2011) predominam na literatura estudos sobre os impactos do intemperismo, especialmente no que tange aos isótopos radioativos de Nd e Sr, sobre rochas ígneas (granitos, basaltos em sua maioria) e ígneas metamorfisadas devido ao interesse econômico em depósitos supergênicos de elementos terras raras (Nesbitt, 1979; Middelburg et al., 1988; Kurts et. al., 2001; Aubert et al., 2001; Oliva et al., 2003; Pokrovsky et al., 2005; Ma et al., 2007; Buss et al., 2008; Yusoff et al., 2013; Thompson et al., 2013; Liu et al., 2016; Babechuk et al., 2014; Babechuk et al., 2015; Campodonico et. al. 2019; Nguetnkam et. al., 2020 e suas referências). Em sedimentos recentes, estudos sobre os elementos terras raras e os isótopos de Nd e Sr são, em sua maioria, voltados para a compreensão da dinâmica e fluxo de sedimentos entre continente e rios/oceanos, ou sobre a origem dos solos formados pela deposição de partículas atmosféricas (loess solos) sendo menos presente estudos que contemplem as transformações minerais desde as rochas primárias até o sedimento transportado e o comportamento desses elementos (Yan et al., 1999; Buggle et. al., 2011; Ndjigui et al., 2013; Ahmand e Singh, 2020).

Nesse sentido, este estudo pretendeu contribuir com as discussões sobre a mobilidade dos isótopos de Nd e Sr, além disso, referente ao perfil laterítico desenvolvido a partir do arenito pretendesse colaborar com a definição da sua gênese associada a processos a processos lateríticos (Oliveira e Muhlmann, 1965; Gonçalves e Schneider, 1970; Pena et. al., 1975 e Weska, 1987).

1.1 Objetivos

Dentre os objetivos específicos, este trabalhou buscou:

- Identificar os elementos móveis ou imóveis durante a alteração das rochas mães e suas correlações minerais.
- Detectar fatores que controlam o fracionamento dos ETR em cada perfil;
- Compreender o comportamento do Sm-Nd e fracionamento dos isótopos de Nd e Sr;

1.2 Área de estudo

1.2.1 Localização dos perfis

Ambos os perfis estão situados no estado de Goiás, Brasil Central, sendo o P1 a leste do estado e sul do Distrito Federal e o P2 no extremo sul do estado, próximo à divisa com o Mato Grosso do Sul (Fig. 1). Ao todo foram coletadas 10 amostras para o P1 e 19 para o P2.

O acesso ao P1, desde Brasília, ocorre por meio da rodovia BR - 040 até a cidade de Luziânia e, a partir desta, é por meio da rodovia GO - 010, passando por Goiânia, e em seguida pela BR - 060 até Serranópolis, se tem acesso ao P2 há 6 km antes da cidade nas margens da rodovia.

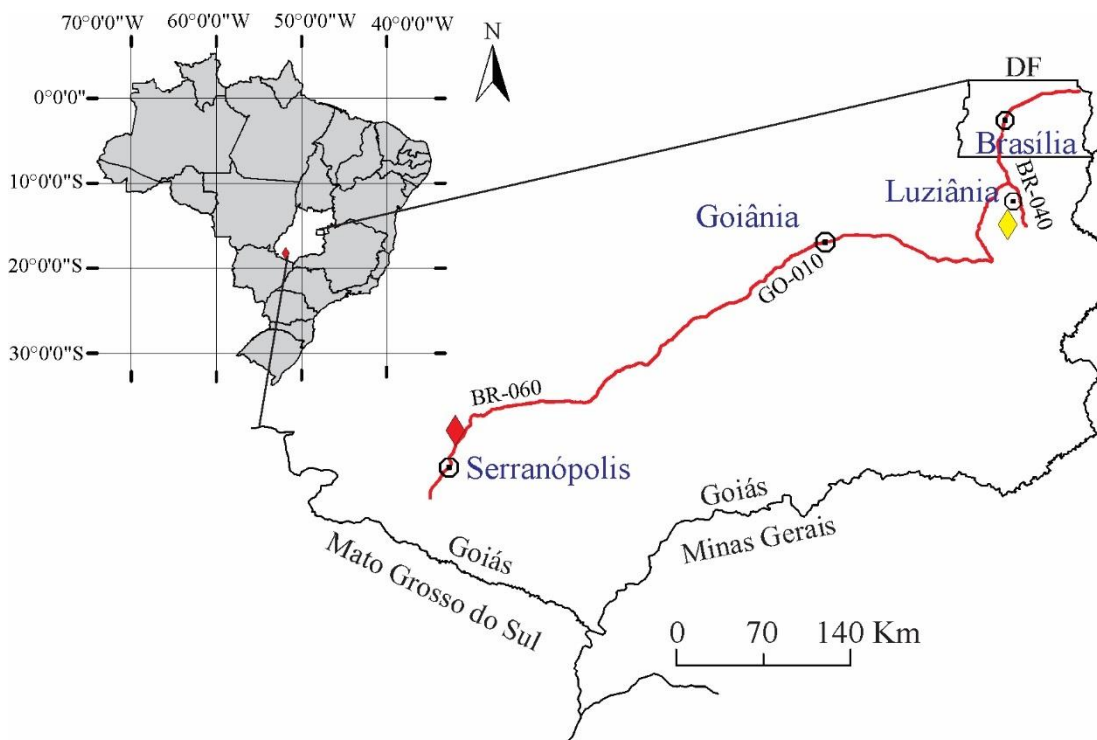


Figura 1: Localização e vias de acesso aos locais dos perfis estudados.

1.2.2 Contexto geológico e geomorfológico

O Perfil 1 (P1), desenvolvido a partir de um filito, está localizado na porção sudoeste da Faixa Brasília onde, localmente, afloram rochas do Grupo Canastra representadas, em sua maioria, por rochas sedimentares psamíticas e pelíticas metamorfisadas sob condições de fácies xisto verde e anfibolito (Dardene, 1978; Silva, 2003) que são agrupadas nas

formações Chapada dos Pilões, Paracatu e Serra do Landim e estão sobrepostas por coberturas detrítico-lateríticas (Martins, 2000; Fig. 2). Idades Nd T_{DM(Nd)} de 2,2 Ga indicam para os sedimentos origem de fontes Paleoproterozóicas derivados principalmente do Cráton do São Francisco (Pimentel et al., 2001; Fig. 2).

O perfil 2 (P2), formado a partir de um arenito, está localizado na porção norte da Bacia do Paranoá onde afloram arenitos eólicos da Formação Botucatu (1,53 a 1,5 Ga, Costa et al., 2016) e basaltos da Formação Serra Geral (137 – 127 Ma, Milani et al., 2007), supersequência jurássica-eocretácea que integram o Grupo São Bento, e arenitos cretáceos da Formação Vale do Rio do Peixe (Grupo Bauru, Menegazzo et al. 2016). Sobreposto ocorrem coberturas detrítico-lateríticas e sedimentos inconsolidados interpretados por alguns como a Formação Cachoeirinha.

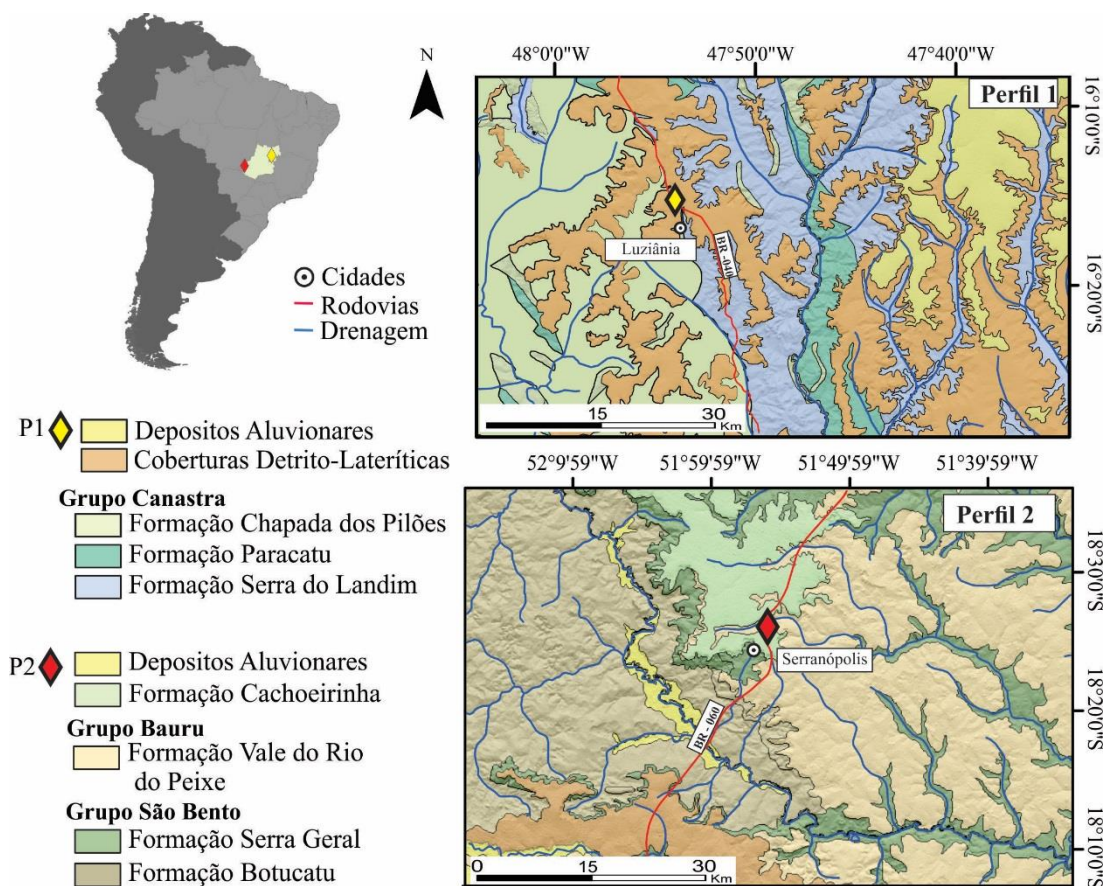


Figura 2: Mapa litológico mostrando a localização dos perfis 1 (P1) próximo a cidade de Luziânia e o perfil 2 (P2) próximos a Serranópolis.

A Formação Cachoeirinha tem origem associada na literatura a dois processos distintos. Oliveira e Muhlmann (1965) descreveram inicialmente como sedimentos inconsolidados e nomearam como Unidade C, posteriormente Gonçalves e Schneider (1970) associaram sua origem com eventos deposicionais e definiram como Fm. Cachoeirinha. Com o avanço das

pesquisas essa interpretação foi reiterada, incluindo os solos argilo-arenos no topo da formação, enquanto outros autores interpretaram como produto do intemperismo e lateritização das rochas que afloram na região e uma terceira interpretação correlaciona os dois processos. A Tabela 1 traz uma síntese das interpretações e suas referências.

Tabela 3: Resumo das interpretações atribuídas a Formação Cachoeirinha.

DEFINIÇÃO	DESCRIÇÃO/INTERPRETAÇÃO	REFERÊNCIA
Unidade C	lentes argilo-arenosas ferruginizadas intercaladas com conglomerados (clastos de quartzo, arenito e silexito) de matriz argilosa.	Oliveira e Muhlmann (1965)
Fm. Cachoeirinha	Semelhante a Oliveira e Muhlmann (1965), associado a eventos sedimentares	Gonçalves e Schneider (1970); Penna et al. (1975)
Cobertura detrítico laterítica associada a sedimentação.	Material detrítico originado por sucessão de eventos geomorfológicos parcialmente lateritizados com conglomerados associado a evento fluvial	Lessa Sobrinho et al. (1971)
Fm. Cachoeirinha	Produto da deposição de sedimentos em ambiente fluvial na base e lacustre no topo com episódios de fluxo de lama e detritos.	Weska (1987)
Cobertura laterítica	Constituída na base por rocha friável seguida de horizonte argiloso (mosqueado) sobreposto por blocos de crosta laterítica e por solo argilo-arenoso com concreções ferruginosas.	Figueiredo et al. (1974) e Padilha et al (1974); Olivatti e Ribeiro Filho (1976); Ghignone (1980); RADAMBRASIL (1981); Oliveira e Campos (2012).

O relevo onde se insere o P1 tem como características escarpas marcadas por chapadas fortemente onduladas com altitudes de 700 m a 1200m. Crostas lateríticas afloram ao longo das escarpas nas porções dissecadas (Lacerda Filho et al, 1999; Martins, 2000, Souza et al. 2021). O relevo do P2 é constituído por extensos chapadões suave-ondulado, sustentados por arenitos com cotas entre 750 a 1750m com depressões onde afloram basaltos (Fm. Serra Geral, Lacerda Filho, 1999). Segundo Martins (2000) o terreno é recoberto por couraças detrítico-laterítica em chapadas mais baixas (altitudes 900-1000 m).

De acordo com a classificação de Köppen, o clima da região do P1 é tropical úmido. A precipitação média anual é da ordem de 1.500 mm. Na região do P2 o clima é tropical semi-úmido, com precipitação média anual de 1218 mm (Sousa, 2009). A vegetação original, em ambas as regiões é representada por matas tropicais, cerrados e matas-galerias e em sua maioria substituídas por pastagens e culturas cíclicas.

2. SÍNTESE DA GEOQUÍMICA DE PERFIS LATERÍTICOS

As rochas ao serem expostas a condições em superfície distintas as quais foram formadas são intemperizadas e seus minerais ao se decompor liberam os elementos em sua estrutura e podem ser lixiviados, precipitados ou adsorvidos em novos minerais, nesse processo minerais como zircão, rutilo, monazita, torita, titanita, com maior resistência ao intemperismo podem permanecer. As alterações mineralógicas e geoquímicas acompanham o intemperismo progressivo das rochas e permitem a estruturação dos seus produtos em horizontes (saprólito, mosqueado e solo), os quais constituem perfis intempéricos. Terrenos tectonicamente estáveis em condições de clima sazonal (quente e úmido) a intensa lixiviação e concentração de óxidos-hidróxidos, geralmente, de Fe e Al permite a formação de coberturas laterítica, compondo assim um perfil laterítico (saprólito, mosqueado, crosta laterítica e solo).

A composição química dos perfis de intemperismo/lateríticos, refletem a composição química da rocha-mãe assim como as condições do ambiente formador (Bradshaw, 1975; Boyle, 1979 e Larizzatti, 2002). Deste modo, combinações entre análises das características estruturais dos perfis associadas ao comportamento dos elementos traços Ti, Zr, Th, Sc, Nb, Ta e Y, que ocorrem na estrutura de minerais resistentes (Taylor e McLennan 1985, Nesbitt e Markovics 1997, Leybourne et al. 2006, Laveuf e Cornu 2009), permitem junto ao estudo dos terras raras (ETR) e isótopos de Nd, investigar a proveniência e evolução da crosta continental, processos intempéricos e lateríticos, assim como as condições físico química do ambiente (p.ex. Wickman 1948; Wasserburg et al. 1965; Faure 1986; Jacobsen 1988; McLennan et al. 1989; Dia et al. 1990; Boulangé e Colin 1994; Ohlander et al. 1996; Braun et al. 1998 e Taunton et al. 2000).

2.1. Elementos terras raras

Os elementos terras raras (ETR) são membros do grupo III B na tabela periódica, têm estado de oxidação 3+ e eletronegatividade próxima às do Ca, Na ou Sr, são litófilos que apresentando maior afinidade com silicatos (Goldschmidt, 1937, Bernat, 1975). De acordo com seu raio iônico podem ser agrupados em leves (ETRL: La – Sm) e pesados (ETRP:Eu – Lu), sendo Eu e Ce encontrados em estados de oxidação (Eu 3+ e Ce 4+) sob condições da superfície terrestre.

Mais de 200 tipos diferentes de minerais contêm ETR os quais concentram grupos distintos de elementos em sua estrutura, por exemplo, minerais pesados contendo Zr e Ti como zircão, rutilo, titanita, ilmenita são concentradas em ETRP, e por serem em sua maioria resistentes ao intemperismo tendem a preservam concentrações altas de ETRP nos produtos do intemperismo (Nickel, 1973; Braun et al. 1990, Walter 1991, Braun et al. 1998, Aubert et al. 2001; Laveuf and Cornu, 2019).

Os fosfatos comumente enriquecidos em ETRL, quando presentes mesmo em pequenas quantidades podem contribuir significativamente com a assinatura dos ETR nos perfis (Bonnot-Courtois, 1981, Papoulis et al., 2004, Galán et al., 2007). Fosfatos primários por serem facilmente

intemperizados são decompostos o que permite formar fosfatos secundários, de modo que alanita, monazita e apatita quando intemperizados formam florencita, rabdofano e xenotímio (Jonasson et al., 1988, Braun et al., 1993, Braun e Pagel, 1994), que por sua vez também são perdidos como o avanço do intemperismo, promovendo perdas de ETRL geralmente em perfis de solos (Taunton et al., 2000).

Dentre os minerais mais susceptíveis ao intemperismo os silicatos são os mais afetados, de acordo com a sequência de Goldich (Goldich, 1938) sendo perdidos nos estágios iniciais e ocasionam diferentes perdas de ETR a depender de qual grupo está enriquecido. Decomposição de feldspatos promove empobrecimento em ETRL (Pan et al. 1994, Tyler 2004), granada e piroxênio em ETRP (Walter, 1991). Além disso, perdas de feldspatos ocasiona anomalias de Eu. Anomalias positivas de Ce são indicadores de ambiente oxidante e podem estar associadas a neoformação da cerianita e presença de esmectita, enquanto as anomalias negativas são associadas a clorita, illita e vermiculitas (Braun et al. 1990, Boulangé e Colin 1994, Ohlander et al. 1996, Land et al. 1999, Laveuf e Cornu, 2009).

