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"LAG" A NEW CLASSIFICATION SYSTEM FOR CONCEALED MINERAL EXPLORATION*

S. ALIPOUR**

Department of Geology, University of Urmia, Urmia, I. R. of Iran
Email: alipour_samad@yahoo.com

Abstract – Lag is a general term applied to coarse grained (> 2 mm), hard, but partially weathered rock fragments, which are concentrated at the surface through attrition of finer materials. Based on morphology, mineralogy and the origin of lag from the Cobar region of Australia, lag may be conveniently grouped into three broad morpho-mineralogical categories; (a) those with a rough, blocky, lithic morphology where fabrics of the parent rock are partially preserved and which evolved predominantly in erosional landforms, (b) a smoother pisoid lag, with a well-developed varnish or polished surface, which is most abundant in deeply weathered, erosional and depositional landforms, and (c) a detrital lag evolving in a range of situations and which is generally more abundant in Quaternary modern drainage landforms. Based on chemistry and magnetic character**,** two distinct types of magnetic and non-magnetic lag are readily recognised. The magnetic type may include both pisoid and occasionally lithic and ferrolithic pregnant with maghemite. Analysis for various trace elements indicates a drastic difference in their chemistry and anomaly detection ability. Magnetic lags contain anomalous Fe, Pb and other heavy metals, while lithics were enriched Cu, Zn and Mn. Spatially, magnetic lag have broader distribution compared to the lithic fraction, which is concentrated close to its original source. These unique characters of lag, revealing weak anomalies in covered surfaces and its abundance in relation to the erosional and depositional landforms, make them a preferred sampling media in geochemical exploration. The chemical data suggest that the magnetic lag fraction is more useful in reconnaissance exploration, and non-magnetics for follow-up work to locate mineralisation, which may justify partitioning a lag sample prior to analysis.

Keywords – Lag, lag classification, geochemical exploration, concealed deposits

1. INTRODUCTION

In the arid and semi-arid regions of the world, a long history of deep weathering of bedrock, lateritization and varying degrees of transported overburden may result in zones of significant mineralization, but exhibit only a subtle geochemical expression at the surface. The reliability of geochemical surveys is therefore heavily dependent upon a clear understanding of physical and chemical characters of surface material including lag, local landform systems and their effect on metal dispersion.

"Lag" is defined [1, 2] as a general term applied to coarse grained (> 2 mm), hard, but partially weathered rock fragments, which are concentrated at the surface through attrition of finer materials (Figs. 1 and 2). Lag investigations have demonstrated that lag, unlike soils, is more remnant of the original profile, especially non-magnetic lithic and ferrolithic types [3-7].

In previous studies incorporating lag or related materials, the evolution of lag has not been considered and lag morphology has not been related to landform and the underlying weathered profile. Classification

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[**] Corresponding author

is not easily performed in the field. Magnetic lag, despite forming a major proportion of coarse surface material, is commonly ignored as a sampling media.

The main objective of this paper is to present a new simple classification of the lag based on new genetic studies in relation to the landforms, easily applicable in the field, with strong relation to metal sources, and capable of anomaly detection in the exploration of concealed deposits.

Fig. 1. Typical pea-size lag, concentrated in the DI geomorphic units

Fig. 2. Typical pea-size lag, concentrated in the DI geomorphic units

2. PREVIOUS STUDIES

The term "lag" was first used in reference to geochemical sampling media consisting of the 2-6 mm fraction of surface materials in Australia [8]. The use of coarse fragments of lateritic capping and bulk pisolitic laterite clasts, is suggested as an appropriate sampling media due to the tendency for As, Cu, V, Mo, Sn, and Nb to accumulate in this material [9-11]. The capacity of lag and equivalent materials termed “pea gravels” [12] to delineate deeply buried mineralization has already been demonstrated around gold deposits in Western Australia [13, 14].

The coarse ferricretes (1.18-2.12 mm) in eastern Australia displayed a more extensive Pb anomaly than the finer stream sediment fraction downstream of the Elura Pb-Zn-Ag mine [15]. Magnetic pisolites and nodules (5-20 mm) indicated elevated Fe, Cr, V, Pb, AS, W, Sb, Bi, and Zn, whereas the non-magnetic division was enriched in Au Al, Si, Cu, Ag, and Ni [13].

A primary classification of ferruginous surface materials [16-21] has identified four basic types of ferruginized surface grains: homogeneous (no internal fabrics), lithorelics (grains with relict primary fabrics and minerals), pseudomorphic (preservation of primary fabrics in secondary minerals) and concentric (presence of multiple rinds), [22-25]. Geochemical comparison [3-5, 7] indicates substantial differences in geochemical patterns and from an exploration point of view, as it provides more reliable sampling media compared to the other conventional sampling materials.

3. METHODOLOGY

Based on fieldwork in the Cobar region of New South Wales (NSW), Australia, a simplified landform scheme recognizing four fundamental landform types, consisting of three erosional and one depositional unit was modified in this study [26] (Fig. 3 and Table 1). These units include DB (Figs. 4 and 5), DP (Fig. 6), DI (Figs1, 2 and 7) and QA (Fig. 8), and can be related to the weathered profile, topography and lag type to facilitate data processing and anomaly detection. On the basis of the examination of lag samples and chemical analysis in this study, together with polished lag slabs, thin and polished sections taken from mineral prospects, a detailed classification of lag has been achieved.

