

Table 1: Summary of the main characteristics of weathering environments, goethite types, and goethite age range.								
Weathering Environment	Locality	Brief description of weathering environment characteristics	Weathering profile stratigraphy	Depth of profiles	Types of goethite	Mineralogical associations	Goethite composition	Goethite age range (Ma)
<i>Lateritized Banded Iron Formation (BIF)</i>	Iron Quadrangle and Carajás Mineral Provinces, Brazil; Hamersley Province, Australia	BIFs are rich in Fe, but poor in U and Th (e.g., Spier et al., 2007). Weathered BIFs are commonly blanketed by an indurated brecciated cap (canga) hosting fragments of BIFs and hypogene hematite-magnetite ore cemented by multiple goethite generations (Door, 1964). Goethite dominates the mineralogy of cangas. In contrast, primary hematite dominates in the lower horizons, where goethite is restricted to veins or local replacement of minor carbonates or silicates (e.g., siderite or grunerite). Iron dissolution-reprecipitation protects the duricrust against physical erosion because broken fragments are quickly recemented and stabilized (Monteiro et al. (2014).	[Top] Duricrust (canga) saprolite (absolute and relative iron enrichment) saprock unweathered BIF [Bottom] (Samama, 1986)	10s -100s of meters	colloform, massive, pisolithic, biogenic	Gth + Hem + Mag; Gth + Hem + Gbs	pure Gth, Al-gth, Ti-gth	~ 290 Ma to < 1 Ma
<i>Channel iron deposit (CID)</i>	Hamersley Province, Australia	CIDs are a unique iron mineral occurrence of great economic significance (Ramanaidou et al., 2003 and references therein). During the Cenozoic, broad meandering rivers carved the BIF landscape in Western Australia. Erosion events in the late Eocene resulted in the production and delivery of sediments into these meandering rivers, aggrading the channels (Heim et al., 2006; Vasconcelos et al., 2013). The mixture of iron-bearing minerals, interstitial water, and organic matter created the conditions for widespread iron dissolution-reprecipitation, cementing and Fe-metasomatizing the fluvial sediments producing massive beds of pisolithic goethites, now iron ore.	[Top] clays and CID units capped by calcrete or silcrete clast-supported conglomerate composed of rock fragments, ooids and psoids of goethite-hematite, wood fragments cemented by goethite (CID) BIF, metabasalts or metasediments, basal conglomerate and clay units [Bottom]	< 1m - 100 m	colloform, massive, pore-filling, pisolithic, replacing wood (fine-grained)	Gth + Hem + Kln; Gth + Hol; Gth + Qtz (Opl)	pure Gth, Al-gth, Ti-gth	~ 33 Ma to ~ 5 Ma
<i>Gossans and Lateritized Fe-Cu-Au deposits</i>	Carajás Mineral Province, Brazil; Tibetan Plateau, China	Weathered massive sulfide deposits are another example of supergene systems that offer a wealth of goethite varieties. Gossans are often present, particularly in the weathered zones directly overlying massive sulfide concentrations at depth. Large masses of goethite form throughout the typically thick lateritic profiles.	[Top] clay-rich soils or detrital cover Fe-Al duricrust mottled zone saprolite gradational or sharp transitions into bedrock [Bottom]	10s -100s of meters	colloform, massive, pore-filling, pisolithic	Gth + Hem + Gbs; Gth + Qtz; Gth + Cml; Gth + Cpr	pure Gth, Al-gth, Cu-gth, Mn-gth, P-gth	~ 80 Ma to < 1 Ma
<i>Nickel Laterite</i>	Ravensthorpe, Western Australia	Weathering of dunites, harzburgites, serpentinites, komatiites, some layered mafic intrusions, or nickel sulfide deposits produce nickel laterites. The Ravensthorpe nickel laterite in Western Australia originates from mafic-ultramafic sequences of the Ravensthorpe greenstone belt. The descending oxidizing weathering solutions promoted rapid breakdown of mafic minerals in the protores, and weathering solutions became progressively less acidic with depth (Golightly, 1981).	[Top] Iron or leached siliceous duricrust limonite horizon clay-rich (smectite) horizon saprolite saprock bedrock [Bottom]	up to ~ 90 meters	massive, pore-filling	Gth + Hem + Qtz + Clays	pure Gth, Al-gth, Ni-gth	~ 5 to ~ 1 Ma