Os ETR liberados podem preservados nas fases secundarias formadas a partir da alteração dos primários, além dos fosfatos já citados isso ocorre com anatásio precipitado pela precipitação de óxido de titânio liberado no intemperismo. Devido as características estruturais (Compton et al. 2003, Wan e Liu, 2004) os argilominerais permitem a concentração de diferentes grupos de ETR, clorita e esmectita podem concentrar mais ETRP, enquanto illita e vermiculita ETRL (Coppin et al. 2002, Li et al. 2006, Galán et al. 2007).

Condições de pH e Eh do ambiente também influenciam na mobilidade dos ETR, enquanto alguns estudos mostram que os ETRP são mais propensos a processos de solubilização, Turner et al., 1981; Wood, 1990; Smedley, 1991 mostram que em condições de pH < 6 os ETRL são mais solúveis devido a menor solubilização dos ETRP e da sua maior preferência em ser absorvidos pelos minerais (Goldschmidt, 1958). Em condições de pH de 4 a 7 é sugerida que caulinita e illita são capazes de complexar em sua superfície ETR (Kulik et al., 2000; Sinitsyn et al., 2000). Yang et al., (2019) observou que além da estrutura mineral há correlações positivas do aumento da adsorção dos pesados na superfície da caulinita.

Durante a lateritização a concentração dos óxi-hidróxidos de Fe/Al e Mn (goethita, hematita, criptomelana, pirolusita) e aumento da cristalinidade desses minerais é descrito como responsáveis pelo empobrecimento dos ETR nos perfis, isso ocorre devido estrutura que esses elementos causam no reticulo cristalino, assim maiores concentrações são associadas as fases de baixa cristalinidade ou amorfas (Courtois 1974, Land et al. 1999, Compton et al, 2003), compatível com estudo em sedimentos suspensos que constata as maiores concentrações de ETR em partículas de composição orgânica ricas em oxi-hidróxido de Fe e Al amorfas (Andersson et al., 2001).

O somatório dos processos durante o intemperismo e lateritização resulta no fracionamento dos ETR, muitas vezes dos leves em relação aos pesados, além disso a transferência de partículas de argilominerais nos perfis (argiluviação) ou mobilização e precipitação dos elementos pode resultar no enriquecimento em ETR em determinadas regiões dos perfis (Bonnot-Courtois; 1981, Braun et al., 1993; Boulangé e Colin; 1994, Öhlander et al., 1996; Nesbitt e Markovics, 1997; Taunton et al., 2000; Ma et al., 2002).

Embora o fracionamento dos ETR e os processos envolvidos sejam um consenso e estejam bem documentados na literatura, ainda existem debates sobre o comportamento do Sm e Nd, especialmente sobre os isótopos de Nd.

2.2. Isótopos de Nd e Sr

O Nd tem sete isótopos (^{142}Nd , ^{143}Nd , ^{144}Nd , ^{145}Nd , ^{146}Nd , ^{148}Nd e ^{150}Nd) dos quais apenas o ^{143}Nd é radiogênico, sendo o ^{144}Nd produto do decaimento do ^{147}Sm . Os resultados dos isótopos são expressos pelas razões $^{143}\text{Nd}/^{144}\text{Nd}$ ou em relação a um reservatório condritico uniforme, como ϵNd (DePaolo e Wasserburg, 1976).

A razão Sm/Nd e de seus isótopos são tidos por muitos estudos como não influenciados por processos intempéricos ou em condições próximas a superfície da Terra e, consequentemente, permitem a preservação da composição isotópica da rocha mãe (McLennan, 1989; McLennan et al., 1993; Goldstein et al., 1984; Nesbitt e Markovics, 1997; Kessakar et al., 2003; Geraldès, 2010; Négrel, 2006; Wei et al. 2018). No entanto, embora variações nas razões isotópicas sejam comumente atribuídas a deposição de partículas eólicas (Kurtz et al., 2001; Dia et al., 2006; Liu et al. 2013; Babechuk et al. 2015), há estudos que sugerem, no intemperismo intenso, a remoção preferencial do Nd e o fracionamento da razão Sm/Nd (Nesbitt e Wilson, 1992; Öhlander et al., 2000; Feng, 2010; Babechuk et al., 2014). Em outros casos o fracionamento é interpretado como consequência do intemperismo diferencial de fases com diferentes razões Sm/Nd e o fracionamento isotópico à lixiviação preferencial do ^{143}Nd (Ma et al., 2010).

Debates sobre o fracionamento isotópico em sedimentos recentes também estão em aberto, há estudos que sugerem a preservação da composição isotópica da rocha fonte na fração silte e argila (Négrel et al., 2000; Négrel et al., 2006; Bayon et al., 2002; Kessakar et al., 2003; Freslon et al., 2014; Jornell et al., 2018) enquanto outros indicam a correlação do fracionamento com a fração granulométrica devido a seleção de fases minerais distintas durante o transporte dos sedimentos (McLennan et al., 1989; Revel et al., 1996; Innocent et al., 1997; Aubert et al., 2001; Garçon et al., 2014; Garzanti et al., 2009; Innocent et al., 2000) ou a dissolução preferencial de minerais com diferentes razões Sm/Nd (Goldstein e Jacobsen 1988, Peucker-Ehrenbrink et al. 2010). Andersson et al., (2001) sugere que essas variações ocorrem devido a influência da matéria orgânica no transporte do Nd.

O Sr é mais solúvel comparado ao Nd sendo comum sua lixiviação de acordo com o avanço do intemperismo e, por consequência, na menor razão $87\text{Sr}/86\text{Sr}$. Apesar dos estudos indicarem que a composição isotópica do Sr é preservada nos sedimentos (Négre et al., 2006; Kessakar et al., 2003), também é sugerido seu fracionamento em função da fração granulométrica devido a triagem hidrodinâmica dos sedimentos durante o transporte (Garçon et al., 2004; Pang et al., 2021) ou a sedimentos originados do intemperismo de diferentes rochas (Négre e Roy, 1998; Zhao et al., 2018). Outros estudos sugerem que processos pedogenéticos fracionam os isótopos de Sr (Halicz et al., 2008), além do intemperismo incongruente de fases primárias com razões heterogêneas de Rb/Sr e $87\text{Sr}/86\text{Sr}$ (Blum e Erel, 1995; Tripathy et al., 2011).

3. MATERIAIS E MÉTODOS

3.1. Composição mineral, químico-mineral e geoquímica.

Ao todo foram coletadas 10 amostras para o P1 e 19 para o P2. Para o estudo da mineralogia foi utilizada difratômetro de raios-x (RIGAKU ÚLTIMA IV, Universidade de Brasília) operando com tubo de cobre e os minerais identificados com auxílio do software Jade 3.0. para Windows®. Para a geoquímica foram analisados SiO_2 , Al_2O_3 , Fe_2O_3 , MgO , CaO , Na_2O , K_2O , TiO_2 , P_2O_5 por ICP-AES e Ba, Cr, Cs, Ga, Hf, Nb, Rb, Sn, Sr, Ta, Th, U, V, W, Y, Zr e ETR por ICP-MS, ambos após fusão com borato de lítio. A perda ao fogo (LOI) foi determinada por aquecimento a 1000°C , enquanto Ag, As, Cd, Cu, Li, Mo, Ni, Pb, Sc, Tl e Zn por ICP-AES, após dissolução ácida (HNO_3 , HClO_4 , HF e HCL), todas as análises por ICP foram determinadas pela ALS-Minerals (Brasil).

Análises isotópicas de Nd e Sr foram realizadas conforme Gioia e Pimentel (1999), por ICP-MS Thermo Scientific TRITON™ Plus e Thermal Ionization Mass Spectrometry (TIMS) nas amostras totais e frações $< 2\mu\text{m}$ do saprólito, mosqueado e crosta do P1 e saprólito, mosqueado e solo do P2. Essas análises e a difração de raios-x foram realizadas nos laboratórios da Universidade de Brasília.

A quantificação mineral foi obtida por cálculo estequiométrico a partir da composição centesimal, com o auxílio dos dados de DRX e geoquímica segundo informações da tabela 2 e 3. O cálculo tem início estimando o percentual de quartzo com base na intensidade da reflexão $d = 3.3$ (101) obtida por DRX. O valor estimado é subtraído do percentual total de SiO_2 da amostra e o restante distribuído para os demais minerais. Em amostras onde coexistem quartzo, caulinita e gibbsita, ao estimar o percentual de quartzo, o restante de sílica é atribuído à caulinita, o percentual de illita é estimado a partir do MgO e o restante de K_2O atribuído a muscovita. Feito isso, é calculado o quanto de Al_2O_3 foi consumido para então determinar a gibbsita e demais minerais. A soma do percentual calculado de cada mineral é recalculada para 100%.

Tabela 2. Minerais presentes no perfil e sua composição centesimal.

MINERAIS	MINERAIS COMPOSIÇÃO CENTESIMAL
Quartzo: SiO_2	$\text{SiO}_2=100 \%$
Microclínio: KAlSi_3O_8	$\text{K}_2\text{O} = 16,92 \%$; $\text{Al}_2\text{O}_3 = 18,32 \%$; $\text{SiO}_2 = 64,76 \%$
Muscovita: $\text{KAl}_2(\text{Si}_3\text{Al}) \text{O}_{10}(\text{OH}, \text{F})_2$	$\text{K}_2\text{O} = 11,81 \%$; $\text{Al}_2\text{O}_3 = 38,36\%$; $\text{SiO}_2 = 45,21\%$ $\text{H}_2\text{O} = 4,07 \%$
Illita: $(\text{K},_3\text{O})$ $(\text{Al},\text{Mg},\text{Fe})_2(\text{Si},\text{Al})_4\text{O}_{10}[(\text{OH})_2,(\text{H}_2\text{O})]$	$\text{K}_2\text{O} = 7,26 \%$ $\text{Al}_2\text{O}_3 = 17,02 \%$ $\text{Fe}_2\text{O}_3 = 1,85 \%$ $\text{MgO} = 3,11 \%$ $\text{SiO}_2 = 54,01 \%$ $\text{H}_2\text{O} = 12,03 \%$
Caulinita: $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$	$\text{Al}_2\text{O}_3 = 39,5 \%$; $\text{SiO}_2 = 46,49\%$; $\text{H}_2\text{O} = 13,96 \%$
Gibbsita: $\text{Al}(\text{OH})_3$	$\text{Al}_2\text{O}_3 = 65,37 \%$; $\text{H}_2\text{O} = 34,63 \%$
Hematita (Fe_2O_3) + goethita FeOOH	$\text{Fe}_2\text{O}_3=100 \%$
Anatásio/Rutilo: TiO_2	$\text{TiO}_2=100\%$

Tabela 4. Passos seguidos para o cálculo da composição mineral.

Mineral	Mineral
Microclínio (Mi)	$\text{Mi} = [(\text{K}_2\text{O total} - \text{K}_2\text{O (Mi)}) / \text{K}_2\text{O (CC)}] \text{Mi} * 100$; $\text{Al}_2\text{O}_3 \text{ (Mi)} = (\text{Al}_2\text{O}_3 \text{ (CC)} \text{Mi} \times \text{Mi}) / 100$; $\text{SiO}_2 \text{ (Mi)} = (\text{SiO}_2 \text{ (CC)} \text{Mi} \times \text{Mi}) / 100$
Illita (I)	$\text{I} = [\text{MgO total} / \text{MgO (CC)}] * 100$; $\text{K}_2\text{O (I)} = (\text{K}_2\text{O (CC)} \text{I} \times \text{I}) / 100$; $\text{Al}_2\text{O}_3 \text{ (I)} = (\text{Al}_2\text{O}_3 \text{ (CC)} \text{I} \times \text{I}) / 100$; $\text{SiO}_2 \text{ (I)} = (\text{SiO}_2 \text{ (CC)} \text{I} \times \text{I}) / 100$; $\text{Fe}_2\text{O}_3 \text{ (I)} = (\text{Fe}_2\text{O}_3 \text{ (CC)} \text{I} \times \text{I}) / 100$
Muscovita (M)	$\text{M} = [(\text{K}_2\text{O total} - \text{K}_2\text{O (I)}) / \text{K}_2\text{O (CC)}] \text{M} * 100$; $\text{Al}_2\text{O}_3 \text{ (M)} = (\text{Al}_2\text{O}_3 \text{ (CC)} \text{M} \times \text{M}) / 100$; $\text{SiO}_2 \text{ (M)} = (\text{SiO}_2 \text{ (CC)} \text{M} \times \text{M}) / 100$
Caulinita (C)	$\text{C} = [(\text{Al}_2\text{O}_3 \text{ total} - \text{Al}_2\text{O}_3 \text{ (I)} - \text{Al}_2\text{O}_3 \text{ (M)}) / \text{Al}_2\text{O}_3 \text{ (CC)}] \text{C} * 100$; $\text{SiO}_2 \text{ (C)} = (\text{SiO}_2 \text{ (CC)} \text{C} \times \text{C}) / 100$;
Gibbsita (G)	$\text{Al}_2\text{O}_3 \text{ (G)} = \text{Al}_2\text{O}_3 \text{ total} - \text{Al}_2\text{O}_3 \text{ (Consumido nas outras fases)}$
Quartzo (Q)	$\text{Q} = \text{SiO}_2 \text{ total} - \text{SiO}_2 \text{ (Consumido nas outras fases)}$
Hematita+Goethita (H+Gt)	$\text{H+Gt} = \text{Fe}_2\text{O}_3 \text{ total} - \text{Fe}_2\text{O}_3 \text{ (Consumido nas outras fases)}$
Anatásio/rutilo (An)	$\text{An} = \text{TiO}_2 \text{ total}$

O fracionamento dos ETR foi normalizado em relação ao condrito de Taylor e McLennan (1985) e as razões de acordo com as equações:

- $\text{Eu/Eu}^* = (\text{Eu}/0.087) / [(\text{Sm}/0.231) \times (\text{Gd}/0.306)]^{1/2}$
- $\text{Ce/Ce}^* = (\text{Ce}/0.957) / [(\text{La}/0.367) \times (\text{Pr}/0.137)]^{1/2}$
- $(\text{La/Yb})_n = (\text{La}/0.367) / (\text{Yb}/0.250)$

CAPÍTULO 2

UNRAVELING PARENT ROCK AND MINERAL INFLUENCES IN TROPICAL WEATHERING PROFILES: REE, ND AND SR ISOTOPIC GEOCHEMISTRY

1. UNRAVELING PARENT ROCK AND MINERAL INFLUENCES IN TROPICAL WEATHERING PROFILES: REE, ND AND SR ISOTOPIC GEOCHEMISTRY

Caroline Araujo Freitas; Adriana Maria Coimbra Horbe *, Rodrigo Tokuta Castro and Márcio Fernando dos Santos Albuquerque

Universidade de Brasília, Campus Universitário Darcy Ribeiro, Instituto de Geociências, 70910-900 Brasília, Distrito Federal, Brasil.

Abstract: This study aims to investigate the effects of parent rock and minerals on lateritic weathering. The study presents X-ray diffraction (XRD), whole-rock geochemistry, and Nd-Sr isotopic data of two profiles, with 10 and 12 m thick, respectively, that illustrate the regional tropical weathering status in the Midwest of Brazil. The profiles formed by saprolite, mottled horizon, lateritic duricrust, and oxisol were developed from metasedimentary and sedimentary rock. The study identifies muscovite, microcline, quartz, kaolinite, hematite, goethite and gibbsite as the primary factors controlling the weathering geochemistry across the profiles. Profile 1 exhibits a more complex lateritic duricrust with textures that are brechoidal/fragmental, pisolitic, and oolitic, whereas profile 2 has an oxisol that mantles the vermiform lateritic duricrust. Fe_2O_3 , accumulated during surface weathering, is a potent element in the geochemical profile control as it preserves the phyllite foliation, and forms the hard goethite to hematite lateritic duricrust, bearing most of the trace elements (As, Cu, Cs, Pb, Sc, Sr, Th, U, V and Zn) with similar ionic radii and electrovalence. The REE are fractionated across the profiles. The LREE have an affinity for the elements of the Fe_2O_3 group of the lateritic duricrust. On the other hand, the K_2O group and the zircon, anatase, and rutile found in the phyllite, saprolite, and mottled horizon of profile 1 are associated with the HREE. Additionally, in profile 2, the HREE is associated with the Al_2O_3 group and the residual minerals in the oxisol. The $\epsilon_{\text{Nd}(0)}$ ratios consistently maintain the signature of the parent rock, despite the REE fractionation. Rb and Sr muscovite and microcline weathering, in profiles 1 and 2 control the decrease of $^{87}\text{Sr}/^{86}\text{Sr}$ signatures of both profiles and the distinct radiogenic ratios. The development of lateritic duricrust in both profiles indicates similar weathering intensity, however, the gibbsite-kaolinite predominance in the oxisol of profile 2 highlights a geochemical reorganization under humid conditions, as well as near-intense soluble silica leaching.

Keywords: Lateritic duricrust; oxisol; REE fractionation; trace elements

1 INTRODUCTION

Researchers studying crustal evolution, sedimentary provenance, and weathering have benefited from the residual character of elements including Ti, Zr, Th, Sc, Nb, Ta, Y, and REE (McLennan *et al.*, 1993; Ohlander *et al.*, 1996; Braun *et al.*, 1998; Ding *et al.*, 2001; Leybourne *et al.*, 2006; Laveuf and Cornu, 2009; Yusoff *et al.*, 2013; Wei *et al.*, 2018; Liu *et al.*, 2013; Clift *et al.*, 2014; Campodonico *et al.*, 2019; Horbe *et al.*, 2022). While some of these elements can be retained or leached during weathering in newly formed minerals such as anatase, clay minerals, phosphates, and oxyhydroxides, others can be found in residual minerals such as zircon, rutile, and columbite, etc All of this behavior depends on the environmental conditions (Eh and pH effects, and presence of

organic matter), intensity and resistance of minerals, and translocation (Braun *et al.*, 1990; Aubert *et al.*, 2001; Tyler, 2004; Steinmann and Stille, 2008;; Ma *et al.*, 2007; Laveuf and Cornu, 2009).

Although the mobility and behavior of REE are widely studied and used in provenance studies, the behavior of Nd isotopes in weathering requires further exploration, especially in tropical zones where the leaching is more intense. Along with other high-mass element isotopes, Nd and Sr isotopes are thought to be unaffected by weathering. Accordingly, the isotopic signature can reveal the origin of the sedimentary rocks and sediments depending on the type and age of the parent rocks (McLennan *et al.*, 1993; Nesbitt and Markovics, 1997; Négrel, 2006; Tripathy, 2011; Wei *et al.*, 2018). Aeolian accretion, hydrodynamic concentration or differential dissolution of minerals with different Sm/Nd ratios, preferential leaching or retention in newly formed minerals, and anthropogenic processes are attributed to the variation in isotopic high-mass elements (Goldstein *et al.*, 1984; Négrel *et al.*, 2000; Ohlander *et al.*, 2000; Albert *et al.*, 2001; Kurtz *et al.*, 2001; Dia *et al.*, 2006; Négrel, 2006; Ma *et al.*, 2010; Liu *et al.*, 2013; Chabaux *et al.*, 2013; Babechuk *et al.*, 2015; Jornell *et al.*, 2018; Zhao *et al.*, 2018; Tripathy *et al.*, 2011; Horbe *et al.*, 2022).

In terms of Sr isotopes, variations in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are attributed to the same mechanisms that control the Sm-Nd, as well as, biogeochemistry effects, since the feldspars and micas (which are Sr and Rb bearing minerals) are less resistant to weathering compared to heavy minerals that contain REE (Blum and Erel, 1997; Capo *et al.*, 1998; Stewart *et al.*, 1998; Souza *et al.*, 2010; Tripathy *et al.*, 2011; Chabaux *et al.*, 2013; Babechuk *et al.*, 2015; Horbe *et al.*, 2022).

Two significant lateritic profiles in the Midwest of the Brazilian tropical zone, over 500 km apart, were chosen for mineralogy, whole-rock geochemistry, and Nd-Sr isotopic investigation. This region represents the extensive and complex lateritic regolith of the Central Brazilian Plateau (Castro *et al.*, 2021), where maximum lateritic leaching resulted in Fe and Al concentrations at the expense of Si and alkalis and can serve as tracers of regional landscape evolution in the Midwest of Brazil. As a result, the primary goal of this research was to identify the influence of the parent rock on geochemistry across the lateritic horizons, to predict the behavior of REE, Rb, Sr, and the Nd and Sr isotopes fractionation and determine the status of lateritic process in this tropical region (Fig. 1).

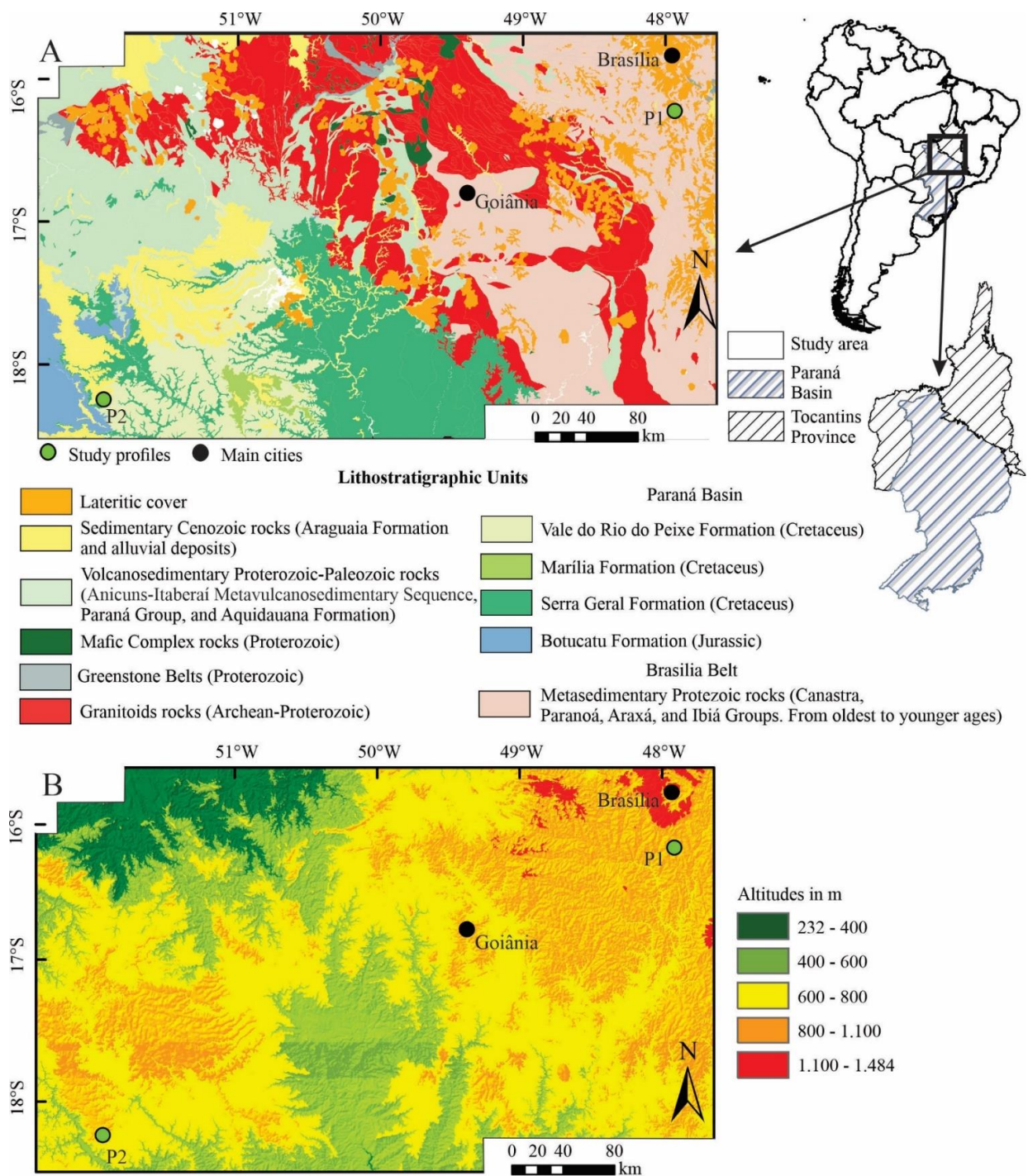


Figure 1. A) Location and simplified geological maps, B) SRTM image showing the Midwest dissected plateaus surface.

2 MATERIALS AND METHODS

The study focuses on two 10 and 12 m thick profiles that is part of the complex geological, geomorphological, and pedological stepped regolith scenario found in the Brazilian Central Plateau, which is located in the Midwest of Brazil (Martins *et al.*, 2004; Latrubesse and Carvalho, 2006; Moraes, 2014; Rosolen *et al.* 2017; Souza *et al.*, 2021; Castro *et al.*, 2022). Quartzites in altitudes ranging from 1230–1650 m above sea level

and an extensive lower lateritic surface, which primarily developed from the Paleoproterozoic metasedimentary rocks of the Paranoá, Canastra, Ibiá, and Bambuí Groups of the Brasília Fold Belt (Pimentel *et al.*, 2001; Rodrigues *et al.*, 2010; Campos *et al.*, 2013) and the Jurassic-Cretaceous sedimentary rocks of the São Bento and Bauru Groups and the volcanic rocks of the Serra Geral Formation of the northern part of Paraná Basin (Milani *et al.*, 2007; Menegazzo *et al.*, 2016), respectively, support this scenario as illustrated in Figure 1.

Profile 1 is in an excavated area at the top of a plateau surface at 1020 m above sea level in the northeast of the study area (Fig. 1). The plateau is one of a series of dissected plateaus supported by lateritic duricrust outcrops with altitudes ranging from 1200 and 800 m above sea level and decreasing from north to south. The phyllite metasedimentary rocks of the Paranoá Group provided the basis for the lateritic duricrust plateau under study.

In the southwestern part of the study area, at 1100 m above sea level, profile 2 is also located at an extensive dissected surface (Fig. 1) supported by lateritic duricrusts overlapped by thick layers of oxisol. The sampled profile is located on a slope's outcrops rock–oxisol developed from the sandstone rocks of Vale do Rio do Peixe Formation, São Bento Group.

Using a copper tube scanned from 2-60° at a speed of 5°/min and a step size of 0.05°, the mineralogy features of the two lateritic profiles were examined using an X-ray diffractor (RIGAKU ULTIMA IV). At Universidade de Brasília, the mineral identification was carried out using Jade 3.0 software for Windows®. At ALS-Minerals, the geochemistry of the major and trace elements was established. The inductively coupled plasma atomic emission spectrometer (ICP-AES) was used to analyze SiO₂, Al₂O₃, Fe₂O₃, MgO, CaO, Na₂O, K₂O, TiO₂, and P₂O₅, while Ba, Cr, Cs, Ga, Hf, Nb, Rb, Sn, Sr, Ta, Th, U, V, W, Y, Zr, and rare earth elements (REE) were analyzed by inductively coupled plasma mass spectrometer (ICP-MS), following fusion with lithium borate and HCl dissolution. Ag, As, Cd, Cu, Li, Mo, Ni, Pb, Sc, Tl, and Zn were determined using ICP-AES following acid dissolution (HNO₃, HClO₄, HF and HCl), while loss of ignition (LOI) was detected by thermal analysis at 1000°C. The analyses used GR-3, OREAS-45c, and OREAS 146 as standard. The uncertainties for major, minor, and trace elements are below 5 and 10%, respectively.

ICP-MS (Thermo Scientific TRITON™ Plus and Thermal Ionization Mass Spectrometry, TIMS) was used to analyze Nd and Sr isotopes at Universidade de Brasília,

following Gioia and Pimentel (1999) technique. The source material and clay fractions ($< 2 \mu\text{m}$) were further analyzed. The clay fraction was extracted from the source material in three steps: 1) To disperse the sample particles, 20 g of the sample was ultrasonicated in 100 ml of ultrapure water in a clean plastic tube for 20 min; 2) the dispersion sample solution was then ultracentrifuged at 750 rpm for 7 min to eliminate particles larger than $2 \mu\text{m}$; the supernatant was ultracentrifuged at 3000 rpm for 30 min to eliminate particles smaller than $2 \mu\text{m}$. The composition of Nd and Sr isotopes in this final fraction was examined.

For the Nd and Sr isotopic studies, 20–40 mg aliquots were separated and digested using concentrated HF/HNO₃ and 6 N HCl on a hot plate under sterile laboratory conditions. The REE and Sr isotopes were separated using chromatographic columns and AG50W-X8 cation-exchange resin, REE and Sr isotopes were separated, while Nd and the other REE were separated using AG50-X2 resin. Sr, Nd, and Sm were loaded separately on a tungsten filament with TaF solution. Following Sr collection, the column was rinsed eight consecutive times with 0.5 ml of HNO₃ (2.9 N) after being brought to equilibrium twice with 1 ml of HNO₃ at the same concentration. The obtained Sr fraction was evaporated to dryness and their precision was monitored using the internationally certified standard NBS-987, with uncertainties expressed at a 2σ level (better than 0.01%). Nd was reprocessed on a double rhenium filament using H₃PO₄ (0.1 M) and measured as metal Nd⁺. Thermo Scientific TRITON™ Plus Thermal Ionization Mass Spectrometer (TIMS) operating in a static multi-collector mode was loaded with the isotopes of Sm, Nd, and Sr isotopes, at the University of Brasilia's Geochronology Laboratory, following the procedures outlined by Gioia and Pimentel (2000).

Jacobsen and Wasserburg (1980) stated that the $^{143}\text{Nd}/^{144}\text{Nd}$ ratios are presented in parts per 104 units from the $^{143}\text{Nd}/^{144}\text{Nd}$ CHUR as measured present-day: $\epsilon\text{Nd}(0) = [(^{143}\text{Nd}/^{144}\text{Nd})_{\text{sample}} / \text{ICHUR}(0) - 1] * 104$, where, $^{143}\text{Nd}/^{144}\text{Nd}$ sample is the present day ratio measured in the sample, and ICHUR(0) (0.512638) represents the $^{143}\text{Nd}/^{144}\text{Nd}$ ratio in the CHUR reference reservoir at the present. The Nd T_{DM} ages were calculated using the method described by DePaolo (1988). Analytical uncertainty is 0.0004 and 0.05% for $^{143}\text{Nd}/^{144}\text{Nd}$ and $^{147}\text{Sm}/^{144}\text{Nd}$, respectively.

Tables 1 and 2. shows that the modal mineral quantification was obtained by stoichiometric computation based on the theoretical chemical composition, supported by XRD and geochemical data. The computation begins by estimating the percentage of quartz based on the $d = 3.3$ (101) reflection intensity obtained by XRD. In samples, where

quartz, kaolinite, and gibbsite coexist, it is estimated that the percentage of quartz is determined, and the remaining silica done by calculating the percentage of illite estimated from MgO and muscovite estimated from K₂O. The amount of Al₂O₃ used to produce illite, muscovite, and kaolinite is then calculated. Gibbsite accounts for the remaining Al₂O₃. The total computed percentage of each mineral is adjusted to 100%. The estimated quartz value can be modified to improve closure by 100%. To determine the geochemical relationships along the horizons, statistical analysis (Statistica 10) was performed using the unrotated principal components method approach. After considerable tests, SiO₂, Al₂O₃, Fe₂O₃, K₂O, TiO₂, P₂O₅, LOI, As, Ba, Cu, Cs, Nb, Rb, Sr, Th, V, Pb, Zn, Zr, and REE were chosen for profile 1 and the same elements including Ga, Ni, Sc, and U for profile 2. To choose these elements, a variance with a cut-off > 70% was used.

Table 1. Chemical composition of the main minerals according to www.webmineral.

Minerals	Theoretical chemical composition
Quartz: SiO ₂	SiO ₂ =100 %
Microcline: KAlSi ₃ O ₈	K ₂ O =16.92 %; Al ₂ O ₃ =18.32 %; SiO ₂ = 64.76 %
Muscovite: KAl ₂ (Si ₃ Al) O ₁₀ (OH, F) ₂	K ₂ O =11,81 %; Al ₂ O ₃ = 38,36%; SiO ₂ =45,21% H ₂ O = 4,07 %
Illite:(K ₃ O) (Al,Mg,Fe) ₂ (Si,Al) ₄ O ₁₀ [(OH) ₂ ,(H ₂ O)]	K ₂ O = 7,26 % Al ₂ O ₃ = 17,02 % Fe ₂ O ₃ = 1,85 % MgO = 3,11 % SiO ₂ = 54,01 % H ₂ O = 12,03 %
Kaolinite: Al ₂ Si ₂ O ₅ (OH) ₄	Al ₂ O ₃ = 39,5 %; SiO ₂ = 46,49%; H ₂ O =13,96 %
Gibbsite: Al(OH) ₃	Al ₂ O ₃ = 65,37 %; H ₂ O =34,63 %
Hematite (Fe ₂ O ₃) + goethite (FeOOH)	Fe ₂ O ₃ =100 %
Anatase/Rutile: TiO ₂	TiO ₂ =100%

Table 2. Mathematical steps for calculation of the mineral content.

Mineral	Mineral
Microcline (Mi)	Mi = [(K ₂ O total - K ₂ O (Mi)) /K ₂ O (CC) Mi] *100; Al ₂ O ₃ (Mi) = (Al ₂ O ₃ (CC) Mi x Mi) / 100; SiO ₂ (Mi) = (SiO ₂ (CC) Mi x Mi) / 100
Illite (I)	I = [MgO total/MgO (CC)I]*100; K ₂ O(I) = (K ₂ O (CC)I x I)/ 100; Al ₂ O ₃ (I) = (Al ₂ O ₃ (CC)I x I)/ 100; SiO ₂ (I) = (SiO ₂ (CC)I x I)/ 100; Fe ₂ O ₃ (I) =(Fe ₂ O ₃ (CC)I x I)/ 100
Muscovite (M)	M = [(K ₂ O total - K ₂ O (I)) /K ₂ O (CC)M] *100; Al ₂ O ₃ (M) = (Al ₂ O ₃ (CC)M x M) / 100; SiO ₂ (M) = (SiO ₂ (CC)M x M)/ 100
Kaolinite (K)	K = [(Al ₂ O ₃ total - Al ₂ O ₃ (I) - Al ₂ O ₃ (M)) / Al ₂ O ₃ (CC)K] *100; SiO ₂ (K) = (SiO ₂ (CC)K x K) / 100;
Gibbsite (G)	Al ₂ O ₃ (G) = Al ₂ O ₃ total - Al ₂ O ₃ (from microcline, illite, muscovite, kaolinite)
Quartz (Q)	Q = SiO ₂ total - SiO ₂ (from microcline, illite, muscovite, kaolinite)
Hematite+Goethite (H+Gt)	H+Gt = Fe ₂ O ₃ total – Fe ₂ O ₃ (illite)
Anatase/rutile (An)	An = TiO ₂ total

CC: theoretical chemical composition.

3 RESULTS

4.1. Profile Structure and Mineral Features

As illustrated figure 2A, the parent rock in profile 1 is a foliated silt-clayey phyllite that is green to whitish with patches of yellow and pink. It is composed of quartz, muscovite, illite, kaolinite, goethite, and hematite as illustrated in Figure 3. The overlying silt-clayey saprolite, which is at least 2 m thick, exhibits interdigitated yellow, pink, and red zones with remnants of the foliated phyllite structures (Fig. 2B and C). It is composed of the same minerals as the parent rock, which is phyllite. Figure 3 shows that the predominant minerals in the yellow zone are muscovite/illite, and kaolinite, whereas the red zones are dominated by goethite and hematite.