<i>Lateritized alkaline-carbonatite complexes</i>	Alto Paranaíba Igneous Province, Brazil	Alkaline-carbonatite complexes (ACC) host a variety of rock types (e.g., glimmerites, phoscorites, carbonatites) and diverse mineralization (Nb, P, REE, Ti, Cu, Ni, etc.). The average concentrations of U and Th in alkaline magmas are 10 and 35 ppm, respectively (Wedepohl, 1978). However, apatite, monazite, and xenotime in alkaline-carbonatite rocks contain hundreds of ppm U and Th, in addition to economic concentrations of other REEs. Goethites resulting from weathering of alkaline-carbonatite rocks show enrichments in U and Th ranging between ~2 to ~50 ppm (e.g., Catalão and Araxá).	[Top] soil duricrust mottled zone saprolite thin saprock bedrock [Bottom]	up to ~120 meters	colloform, massive, pore-filling, pisolithic	Gth + Hem + Qtz + Kln; Gth + Mnz + Qtz + Ap	pure Gth, Al-gth	~ 40 to < 1 Ma
<i>Lateritized basalts and acid to intermediate igneous rocks</i>	Paraná Plateau, Brazil; Guiana Shield, French Guiana, Suriname	The complex texture observed in ferricretes and bauxites formed on igneous precursors arises from the co-existence of different types of oxyhydroxides and clay minerals in crusts, pisoliths, cements, and from the iron metasomatism and pseudomorphic replacement of silicates.	[Top] soil ferricrete bauxite mottled zone saprolite saprock bedrock [Bottom]	10s of meters	colloform, massive, pore-filling, pisolithic	Gth + Hem + Mag + Ilm + Ant + Rt + Gib + Bhm + Kln	pure Gth, Al-gth, Ti-gth	~ 35 to ~2 Ma

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Lateritized continental sediments	South and northeastern Brazilian Coast; Central and southwestern Amazon, Brazil; Central Europe (Switzerland); Western Australia	Deeply weathered continental sediments, often of unknown age, commonly contain both detrital and authigenic iron oxides and hydroxides suitable for (U-Th)/He geochronology. The mobilization and accumulation of iron can be associated with variations of pH-Eh boundary conditions by vertical fluctuation of the water table and the invasion of seawater, the release of organic acid by plants, and microbial activities (Monteiro et al., 2022). Buried paleosols offer a snapshot of the time when rocks exposed at the surface underwent deep weathering under oxidizing conditions.	[Top] goethitic soil pisolitic layer ferricrete mottled zone saprolite saprock [Bottom]	10s of meters	massive, filling, biogenic, pore- pisolithic, Cml	Gth + Hem + Qtz + Kln +	pure Gth, Al-gth	~ 50 to < 1 Ma
Karst	High Atlas, Morocco; Espinhaço Range, Minas Geras, Brazil	Karst environments are formed by the congruent dissolution of rocks – dolostones, quartzites – interacting with surface and subsurface waters over thousands to tens of millions of years. Geological and environmental parameters such as lithology, permeability, degree of fracturing, relief, hydraulic gradient between recharge and discharge areas, and climate control karst development (Samama, 1986). Alkaline conditions and relatively arid climates favor the preservation of old goethites (e.g., Verhaert et al., 2021). Supergene goethites are also present in quartzite karst across the planet (Wray et al., 2017).	[Top] soil mottled duricrust bauxite saprolite saprock bedrock (hematite-phyllite) [Bottom]: weathering profile at the Espinhaço Range, Brazil	10s of meters	colloform, massive, filling, pore-	Gth + Hem + Pyr + Dol; Gth + Kln + Hol; Gth + Hem +	pure Gth, As-gth, Al-gth	~ 93 to ~ 47 Ma (Morocco); ~ 18 to < 1 Ma (Brazil)
Coal deposit	Springsure, Queensland, Australia	Goethite replacing a tree trunk was collected in a coal mine. Total preservation of the tree cells shows minimum compression of the fossilized trunk, suggesting that ferruginization preceded burial and coalification of associated vegetation.	unknown	unknown	replacing wood	Gth + Hem + Pyr	unknown	~ 120 to ~ 90 Ma