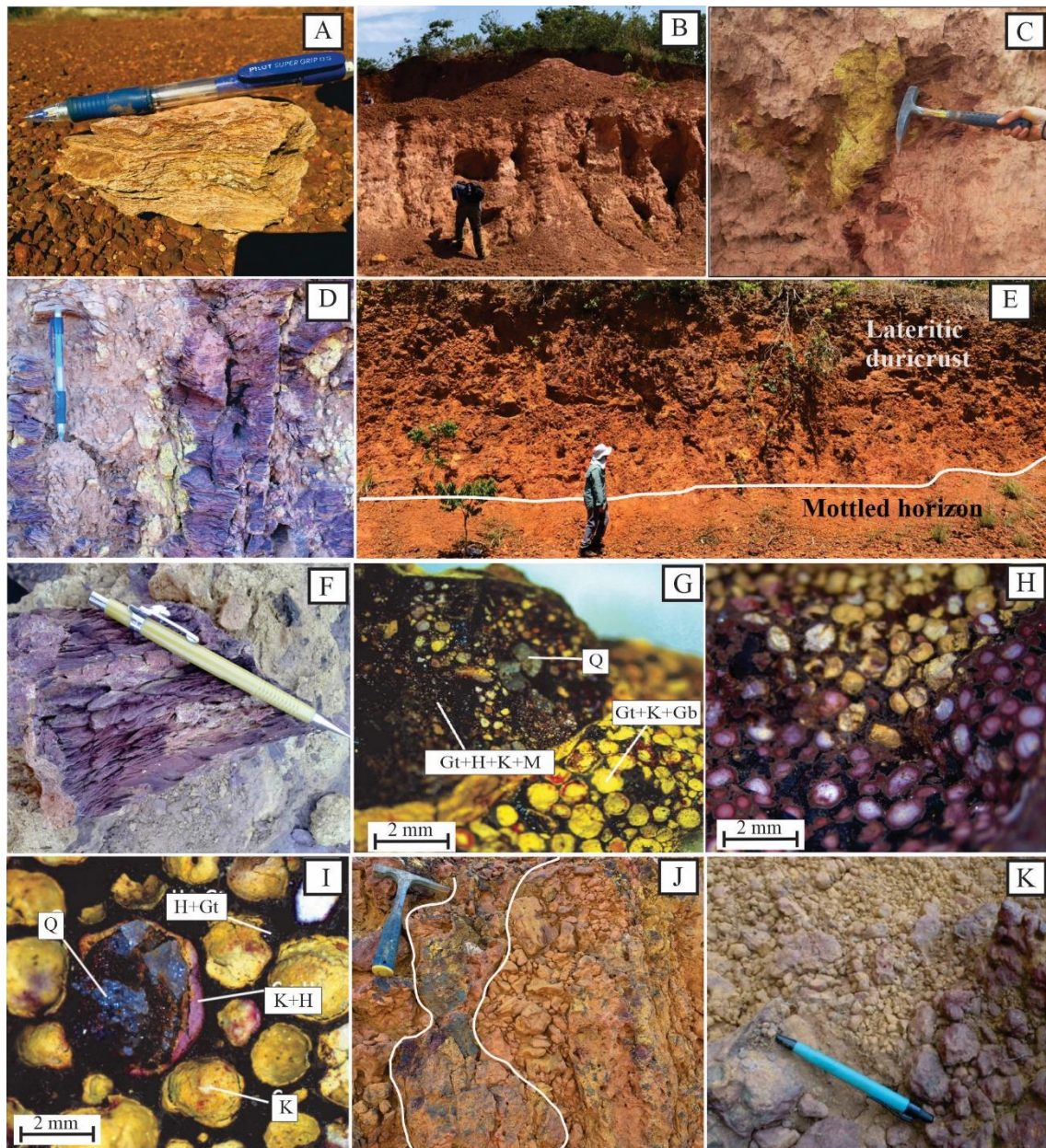


Figure 2. Features of profile 1: A) silt-clayey phyllite parent rock; B) view of saprolite horizon; C) interdigitated yellow and red zones of the saprolite horizon with the phyllite foliated structure; D) the interdigitated yellow and red zones of the mottled horizon still showing the well preserved phyllite foliated structure in the red zones; E) mottled horizon in contact to the upper columnar lateritic duricrust; F) relict of ferruginized fragment with the well phyllite foliation preserved forming the brechoidal/fragmental facies of the lateritic duricrust; G) yellowish goethite (Gt), kaolinite (K) and gibbsite (Gb) oololiths in a matrix with the same minerals as well as muscovite and quartz relicts; H) white kaolinite oololiths with brown to yellowish cortex formed by a mixture of kaolinite, goethite and hematite; I) quartz grains also with brown to yellowish cortex formed by a mixture of kaolinite, goethite and hematite; J) dismantled lateritic duricrust with roots marks highlighted by the white lines; K) lateritic pisolith and fragments with up to 20 cm in diameter forming the dismantled lateritic duricrust.

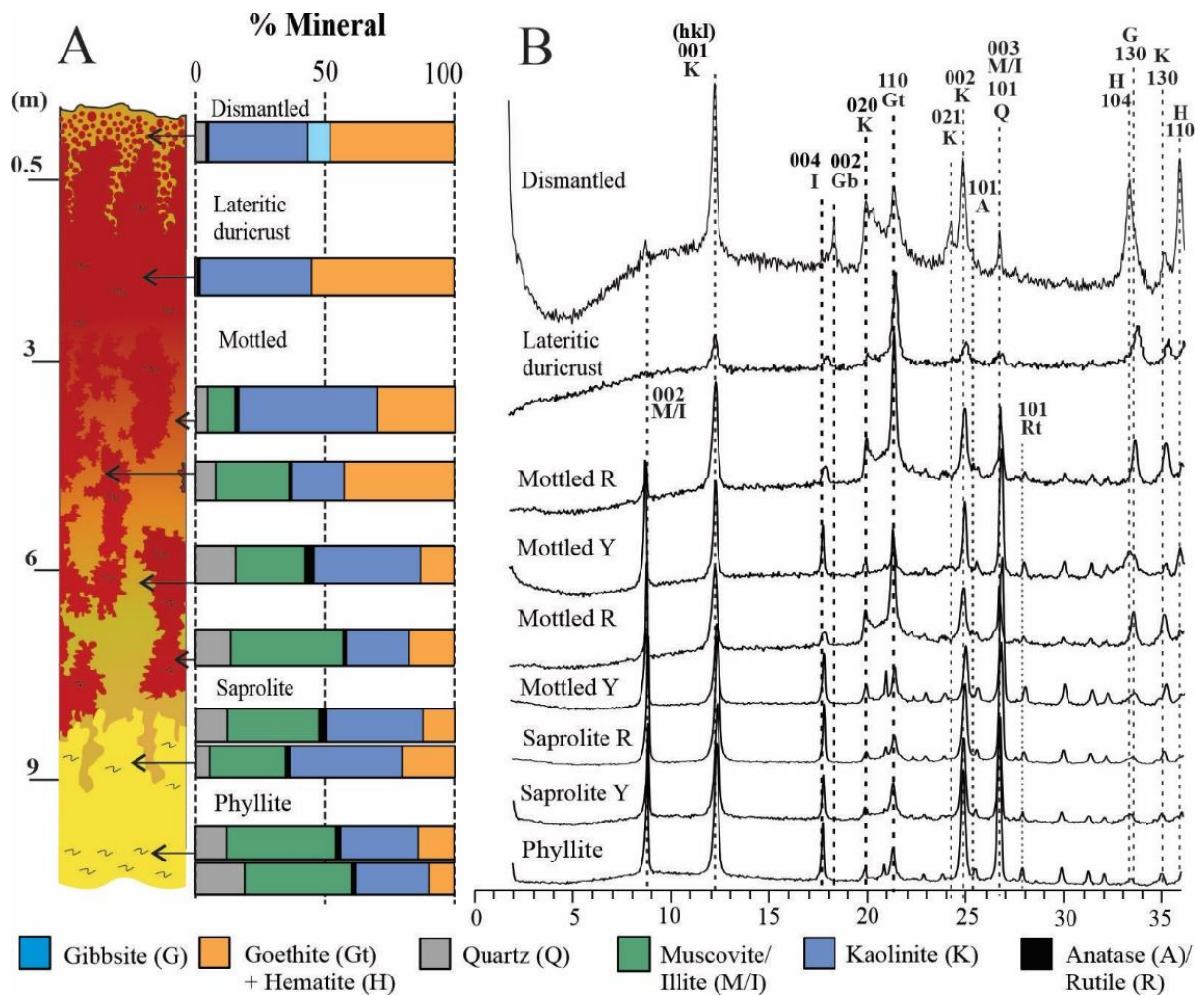


Figure 3. A) Calculated mineral composition of profile 2 in % and B) XRD data. R is the red zones and Y the yellow portion.

Like the saprolite, the mottled horizon has well-defined, interdigitated vertical sections of yellow, pink, and red range in thickness from 2 to 4 m (Fig. 2D). The red zone still preserves the foliated phyllite structure. The mottled horizon presents the same mineral phases as the underlying saprolite. However, the proportion of muscovite/illite diminishes as one approaches the top of the horizon (Fig. 3), where pisoliths (<2 cm in diameter) and red and yellow semi-friable concretions indicate the transition to the lateritic duricrust. There are traces of muscovite/illite, gibbsite, anatase, and rutile in the ferruginous lateritic

duricrust, which is up to 3 m thick (Fig. 2E) and primarily formed of goethite, hematite, and kaolinite (Fig. 3). It is columnar and contain three interdigitated facies zones: 1) reddish-brown brechoidal/fragmental facies, with fragments ranging from 6 to 10 cm in diameter that preserve the phyllite foliation (Fig. 2F); 2) pisolitic to nodular facies, formed by hardened yellow nodules and pisoliths up to 8 cm in diameter and; 3) oolitic facies with two different types of oololiths, the majority of which have a diameter of less than 1 mm. The first one is yellowish, composed of a mixture of goethite, kaolinite, and gibbsite, whereas the others are white and contain kaolinite (Fig. 2H). Quartz grains can also be found among the oololiths. Figures 2G, H, and I show that the oololiths and quartz grains are surrounded by clayey kaolinite, goethite, and gibbsite cortex. The top of the lateritic duricrust, which can be up to 0.5 m thick, is disassembled as illustrated in Figures. 2J and K, revealing hard and loose fragments of the lateritic duricrust which can be up to 10 cm in diameter, embedded in a yellowish and pinkish clayey matrix. There are root marks filled with these fragments (Fig. 2J). (Fig. 2J). Whitish quartz grains measuring up to 2 cm in diameter are typical in all horizons. Profile 2, which is less complex compared to profile 1, originated from the massive, hard, and finely grained pinkish sandstone (Fig. 4A), is composed primarily of quartz and smaller amounts of microcline and illite (Fig. 5). Figure 5 show that the sandy-clay saprolite, consisting of quartz, goethite, hematite, kaolinite, gibbsite and anatase, is friable, pink to yellow, and at least 1 m thick. Although there is less quartz and more goethite, hematite, and gibbsite (Fig. 5), the yellow, clayey, mottled horizon that is 4.5 m thick as illustrated in Figure 4B, has a similar mineral composition to saprolite. Figure 5 show that in the upper part of the mottled horizon, there are numerous friable brownish goethite and hematite pisoliths that are less than 1 cm in diameter.

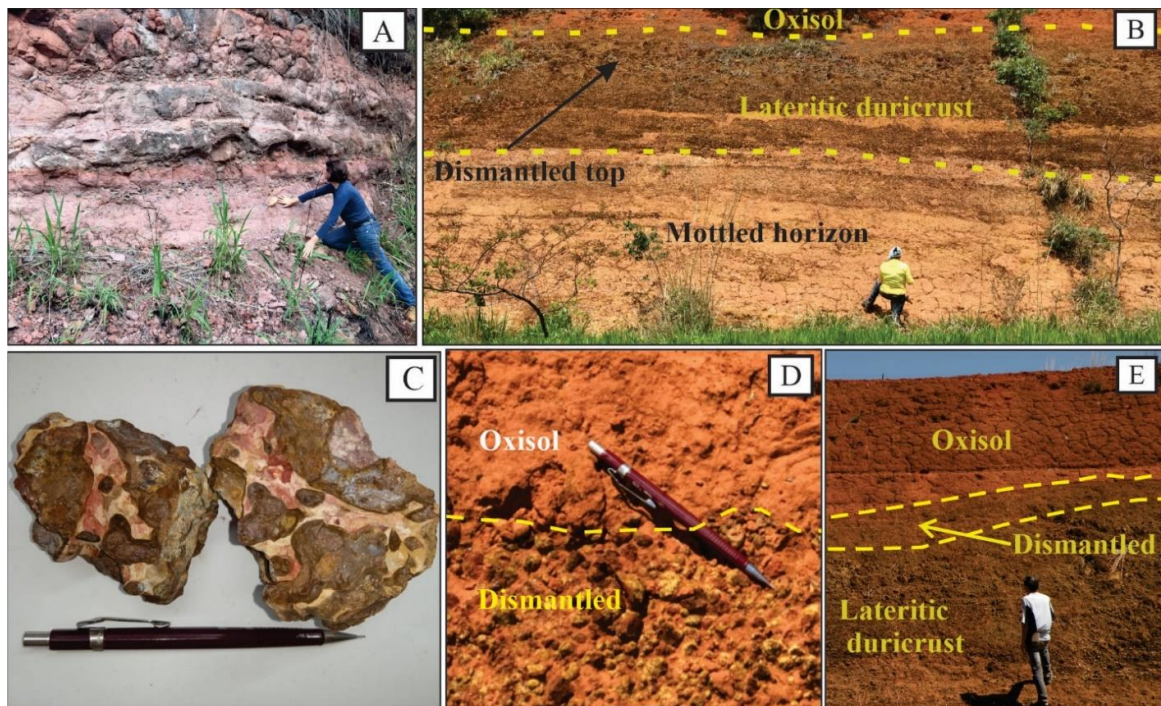


Figure 4. Features of perfil 2: A) pink to yellow sandy clay saprolite; B) view of the profile 2 outcrop showing the lower horizons; C) redd brown, ferruginous, vermiform fragments of the lateritic duricrust; D) detail view of the top of the dismantled lateritic duricrust with concretions and nodules up to 9 cm in diameter embedded by a yellow pinkish clayey matrix; E) view of the profile 2 outcrop showing the upper horizons.

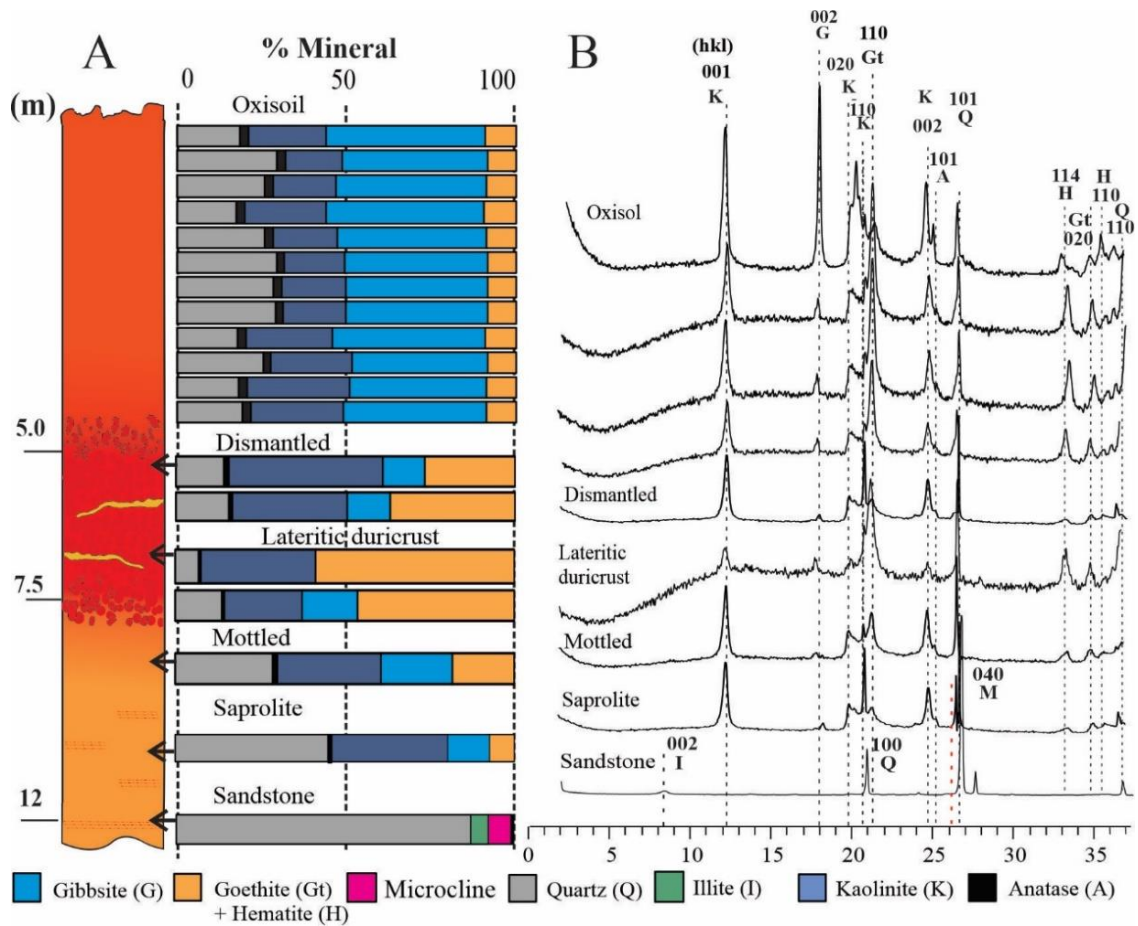


Figure 5. Calculated mineral composition of profile 2 in % and XRD data.

Vermiform, the reddish-brown ferruginous lateritic duricrust (2.5 m thick), is more friable at the base and hardened at the top with a well-preserved root marking (Fig. 4B and C). Laterally, the lateritic duricrust is discontinuous with interdigitated clayey zones, undulatory bottom, and higher contacts indicating some lateral slip. At the dismantled top, there are concretions and nodules between 1 and 9 cm in diameter embedded by a yellowish and pinkish clayey matrix (Fig. 4D). Figure 5 shows that goethite and hematite are the main minerals. The clayey reddish-yellow oxisol (5 m thick), is homogeneous and friable (Fig. 4E), with a notable feature being the significant prevalence of kaolinite and gibbsite (Fig. 5). Anatase is present throughout the profile, with the oxisol having a higher concentration.

3.2. Geochemistry

3.2.1. Major Elements

The profiles are chemically distinct. Profile 1 generally has a higher content of Na_2O , K_2O and MgO (up to 4.43%) compared to profile 2 (up to 0.84%) (Table 3). However, in both profiles, these elements decrease from the base parent rock to the top of the lateritic duricrust, while Fe_2O_3 , P_2O_5 , and TiO_2 levels increase in the overlying lateritic horizons (Fig. 6A and Table 3). Profile 1 shows that the phyllite, and the yellow areas of the saprolite and the mottled horizon have higher levels of Al_2O_3 (24.3 to 27.6%) and SiO_2 (32.6 to 45.5%) than the respective red ferruginous areas (17.5 to 27.3% and 27.4 to 40.8%, respectively).

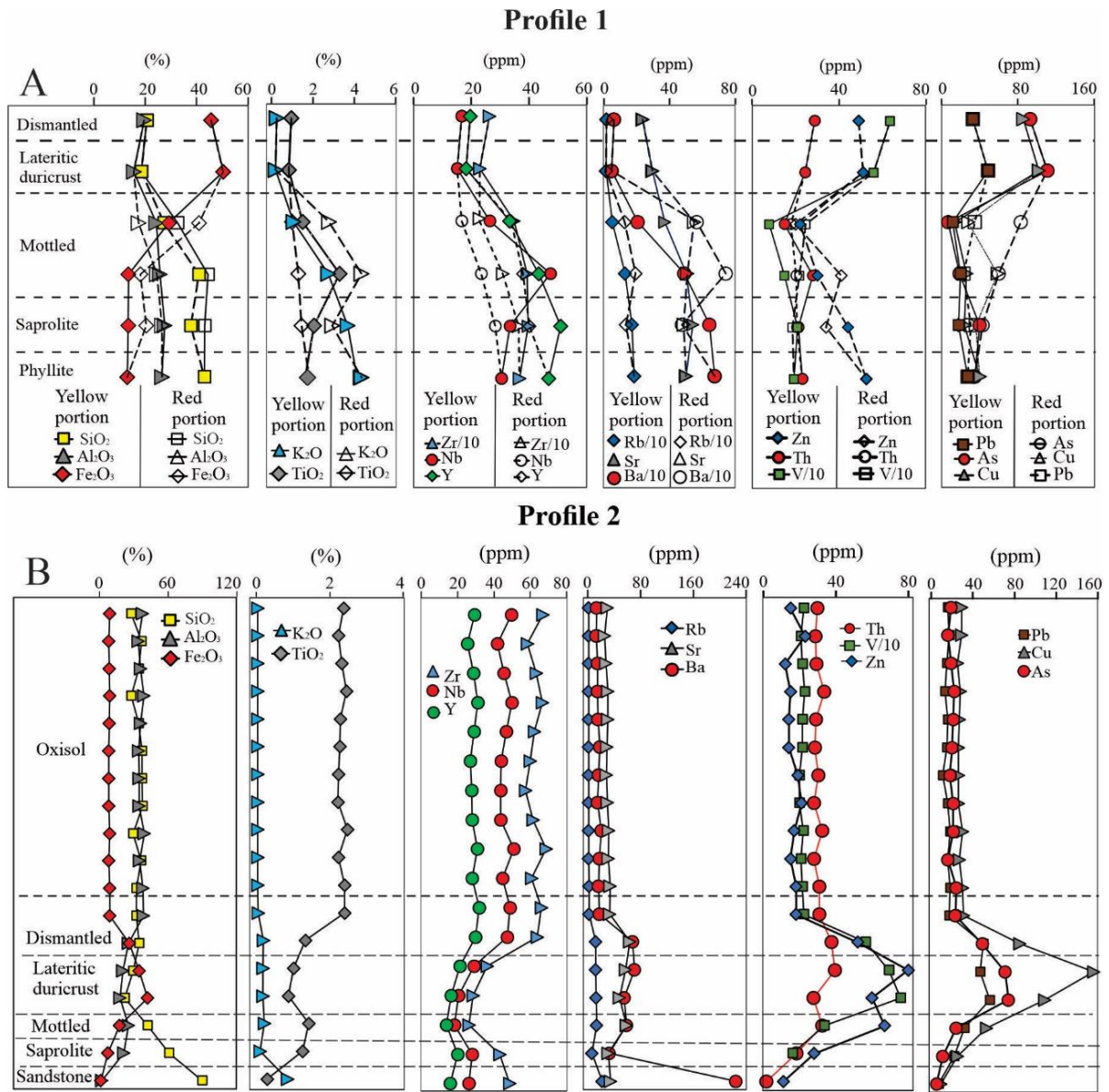


Figure 6. Chemical composition across the profiles: A) profile 1, B) profile 2.

Table 3. Chemical composition in wt %. Y and R are respectively the yellow Si-Al zones and the red Fe zones.

Horizon	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	Na ₂ O	K ₂ O	MgO	P ₂ O ₅	TiO ₂	LOI	Total
PROFILE 1											
Dismantled	20.7	19.6	45.7	<0.01	0.03	0.25	0.02	0.12	0.96	12.7	100.09
Lateritic duricrust	18.5	15.6	50.4	<0.01	<0.01	0.20	0.03	0.11	0.84	13.0	98.60
Mottled Y	32.6	24.3	29.2	<0.01	0.06	1.07	0.10	0.02	1.50	12.6	101.45
Mottled R	27.4	17.5	40.9	<0.01	0.15	2.78	0.26	0.10	0.99	8.1	98.12
Mottled Y	44.4	25.7	13.5	<0.01	0.14	2.74	0.27	0.03	3.29	9.7	99.73
Mottled R	40.8	24.6	18.2	<0.01	0.22	4.34	0.41	0.02	1.29	8.0	97.88
Saprolite Y	43.2	27.6	13.4	<0.01	0.19	3.67	0.36	0.03	2.05	9.1	99.61
Saprolite R	37.7	26.5	20.4	<0.01	0.13	2.93	0.30	0.03	1.45	10.1	99.54
Phyllite Y	45.5	25.7	11.0	<0.01	0.18	4.13	0.42	0.02	1.63	7.7	96.29
Phyllite R	40.5	27.3	15.1	<0.01	0.21	4.34	0.43	0.02	1.83	8.7	98.43
PROFILE 2											
Oxisol 12	27.8	37.7	8.77	<0.01	<0.01	0.03	0.03	0.06	2.38	22.2	98.99
Oxisol 11	36.6	33.8	8.14	<0.01	<0.01	0.03	0.03	0.05	2.24	18.6	99.51
Oxisol 10	34.1	36.0	8.57	<0.01	<0.01	0.03	0.03	0.06	2.33	19.1	100.24
Oxisol 9	27.8	38.7	9.12	<0.01	<0.01	0.04	0.03	0.05	2.46	19.7	97.97
Oxisol 8	34.4	35.9	8.53	<0.01	<0.01	0.04	0.03	0.05	2.29	17.9	99.16
Oxisol 7	37.3	34.3	8.31	<0.01	<0.01	0.03	0.03	0.04	2.27	17.5	99.80
Oxisol 6	37.2	34.8	8.22	<0.01	<0.01	0.04	0.03	0.04	2.24	17.1	99.69
Oxisol 5	37.4	34.6	8.22	<0.01	<0.01	0.03	0.03	0.04	2.22	17.1	99.66
Oxisol 4	29.5	39.1	9.07	<0.01	<0.01	0.04	0.03	0.04	2.48	18.9	99.23
Oxisol 3	36.3	35.2	8.31	<0.01	<0.01	0.04	0.03	0.04	2.24	16.9	99.13
Oxisol 2	32.3	38.1	8.89	<0.01	<0.01	0.04	0.03	0.05	2.41	18.0	99.89
Oxisol 1	32.1	38.2	8.92	0.02	<0.01	0.05	0.03	0.05	2.41	18.3	100.14
Dismantled	34.6	25.4	26.1	0.02	<0.01	0.19	0.04	0.08	1.33	13.3	101.07
Dismantled	29.3	20.2	34.5	<0.01	<0.01	0.18	0.03	0.14	1.01	13.8	99.23
Lateritic duricrust	20.2	11.8	52.0	<0.01	<0.01	0.12	0.02	0.20	0.55	13.8	98.76
Lateritic duricrust	22.2	17.8	42.0	0.02	<0.01	0.18	0.03	0.14	0.87	14.8	98.05
Mottled horizon	41.9	25.4	17.70	0.02	<0.01	0.21	0.05	0.06	1.43	13.0	99.78
Saprolite	60.7	21.4	7.33	0.02	<0.01	0.10	0.03	0.03	1.26	9.97	100.85
Sandstone	89.8	1.98	1.12	0.51	0.02	0.84	0.99	0.01	0.29	2.70	98.26

The phyllite and red ferruginous areas of the lower mottled horizon area, where the muscovite/illite remnant of the foliated parent rock is better retained, has greater K_2O (4%) contents. Additionally, TiO_2 (1.5 to 3.29%) is also higher in the yellow zones of the saprolite and mottled horizon. Table 1 and Figure 3 shows that the gibbsite content and clay minerals are followed by loss of ignition (7 to 13%).

In profile 2, the sandstone has greater concentrations of SiO_2 (89%), MgO (0.99%), K_2O (0.84%), and CaO (0.51%) compared to the ferruginous lateritic duricrust containing up to 52% of Fe_2O_3 and 0.14 to 0.2% of P_2O_5 respectively. The lowest content of Fe_2O_3 (8%) and the highest content of Al_2O_3 and TiO_2 (averages of 35.95 and 2.31%, respectively) are the distinctive features of the oxisol. Table 1 and Figure 5 shows an increase in LOI for the oxisol (16.9 to 22.2%) as a resulting from high gibbsite content.

3.2.2. Trace Elements

Except for As, Cu, Rb, Sc, Sr, Th, U, V, and Zn, which are more prevalent in profile 2, most trace elements are more abundant in profile 1 (Table 3). However, each profile have distinct trace element behaviors. In profile 1, Ba, Cs, Hf, Nb, Rb, Sr, Sc, Ta, Y, and Zr have lower upper-horizon concentrations, similar to SiO_2 and Al_2O_3 . On the other hand, As, Cu, Pb, Th, and V higher in the upper horizons exhibit the same behavior as Fe_2O_3 (Table 3, Fig. 6A). These geochemical behaviors allow the yellow silico-aluminous and red ferruginous sections to be distinguished across the profile. As, Cs, Cu, Ga, Pb, Sc, Sr, Th, U, V, Zn, and Zr exhibit similar behavior as Fe_2O_3 , with higher concentrations in the lateritic duricrust and dismantled horizon. Ba and Rb exhibit similar behavior as SiO_2 , NaO, K_2O , and MgO , with higher concentrations in the parent rock, while Hf, Nb, Ni, Ta, Y, and Zr exhibit similar behavior as Al_2O_3 , with higher concentrations in the oxisol (Tables 2 and 3 and Fig. 6B).

Figure 1A shows that the horizons normalized patterns of profile 1 are similar in terms UCC elements. In general, Fe_2O_3 , TiO_2 , As, Cu, and V are enriched while CaO , MgO , Ba Ni, Br, and Sr are depleted. There is a slight depletion of MgO , K_2O , Na_2O , As, Cu, Ba, Rb, and V in the phyllite parent rock and in the yellow silico-aluminous zones, and an enrichment of Fe_2O_3 , P_2O_5 , As, Cu and V in the red ferruginous zones. This pattern is seen in both the ferruginous duricrust and the disassembled duricrust. Part of the elements are close to the parent rock composition, except for Fe_2O_3 , P_2O_5 , As, Cu, and V, which are slightly enriched and MgO , K_2O , Na_2O , Ba, Cs, Ni and Rb slightly depleted (Fig. 7B).

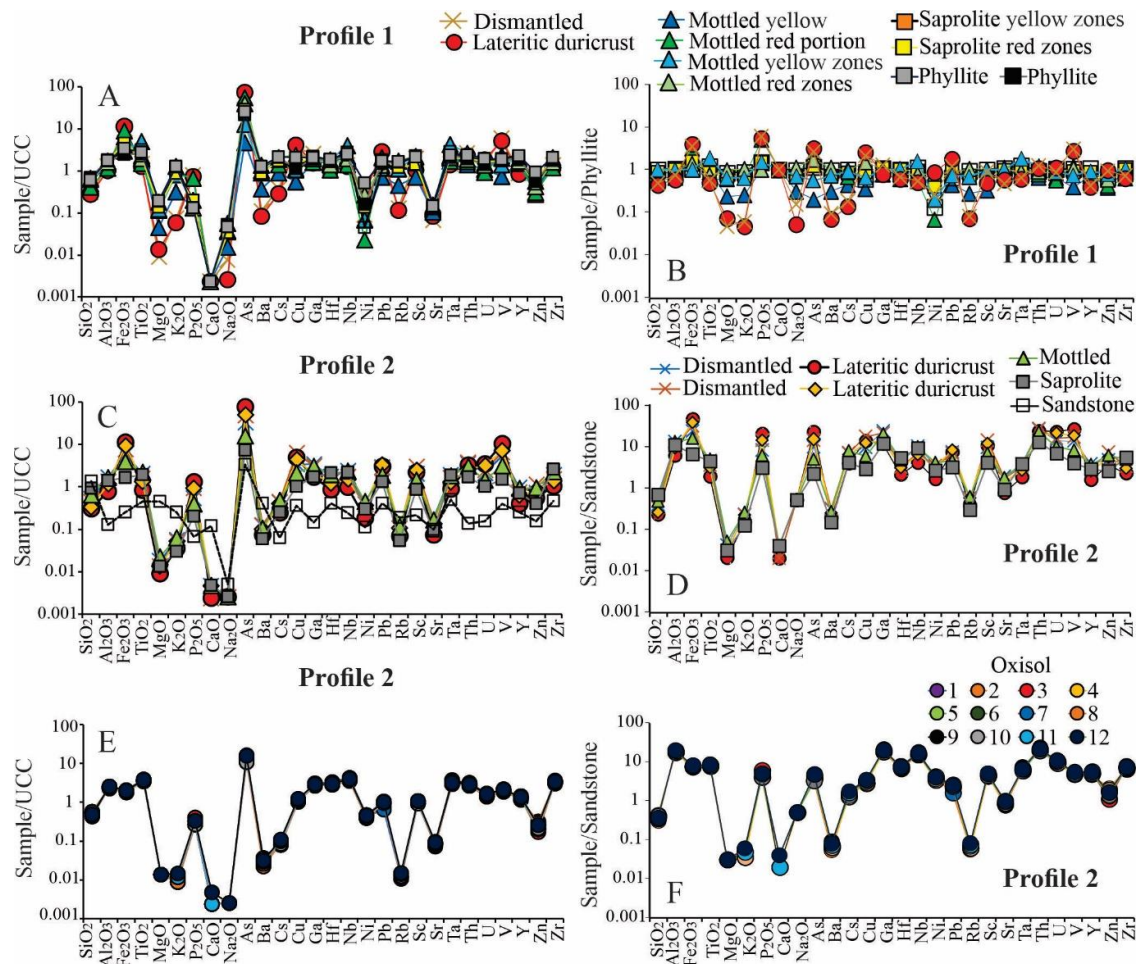


Figure 7. Normalized major and trace elements A, C and E relative to UCC of Taylor and McLennan (2001) and B, D and F relative the parent rocks.

Figure 7C shows that in profile 2, the sandstone is enriched in SiO_2 , MgO , K_2O , CaO , Na_2O , Ba , and Rb in terms of UCC-normalized elements, while the horizons follow the UCC pattern of profile 1. This pattern is consistent with the parent rocks-normalized elements although some of them are slight more enriched (Fig. 7D). The oxisol has a similar fractionation pattern to the underlying horizons, but with a subtle Al_2O_3 enrichment (Figs. 7E and F).

3.2.3. REE and Nd and Sr Isotopes

Table 3 and Figure 8 show that the concentration of REEs, particularly, La and Ce, is higher in profile 2 even though both profiles have higher LREE concentrations than HREE. However, the horizons have distinct REE signatures. In profile 1, LREE concentrations are higher at the top of the mottled horizon and in the ferruginous duricrust (79 to 83 ppm) than in the phyllite parent rock (26 to 27 ppm). However, as can be seen in Table 3 and Figure 8A, the HREE values are higher in the phyllite (25 to 29 ppm) and lower in the ferruginous duricrust and the dismantled horizon (12 ppm). While the

saprolite red zones is the slightly more radiogenic sample, the Sm/Nd , $^{147}\text{Sm}/^{144}\text{Nd}$, and $\epsilon_{\text{Nd}(0)}$ (-13 to -6) ratios all exhibit the same HREE behavior (Fig. 8A). Table 4 shows that T_{DM} values in unfractionated samples ($^{147}\text{Sm}/^{144}\text{Nd} < 0.23$) range from 2.52 to 1.88 Ga. The Rb/Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios gradually decrease toward the top of profile 1 (Fig. 8A). The isotope clay fraction values coincide with the respective source material. The normalized REE patterns indicate a slight HREE enrichment across the profile for the UCC and an LREE enrichment for the parent rock (Fig. 9A and B).

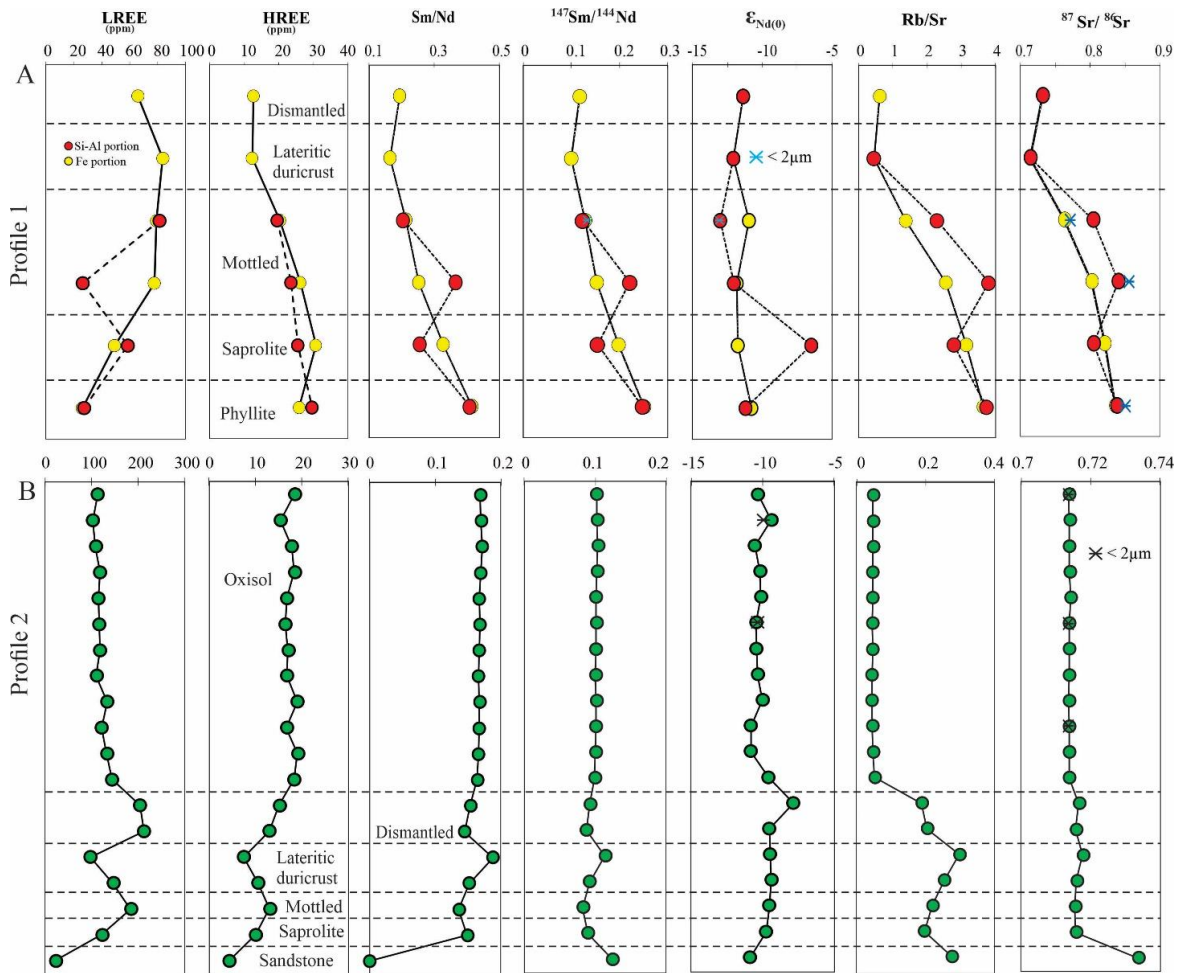


Figure 8. REE, Sm/Nd , $^{147}\text{Sm}/^{144}\text{Nd}$, $\epsilon_{\text{Nd}(0)}$, Rb/Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ composition, A) across profile 1 and B) across profile 2.

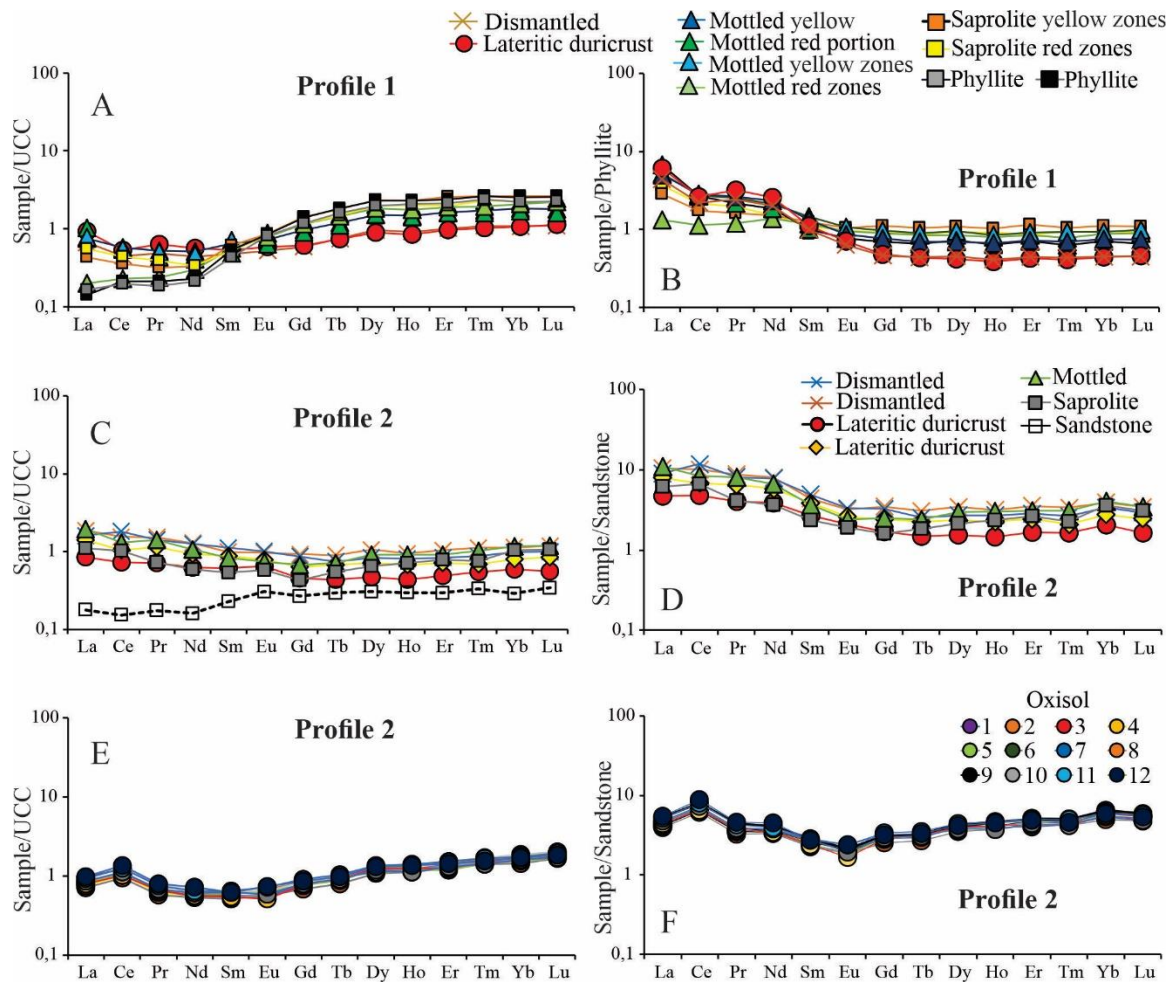


Figure 9. Normalized REE. A, C and E) relative to UCC of Taylor and McLennan (2001) and B, D and F) relative the parent rocks.

Table 4. Trace element concentration in ppm. Y and R are respectively the yellow Si-Al zones and the red Fe zones.

Horizon	As	Ba	Cs	Cu	Ga	Hf	Nb	Ni	Pb	Rb	Sc	Sr	Ta	Th	U	V	Y	Zn	Zr
PROFILE 1																			
Dismantled	93	62	1.75	86	44.0	6.9	16.7	4	33	15	28	24	1.5	29	4.11	634	19.6	49	263
Lateritic duricrust	111	47	1.32	102	26.3	6.2	15.2	13	49	13	15	30	1.4	24	5.14	559	18.2	51	230
Mottled Y	7	205	4.19	14	27.2	9.1	26.4	3	12	51	10	37	2.3	15	3.03	79	33.3	20	348
Mottled R	83	565	6.51	28	27.1	6.2	16.7	1	35	126	22	55	1.7	18	2.59	247	33.8	22	229
Mottled Y	19	489	8.66	26	32.9	10.7	47.4	3	20	128	30	50	4.2	28	4.17	149	43.4	41	393
Mottled R	60	742	9.59	59	34.6	8.1	23.4	12	23	193	31	51	2.1	20	3.85	217	37.9	30	309
Saprolite Y	40	643	9.60	24	37.4	10.2	33.4	2	18	171	31	54	2.9	21	4.91	209	51.0	34	397
Saprolite R	43	475	7.98	36	36.5	10.1	28.3	6	31	135	20	49	2.1	21	4.67	185	40.2	44	364
Phyllite Y	38	651	9.46	28	33.6	9.6	30.0	7	26	181	32	50	2.3	21	3.92	181	43.3	39	336
Phyllite R	32	699	9.79	52	35.4	11.0	30.8	23	29	188	30	50	2.4	25	5.46	205	50.4	66	399
PROFILE 2																			
Oxisol 12	19	13	0.43	29	51.7	18.8	49.6	20	16	1.4	15	30	3.5	30	4.00	223	29.4	15	668
Oxisol 11	16	12	0.40	29	44.0	16.3	41.8	19	17	1.2	15	25	3.1	29	3.84	208	25.5	23	584
Oxisol 10	19	15	0.38	25	48.0	17.6	45.6	17	15	1.3	14	27	3.1	29	4.01	216	28.7	12	634
Oxisol 9	22	14	0.39	28	51.3	18.9	50.0	19	13	1.4	15	30	3.7	34	4.60	229	31.1	15	667
Oxisol 8	21	16	0.36	27	49.4	16.9	46.7	20	16	1.4	13	30	3.2	29	4.04	214	28.9	14	623
Oxisol 7	20	18	0.37	26	45.8	16.3	43.9	17	15	1.3	13	29	3.0	29	3.84	215	26.9	14	599
Oxisol 6	18	16	0.39	26	44.5	16.2	43.8	19	11	1.3	13	28	2.9	30	4.20	200	27.7	19	573
Oxisol 5	21	14	0.37	26	45.5	16.4	43.8	170	16	1.3	13	30	3.1	28	3.86	200	28.0	21	616
Oxisol 4	21	20	0.41	30	49.7	19.0	51.0	21	18	1.4	14	32	3.5	33	4.76	219	30.8	17	688
Oxisol 3	16	17	0.39	27	47.0	16.7	44.7	18	16	1.4	13	31	2.9	28	4.18	207	28.1	15	606
Oxisol 2	24	16	0.46	30	50.5	17.8	48.9	21	18	1.6	15	33	3.2	31	4.40	216	31.8	18	661
Oxisol 1	23	17	0.50	31	49.4	17.2	47.4	20	17	1.7	15	33	3.2	31	4.49	222	29.7	18	637
Dismantled	49	68	1.97	85	58.4	9.9	28.9	17	50	12	28	64	1.9	38	5.93	564	21.2	52	363

Horizon	As	Ba	Cs	Cu	Ga	Hf	Nb	Ni	Pb	Rb	Sc	Sr	Ta	Th	U	V	Y	Zn	Zr
Dismantled	71	70	2.06	156	52.7	7.4	20.6	17	47	12	42	57	1.6	40	6.81	693	16.4	80	286
Lateritic duricrust	114	41	1.14	122	28.6	5.0	11.8	8	51	7.8	31	26	0.9	35	9.71	1110	8.7	39	197
Lateritic duricrust	74	55	1.83	109	35.3	7.1	18.2	16	56	12	35	48	1.3	28	8.95	757	13.8	60	262
Mottled	24	59	2.24	53	51.1	11.3	28.0	20	32	13	20	59	1.8	33	4.11	336	20.0	67	432
Saprolite	11	32	1.16	25	28.8	12.3	26.2	13	22	6	12	31	1.9	18	2.88	161	15.8	28	485
Sandstone	5	224	0.29	9	2.5	2.40	2.90	5	7	21	3	34	0.5	1	0.43	42	5.6	11	89

*Ag, Cd, Mo e Li < 0.01 ppm.

In profile 2, the sandstone parent rock has the lowest REE concentrations (LREE = 21.8 ppm and HREE = 4.34), though the LREE are locally more concentrated in the two samples of the dismantled horizon (LREE = 204 to 213 ppm) and the HREE in the oxisol (HREE = 15.3 to 18.9 ppm) (Table 4 and Fig. 8B). Figure 8B and Table 4 show that a homogenous behavior was observed for both Sm/Nd and $^{147}\text{Sm}/^{144}\text{Nd}$, with the exception of the parent rock. The $\epsilon_{\text{Nd}(0)}$ values exhibit homogeneity throughout the profile, becoming a slightly more radiogenic sample ($\epsilon_{\text{Nd}(0)} = -6.50$) at the top of the dismantled horizon. Compared to profile 1, profile 2 is more radiogenic than profile 1 (Table 4) and the T_{DM} values in the unfractionated samples ($^{147}\text{Sm}/^{144}\text{Nd} < 0.23$) indicate higher variability (2.37 to 1.01 Ga) (Table 4). While the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are rather homogeneous across the profile (~ 0.716 in the lateritic duricrust to 0.713 in the oxisol) and less radiogenic than the parent rock (0.734) (Table 4, Fig. 8B), the Rb/Sr ratios are lower in the oxisol (< 0.052). As seen in profile 1, the clay fraction exhibits an isotopic signature that is similar to the corresponding source sample (Table 4, Fig. 8B).

The REE, particularly the LREE, are leached in the parent rock in relation to the UCC-normalized pattern and are close to the UCC pattern in the remaining horizons with very moderate MREE depletion (Fig. 9C). Furthermore, when compared to the parent rock-normalized REE pattern (Fig. 9D), the LREE exhibits a more prominent widespread REE enrichment. The oxisol follows the behavior of the remaining horizons, although there is a slight positive Ce/Ce* anomaly across the horizon relative to the UCC and parent rock (Fig. 9E and F).

4 DISCUSSION

4.1. Geochemical Features of the Profiles

Figure 10 shows that profile 1 is defined by two groups of elements and profile 2 defined by three group elements according to the main component statistics procedures. In profile 1, SiO_2 , Al_2O_3 , K_2O , TiO_2 , Ba, Cs, HREE, Nb, Rb, Sr, and Zr (group 1, Figs. 10A and B) represent the chemical composition of phyllite parent rock, saprolite and mottled horizon, where muscovite/illite, rutile and anatase predominate (Fig. 3). Fe_2O_3 , P_2O_5 , LOI, LREE, As, Cu, Pb, Th, V, and Zn (group 2) represent the ferruginous and the

dismantled duricrust due to the goethite and hematite predominance (Fig. 3). K₂O, Ba, and Rb associations in profile 1 up to the mottled horizon were due the reduced muscovite susceptibility to weathering and illite formation (group 1, Fig. 10A). Similar to the results obtained by Peng *et al.* (2014) and Onana *et al.* (2016), the MgO and Na₂O phyllite parent rock-normalized close to 1 are also associated with remains of muscovite/illite across profile 1 (Fig. 3), emphasizing the autochthonous relationship between the horizons (Banakeng *et al.*, 2016). The SiO₂, K₂O, Ba, and Sr association (group 1, Fig. 10C and D) in profile 2 illustrate the chemistry sandstone and saprolite, as well as the dominance of quartz over microcline and muscovite/illite (Fig. 5). Fe₂O₃, P₂O₅, LOI, LREE, As, Cu, Cs, Pb, Sc, Sr, U, V, and Zn association (group 2) reflect the chemistry of the mottled horizon, ferruginous duricrust and dismantled duricrust where goethite, hematite and kaolinite are the main constituents relative to quartz (Fig. 5).

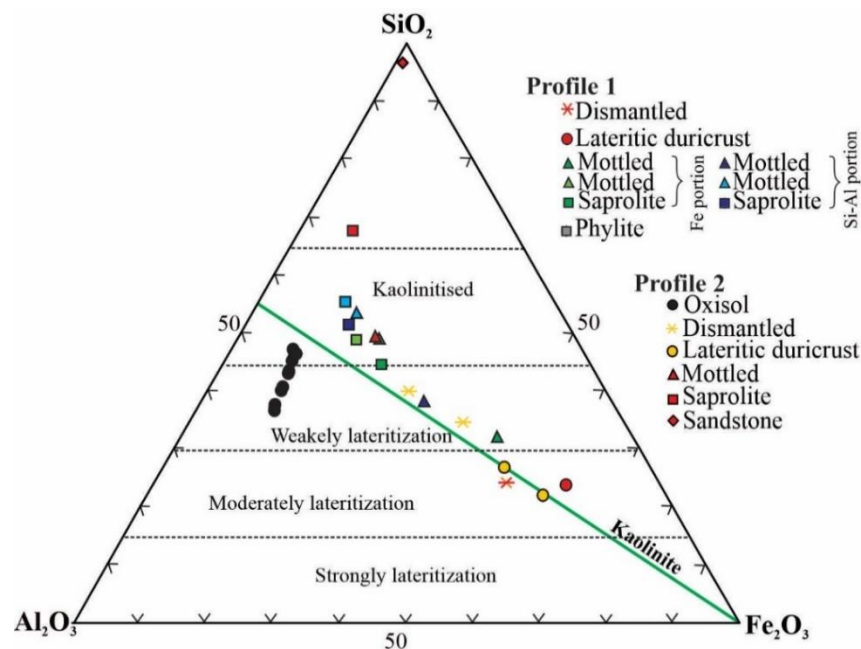


Figure 10. Ternary diagram classification according to the different degrees of lateritization diagram of Schelman (1983).

Although the P₂O₅ and Sr correlation suggests the presence of secondary phosphates (Buol and Weed, 1991; Sequeira Braga *et al.*, 2002; Santos *et al.*, 2019), these elements can be linked to Fe₂O₃ since it is the most concentrated element. Al₂O₃, TiO₂, LOI, Ga, HREE, Nb, Ni, Th, and Zr association (group 3, Fig. 10C and D) is attributed to the oxisol, particularly the abundance of gibbsite and kaolinite along with anatase (Fig. 5) and residual minerals such as zircon. Microcline and muscovite highlight their almost complete transformation to kaolinite in the saprolite (Fig. 5) and

the consequent leaching of the associated elements related to the parent rock (SiO_2 , K_2O , MgO , $(\text{CaO}, \text{Na}_2\text{O})$ Ba and Rb) (Fig. 7 D).

The similarity of the geochemical associations between group 2 in profile 1 and group 2 in profile 2 (Fig. 1), highlights the classical lateritic duricrust Fe_2O_3 minerals and the similar electronic configuration trace elements association (Anand and Paine, 2002). Goethite and hematite precipitate, form, and concentrate as leaching progresses, hardening the ferruginous lateritic duricrust. Fixing Fe_2O_3 , P_2O_5 , LOI, As, Cu, LREE, Pb, V, Th, and Zn in profile 1 was made possible by this process. As demonstrated by the higher goethite 110 XRD reflection (Fig. 3), the Fe_2O_3 and LOI association in profile 1 (group 2, Fig.11) shows a correlation with goethite, which is more frequent than hematite in the lateritic duricrust. These elements (excluding Th and LOI), as well as Cs, Sc, and U, are concentrated in the more hematite (no Fe_2O_3 and LOI association) lateritic duricrust of profile 2 (Figs. 5 and 7). This behavior which fixes these elements in goethite and hematite is similar to other lateritic profiles globally (Yan *et al.*, 2010; Costa *et al.*, 2014; Négrel *et al.*, 2018; Baidaya *et al.*, 2019; Santos *et al.*, 2019), and allows their enrichment relative to the parent rock.

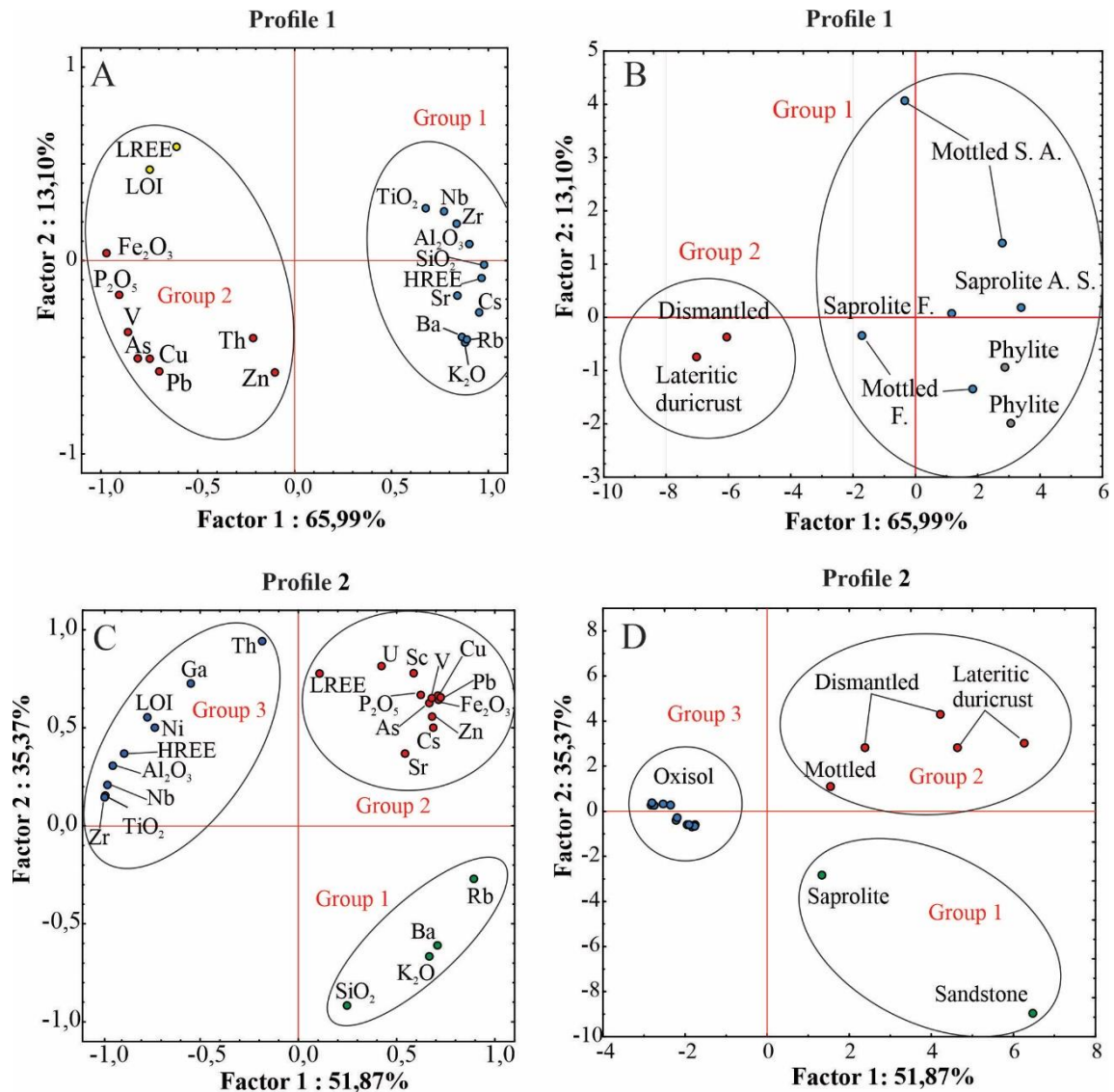


Figure 11. The main component statistics procedures showing the geochemical association A and B: profile 1 and C and D: profile 2.

4. REE, Nd and Sr Isotopes Behavior

The elements from the Fe₂O₃ group (P₂O₅, LOI, As, Cu, LREE, Pb, V, Th, and Zn in profile 1 and Cs, Sc and U in profile 2) are linked to LREE in the examined profiles, and these elements reflect the lateritic duricrust composition in both profiles (Figs. 11A and C). HREE are linked to the phyllite parent rock, saprolite, and mottled horizon in profile 1, as well as K₂O, Rb, Ba, Sr, and residual minerals including rutile, anatase, and zircon (group 1). In profile 2, HREE is likewise linked to residual minerals (group 3) and Al₂O₃, and hence to the oxisol. Different minerals exhibit different REE behavior, which subsequently varies across the lateritic horizons.

Table 3 and Figure 8 suggest REE's are associated with specific mineral phases. LREE may be associated with phosphates such as monazite or goethite and hematite, whereas the HREE are assigned to zircon and rutile/anatase, classical minerals that carry

these elements (Braun *et al.*, 1990; Braun *et al.*, 1998; Aubert *et al.*, 2001; Laveuf and Cornu, 2009; Horbe and Costa, 1999; Velbel, 1999; Harlavan *et al.*, 2009). The REE can also be sorbed into the intercellular crystals of clay minerals (Coppin *et al.*, 2002). The LREE association with P_2O_5 and Fe_2O_3 in both profiles (Fig. 10) suggests primary mineral dissolution, probably apatite, and iron and/or aluminum phosphate formation in the lateritic duricrust, as indicated by the higher P_2O_5 content in both profiles relative to the parent rock (Table 1).

The higher TiO_2 , HREE, and Zr concentration in the oxisol of profile 2 (Table 3), which is the most leached horizon due to the higher gibbsite content, suggests that these elements are associated with rutile/anatase and zircon residual minerals. On the other hand, the positive Ce anomaly (Fig. 9E and F) probably related to cerianite formation can also carry REE. The HREE association with P_2O_5 , TiO_2 , Zr and the cerianite formation, could explain the higher REE concentration in profile 2 relative to profile 1. However, in profile 1, the HREE are more concentrated from the parent rock toward the mottled horizon, where K_2O is also higher (Figs. 6 and 8). Consequently, muscovite/illite in the lower horizons connected to K_2O , which may be responsible for some of the HREE geochemical regulation (K_2O vs. HREE = 0.76). Although the REE can also be associated with kaolinite (Laveuf and Cornu, 2009 and the $r=0.81$ of Al_2O_3 vs HREE in profile 1), the higher REE concentration in the lateritic duricrust (Table 3) suggests a Fe oxyhydroxides environment preference (Ma *et al.*, 2007) and an oxidant dominant condition that aids in the formation of cerianite in the oxisol. This variation in REE control resulted in LREE fractionation relative to HREE across profiles (Fig. 9).

Despite the distinct mineral control of the REE in both profiles, the Sm/Nd and $\epsilon_{Nd(0)}$ ratios retain the signature of the parent rocks (Fig. 8). This indicates that the geochemical signatures of the phyllite and sandstone were not affected by lateritization, although the REE geochemical and fractionation changes throughout the profiles such as reported by Nesbitt and Markovics (1997), Laveuf and Cornu (2009), Tripathy (2011), and Wei *et al.* (2018). Furthermore, unlike Horbe *et al.* (2022), the oxisol was unaffected. The invariability of $\epsilon_{Nd(0)}$ relative to the more radiogenic oxisol signature of Horbe *et al.* (2022), can be attributed to the lower Zr and higher REE contents, as well as the positive Ce anomaly in profile 2. In conclusion, the differences in isotopic signature and T_{DM} ages between the profiles are caused by the parent rock signature, which is less radiogenic in profile 1 and more in profile 2.

The K replacement by Rb in the mineral structures is favored by the similarities between their ionic radii and electrovalence, hence its radiogenic decay results in minerals with a higher $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (Tripathy *et al.*, 2011). As a result, the higher Rb/Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in profile 1 (Fig. 8) correspond to muscovite, particularly in the red ferruginous zones of the saprolite and mottled horizon where it is still retained (Fig. 3). The K-bearing phase in profile 2, has a naturally lower Rb concentration (Table 2), which results in a lower Rb/Sr ratio and less radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ (Table 4, Fig. 8). Thus, the decrease in the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio across both profiles is a reflection of the composition of the parent rock and the consequent muscovite and microcline weatherability degrees, which affect the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio during leaching. The similarity of $\epsilon_{\text{Nd}(0)}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in the whole-rock and clay fractions indicate that REE and Sr-Rb minerals are equally distributed in the grains size fractions. Furthermore, it shows the grain size fraction does not influence the isotopic signature in the research profiles.

4.2. The Lateritic Process and the Parent Rock Inheritance

The weathering of the phyllite and sandstone parent rocks of Paranoá and São Bento Group, respectively, resulted in a progressive Al_2O_3 and Fe_2O_3 accumulation and intense SiO_2 and alkalis leaching. This forms the near-surface lateritic ferruginous goethite-hematite columnar duricrust and the lateritic ferruginous hematite-goethite vermiform duricrust in profiles 1 and 2, respectively (Figs. 3 and 5). The interdigitated yellow and red zones that are most probable inherited structures from the deformed Paranoá rocks (Pimentel *et al.*, 2001), are examples of this remobilization across the saprolite and mottled horizons.

The maximum Fe_2O_3 concentration and the weathering intensity on the Brazilian Midwest are exemplified by the lateritic duricrusts of the studied lateritic profiles even though the lateritic duricrusts of both profiles were classified as formed under moderate weathering intensity (Fig. 11). This results from the slow Si leaching of the centimeter quartz grains, particularly in profile 1, maintaining the SiO_2 proportion between 20 and 35% (Table 1). The displacement of the oxisol to the higher Al_2O_3 field (Fig. 11), highlights the higher Fe_2O_3 leaching relative to Al_2O_3 at the top of profile 2 (as indicated by the Al/Fe ratio from 0.6 in the ferruginous duricrust to 4.3 in the oxisol (Table 6), as well as a geochemical reorganization with a significant amount of gibbsite formation.

Table 5. REE trace element concentration in ppm. Y and R are respectively the yellow Si-Al zones and the red Fe zones.

Horizon	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	REE	LRE E	HREE
PROFILE 1																	
Dismantled	20.0	28.7	3.4	11.5	2.1	0.5	2.2	0.5	3.4	0.7	2.3	0.4	2.4	0.4	78.4	65.7	12.6
Lateritic duricrust	28.0	34.2	4.5	14.6	2.4	0.5	2.3	0.5	3.1	0.7	2.2	0.3	2.3	0.4	96.0	83.7	12.3
Mottled Y	22.7	36.6	3.7	13.3	2.9	0.6	3.7	0.8	5.2	1.2	3.8	0.6	4.0	0.6	99.5	79.2	20.3
Mottled R	30.7	34.8	3.1	10.5	2.2	0.6	3.4	0.7	5.3	1.1	3.7	0.5	3.7	0.5	100.7	81.2	19.5
Mottled Y	23.6	35.3	3.6	12.1	3.2	0.8	4.7	1.0	7.1	1.5	4.7	0.8	4.9	0.8	103.9	77.0	26.0
Mottled R	6.0	14.7	1.7	7.8	2.5	0.7	4.3	0.9	6.3	1.4	4.3	0.6	4.6	0.7	56.6	26.4	23.6
Saprolite Y	13.0	22.5	2.3	8.6	2.7	0.8	5.4	1.2	8.2	1.8	5.9	0.9	5.8	0.8	79.8	49.1	30.7
Saprolite R	16.7	28.2	2.8	8.7	2.4	0.7	4.4	0.9	6.9	1.6	4.5	0.8	4.9	0.7	84.2	58.7	25.4
Phyllite Y	4.9	12.5	1.3	5.5	1.9	0.7	4.4	1.0	6.9	1.7	4.9	0.8	4.9	0.7	52.1	26.1	25.9
Phyllite R	4.2	13.4	1.5	5.9	2.4	0.7	5.3	1.2	8.0	1.9	5.4	0.9	5.6	0.8	57.1	27.4	29.6
PROFILE 2																	
Oxisol 12	23.4	66.9	4.6	14.8	2.58	0.60	3.11	0.57	4.42	1.07	3.47	0.53	3.94	0.6 2	130.7	112. 3	18.3
Oxisol 11	21.2	60.8	4.0	13.8	2.32	0.50	2.60	0.51	3.78	0.90	2.91	0.46	3.17	0.5 3	117.6	102. 2	15.3
Oxisol 10	22.5	64.6	4.4	14.4	2.48	0.51	3.00	0.62	4.38	0.99	3.22	0.49	3.93	0.6 0	126.1	108. 4	17.7
Oxisol 9	25.7	69.4	4.7	15.2	2.69	0.55	2.93	0.60	4.36	1.08	3.52	0.56	4.08	0.6 4	136.0	117. 7	18.3
Oxisol 8	24.2	68.8	4.7	14.2	2.53	0.50	2.85	0.62	3.95	0.97	3.21	0.52	3.56	0.5 7	131.2	114. 5	16.7
Oxisol 7	24.8	68.1	4.8	15.7	2.71	0.57	2.88	0.56	4.29	0.95	2.75	0.47	3.41	0.5 3	132.5	116. 1	16.4
Oxisol 6	25.5	70.8	4.74	14.6	2.38	0.52	3.01	0.59	4.21	0.97	3.11	0.49	3.53	0.5 5	135.0	118. 0	16.9
Oxisol 5	23.9	64.7	4.65	14.6	2.45	0.45	2.92	0.61	4.29	1.00	2.90	0.48	3.49	0.5 7	127.0	110. 3	16.7
Oxisol 4	28.6	79.2	5.49	17.1	2.92	0.57	3.21	0.62	4.65	1.11	3.46	0.55	4.12	0.6 5	152.3	133. 3	18.9
Oxisol 3	25.8	71.8	4.84	15.9	2.79	0.52	3.02	0.58	4.13	0.90	2.98	0.46	3.54	0.5 4	137.8	121. 1	16.6
Oxisol 2	27.8	80.0	5.35	16.6	2.91	0.64	3.42	0.67	4.78	1.13	3.46	0.55	3.79	0.6 2	151.7	132. 7	19.0
Oxisol 1	29.6	86.7	5.69	18.8	2.80	0.65	3.24	0.63	4.53	1.08	3.29	0.51	3.75	0.5 9	161.9	143. 6	18.2
Dismantled	56.0	99.6	10.90	33.8	4.49	0.86	3.54	0.58	3.72	0.76	2.40	0.37	2.50	0.3 8	219.9	204. 8	15.1
Dismantled	48.5	117. 0	10.10	32.8	5.05	0.89	3.30	0.48	2.93	0.65	1.93	0.29	2.16	0.3 2	226.4	213. 5	12.9
Lateritic duricrust	25.4	47.1	5.06	16.3	2.76	0.57	1.73	0.28	1.65	0.35	1.14	0.18	1.31	0.1 8	104.0	96.6	7.39
Lateritic duricrust	42.7	67.2	8.13	24.2	3.96	0.70	2.45	0.43	2.52	0.54	1.65	0.23	1.77	0.2 7	156.8	146. 2	10.5
Mottled	58.7	83.4	10.00	27.8	3.75	0.65	2.56	0.46	3.21	0.73	2.11	0.34	2.60	0.3 8	196.7	183. 7	13.0
Saprolite	33.0	65.5	5.15	15.5	2.44	0.51	1.65	0.35	2.29	0.57	1.80	0.25	2.29	0.3 4	131.6	121. 6	10.0
Sandstone	5.4	9.9	1.25	4.2	1.03	0.27	1.02	0.19	1.08	0.24	0.68	0.11	0.64	0.1 1	26.1	21.8	4.34

Table 6. Sm and Nd concentration in ppm, Rb/Sr and Nd and Sr isotopes ratios.

Horizon	Sm	Nd	Rb/Sr	Sm/Nd	¹⁴⁷ Sm/ ¹⁴⁴ Nd	¹⁴³ Nd/ ¹⁴⁴ Nd±2SE	ε _{Nd(0)}	T _{DM} (Ga)	⁸⁷ Sr/ ⁸⁶ Sr±2SE
PROFILE 1									
Dismantled	2.284	11.784	0.618	0.194	0.1172	0.512056+/-11	-11.36	1.55	0.73172+/-2
Lateritic duricrust	2.387	14.490	0.447	0.165	0.0996	0.512019+/-5	-12.07	1.36	0.71417+/-7
Mottled Y	2.578	12.135	1.367	0.212	0.1284	0.512077+/-19	-10.94	1.71	0.76324+/-5
Mottled Y clay	2.164	10.264	-	-	0.1274	0.511972+/-15	-12.98	1.88	0.77160+/-1
Mottled R	2.093	10.220	2.290	0.205	0.1238	0.511970+/-5	-13.02	1.80	0.80429+/-4
Mottled Y	2.802	11.089	2.554	0.253	0.1527	0.512033+/-7	-11.81	2.52	0.80219+/-3
Mottled R	2.368	6.458	3.806	0.367	0.2217	0.512021+/-4	-12.04	-	0.84029+/-5
Mottled R clay	-	-	-	-	-	-	-	-	0.85559+/-1
Saprolite Y	2.712	8.284	3.154	0.327	0.1979	0.512035+/-26	-11.77	-	0.82100+/-1

Horizon	Sm	Nd	Rb/Sr	Sm/Nd	¹⁴⁷ Sm/ ¹⁴⁴ Nd	¹⁴³ Nd/ ¹⁴⁴ Nd±2SE	ε _{Nd(0)}	T _{DM} (Ga)	⁸⁷ Sr/ ⁸⁶ Sr±2SE
Saprolite R	2.573	10.062	2.783	0.256	0.1546	0.512305+/-13	-6.50	1.88	0.80501+/-3
Phyllite Y	2.384	5.740	3.641	0.415	0.2511	0.512086+/-1	-10.76	-	0.83626+/-2
Phyllite R	2.425	5.914	3.740	0.410	0.2479	0.512065+/-37	-11.18	-	0.83836+/-2
Phyllite R clay	-	-	-	-	-	-	-	-	0.85047+/-6
PROFILE 2									
Oxisol 12	2.615	15.551	0.0472	0.168	0.1016	0.512109+/-12	-10.33	1.26	0.71374+/-1
Oxisol 11	2.384	14.062	0.0478	0.170	0.1025	0.512156+/-19	-9.41	1.30	0.71392+/-1
Oxisol 11 clay	2.793	16.496	-	0.169	0.1024	0.512107 +/- 9	-10.36	1.27	0.71392+/-3
Oxisol 10	1.878	10.958	0.0478	0.171	0.1036	0.512098+/-13	-10.54	1.26	0.71383+/-2
Oxisol 9	2.609	15.445	0.0462	0.169	0.1021	0.512116 +/- 8	-10.19	1.24	0.71387+/-5
Oxisol 8	2.602	15.597	0.0470	0.167	0.1008	0.512119 +/- 8	-10.13	1.27	0.71426+/-4
Oxisol 7	2.521	15.039	0.0455	0.168	0.1013	0.512101+/-19	-10.47	1.26	0.71377+/-3
Oxisol 7 clay	2.550	15.643	-	0.163	0.0986	0.512120+/-12	-10.10	1.21	0.71375+/-2
Oxisol 6	2.565	15.376	0.0459	0.167	0.1009	0.512103+/-15	-10.43	1.25	0.71375+/-6
Oxisol 5	2.546	15.385	0.0441	0.165	0.1000	0.512106 +/- 9	-10.37	1.24	0.71383+/-2
Oxisol 4	2.858	17.115	0.0439	0.167	0.1009	0.512124+/-12	-10.03	1.29	0.71373+/-3
Oxisol 3	2.673	16.054	0.0452	0.167	0.1007	0.512082+/-15	-10.84	1.28	0.71381+/-1
Oxisol 2	2.895	17.496	0.0479	0.165	0.1000	0.512083+/-12	-10.83	1.18	0.71382+/-2
Oxisol 2 clay	2.991	18.321	-	0.163	0.0987	0.511248+/-53	-	2.37	0.71410+/-5
Oxisol 1	3.496	21.386	0.0520	0.163	0.0988	0.512146+/-10	-9.59	-	0.71385+/-5
Dismantled	5.225	34.142	0.1887	0.153	0.0925	0.512235+/-20	-7.86	1.01	0.71664+/-1
Dismantled	5.031	34.824	0.2045	0.144	0.0873	0.512148 +/- 7	-9.56	1.08	0.71574+/-1
Lateritic duricrust	2.324	12.383	0.2989	0.188	0.1135	0.512152 +/- 8	-9.48	1.34	0.71770+/-3
Lateritic duricrust	3.866	25.470	0.2547	0.152	0.0918	0.512156+/-11	-9.41	1.10	0.71595+/-2
Mottled	3.867	28.511	0.2201	0.136	0.0820	0.512149 +/- 9	-9.54	1.03	0.71547+/-1
Saprolite	2.426	16.349	0.1968	0.148	0.0897	0.512138 +/- 9	-9.76	1.11	0.71568+/-1
Sandstone	0.901	4.381	0.0002	0.278	0.1243	0.512080+/-9	-10.88	1.63	0.73364+/-2

The positive correlations of TiO₂ vs Nb, Zr vs Hf, Nb vs Ta, and Y vs HREE (Fig. 12), which are residual elements used in provenance studies, are supported by the normalized spectra relative to UCC and parent rocks, as well as the Nd isotopes signatures (Figs. 7, 8 and 9), indicating that the horizons formed *in situ* from the weathering of the underlying respective horizon without foreign inputs. However, the Zr-V-Y relationship highlights the Zr and Y geochemical mitigation compared to V, as the parent rock of the lateritic duricrusts in both profiles (Fig. 13), highlighting the affinity of V and Fe₂O₃ (Figs. 10A and C). While profile 1 is identified by the highest Y proportion, profile 2 can be distinguished from profile 1 by having the largest Zr content, which supports the sedimentary environment and felsic supply for profile 2. Figure 13 also demonstrates the surface reorganization process, which generated the oxisol in profile 2, making it geochemically similar to the mottled horizon and saprolite. This behavior, highlighted by the lower V proportion relative to the lateritic duricrust and the dismantled horizon underneath, suggests that the oxisol features result from the underlying horizons mixing and lateritic duricrust desegregation due to surface processes such as vegetation activity, landslides, and previous truncation in humid condition.

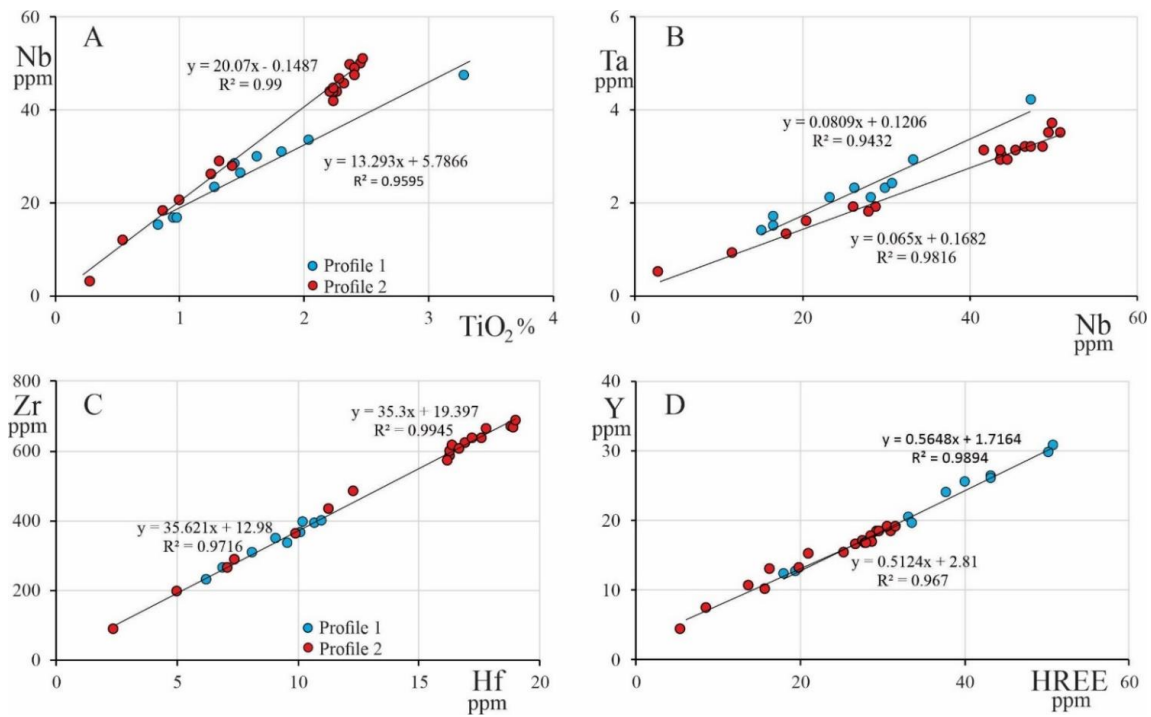


Figure 12. Relationship between A) TiO₂ vs Nb, B) Zr vs Hf, C) Nb vs Ta and D) Y vs ETRP.

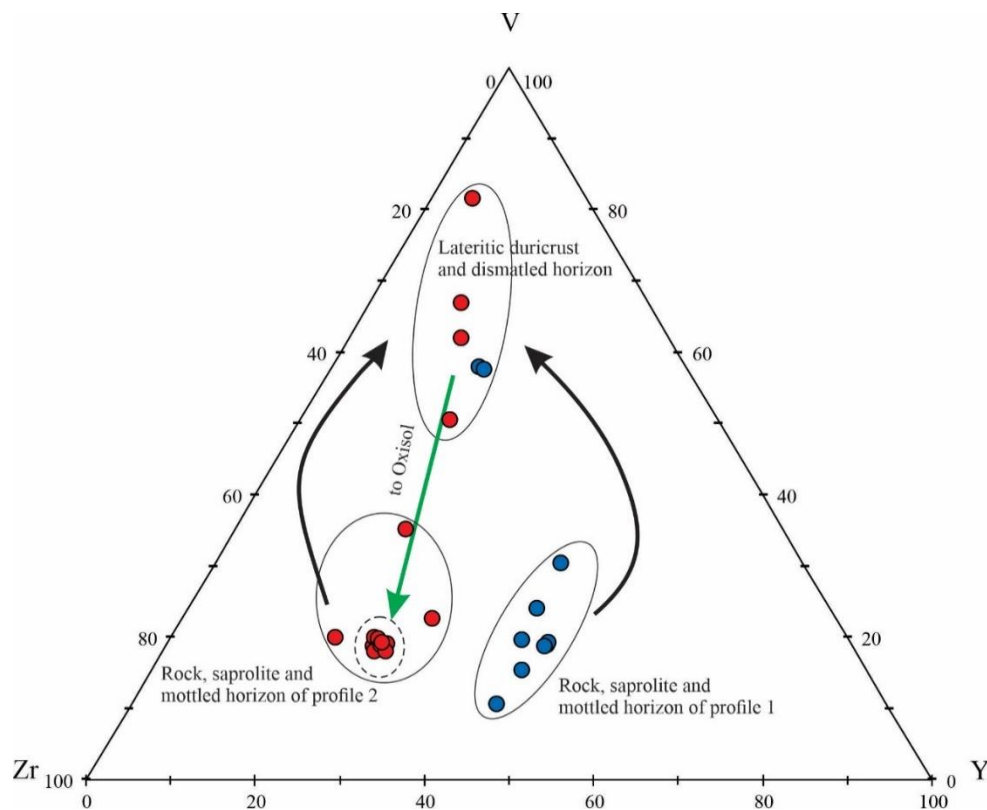


Figure 13. Ternary diagram Zr-V-Y relationship among the profiles and respective horizons.

Evidence of truncation, previous dismantling, and the mixture of fragments are indicated by the brechoidal/fragmental facies of the lateritic duricrust (Anand and Paine, 2002). In lateritic regions, concentrations of gibbsite and kaolinite on the surfaces of the

profiles, along with TiO₂, HREE, Ga, Nb, Th and Zr retention, mostly carried in residual minerals, are common surface features (Horbe and Costa, 2005; Costa *et al.*, 2014; Negrão *et al.*, 2018; Momo *et al.* 2019; Santos and Costa, 2021). A similar, but incipient process also occurs in profile 1, as evidenced by the rare yellowish and pinkish clayey matrix of the dismantled horizon.

Thus, progressive landscape transformation might result in fine material accumulation on the top of the lateritic duricrust. The predominance of gibbsite in the oxisol of profile 2 (Fig.5) emphasizes how humid weather promotes the geochemical reorganization, supported by biological activity, particularly from roots (Fig. 2F) and near-intense soluble silica leaching. As a result, the oxisol is the regional modern *in situ* pedogenesis product in equilibrium with the profile 2 landscape, which promotes Al₂O₃ accumulation and bauxite formation. The oxisol and the lateritic duricrust represent and sustain the regional planation surface of the complex geological, geomorphological, and pedological stepped regolith scenario of the Brazilian Midwest tropical environment. The less extensive lateritic duricrust outcrops on the southwest part of the study area (Fig. 1) maybe was underestimated in consequence of oxisol cover.

5. CONCLUSIONS

Lateritic profiles were formed in the Midwest Brazilian as a result of the tropical weathering of metasedimentary and sedimentary rocks that were 500 km apart. However, the study identified differences between the two profiles, while profile 1, on a deformed metasedimentary phyllite rock, developed a more complex mottled horizon and lateritic duricrust textures, profile 2, on sedimentary rocks, has a thick gibbsite-kaolinite oxisol on the top of the lateritic duricrust. Different geochemical features are also recorded by the parent rock across the profiles. The weathering process resulted in the leaching of SiO₂, MgO, K₂O, CaO, Na₂O, Ba, and Rb due primarily to the transformation of quartz, muscovite/illite (profile 1), and microcline (profile 2) to kaolinite, as well as the enrichment of Al₂O₃, Fe₂O₃, As, Cu, Pb, V, and Zn linked to goethite, hematite, and gibbsite. The minerals such as phosphates, zircon, rutile/anatase, cereanite, and muscovite/illite in the parent rock of profile 1 caused the REE fractionation across the profiles. On the other hand, the parent rock signature is maintained by the Nd isotopes along the horizons. The fractionation caused by the Rb-Sr minerals leaching is indicated by the reduced ⁸⁷Sr/⁸⁶Sr ratios up the two profiles. Muscovite in profile 1 controls a more radiogenic signature compared to the microcline in profile 2. Both the raw and clay fractions have similar isotopic ratios excluding grain

size control. The oxisol in profile 2 results from favorable unique surface reorganization under more humid conditions that allowed silica leaching and gibbsite formation. This set of information and the geochemical behaviors are the regional lateritic footprint.

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7. CONCLUSÕES SOBRE A PESQUISA

Os resultados obtidos nesta pesquisa, permitiram até o momento, identificar atuação do intemperismo de forma similar nos dois perfis estudados, além de identificar a origem in situ dos perfis, corroborando as interpretações atribuídas aos sedimentos da Formação Cachoeirinha com produto do intemperismo do arenito da Fm. Botucatu, e além disso relacionar também o latossolo sobreposto.

O Perfil 1 formado por um filito é menos concentrado em minerais pesados em comparação ao perfil 2 o que impactou na menor concentração dos ETR e na mobilidade e empobrecimento maior dos ETRP com o avanço do intemperismo, enquanto os ETRL foram preferencialmente enriquecidos em ambos os perfis. Isso reforça o papel importante que os resistentes têm. Embora o perfil 1 apresente porções haja o predomínio de argilominerais em relação a óxidos-hidróxidos de Fe e Al ambas as partes concentraram de modo similar os ETR.

A menor susceptibilidade ao intemperismo da muscovita permitiu que a assinatura química da rocha mãe, até mesmo dos óxidos maiores, fosse mais preservada nas porções vermelhas ferruginosas comparadas as amarelas sílico-aluminosas, e apesar de apresentar maior razão Rb/Sr e $^{87}\text{Sr}/^{86}\text{Sr}$ isso não afeta as razões Sm/Nd e do $\epsilon_{\text{Nd}(0)}$, corroborando com os estudos que alegam não haver fracionamento dos isótopos de Nd durante o intemperismo e a mobilidade maior dos isótopos de Sr. Além da geoquímica a complexidade textural dos perfis também reflete a natureza da rocha mãe.

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