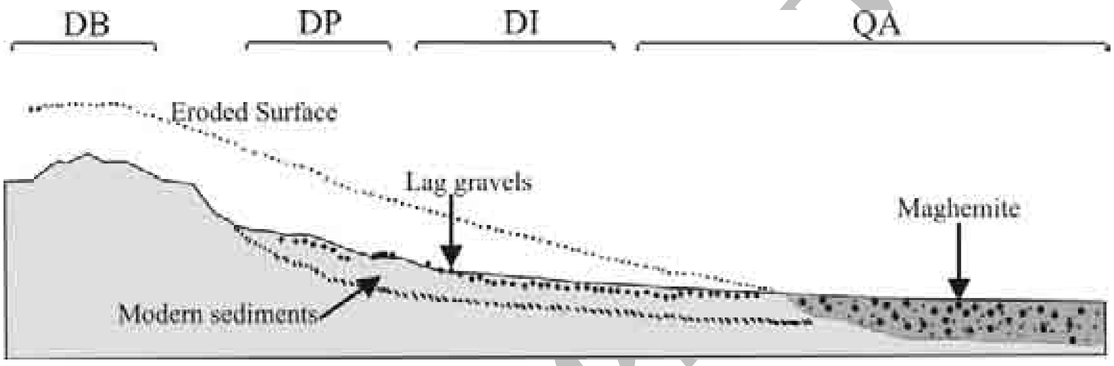


Fig. 3. Schematic classification of landform geomorphological classification units in erosional and epositional environments of surface sediments (after Senior, 1992)

Table 1. Erosional and Depositional landform

Erosional Landforms	
DB Unit	Areas of partially weathered outcrop or high relief sub-crop with minimal overburden grading to gently undulating domains, typified by ridges of coarse pebbly conglomerates and sandstone of Devonian age which display precursor fabric due to silicification.
DP Unit	A Pediment environment with deeper weathering than DB unit associated with undulating rises, dome-like landforms and up to 1m of residual alluvial and colluvial soils. Substantial amounts of lithic fragments with scattered, exotic quartz and patchy veneers of maghemite may be observed.
DI Unit	Very gentle sloping to undulating pediment environment. Up to 2m of soil cover containing similar components to that of DP with sporadic saprolite outcrop and local relief of only a few cm. This unit is more widespread and displays a larger proportion of magnetic fragments
Depositional Landforms	
QA Unit	Mostly are composed of alluvial materials, with near horizontal deposition. Lags are dominated by small rounded pisoid clasts. The QA units conform to the annular modern drainage system. Minimal amounts of lag occur at surface with elevated maghemite contents at depth.

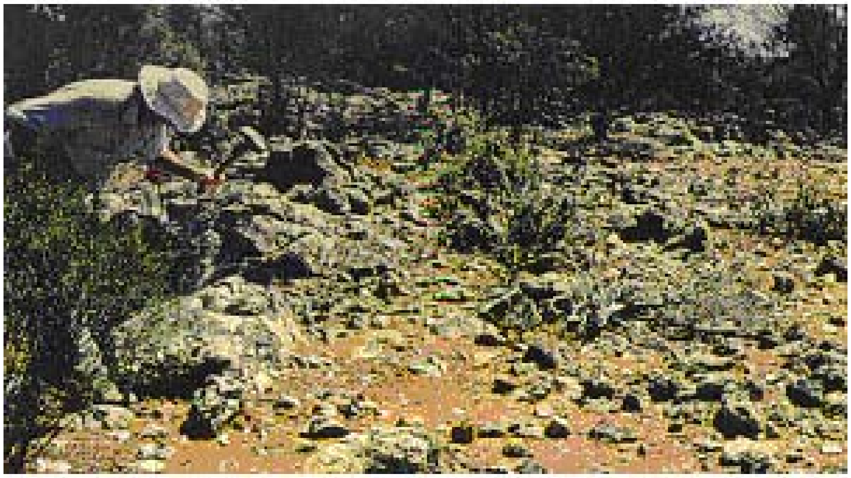


Fig. 4. Weathered lithic sandstone lag, typical of DB Environment with less polish and weakly rounded

Fig. 5. Weathered lithic sandstone lag, typical of DB environment
less polished and rounded associated with extensive quartz veins

Fig. 6. Weathered lithic siltstone lag, typical of DP environment with less polish and rounded

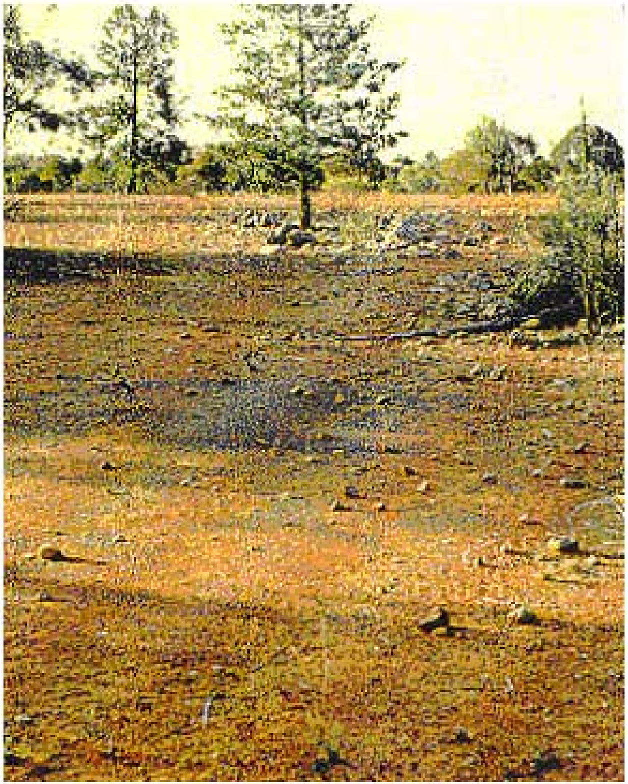


Fig. 7. Gently sloping DI environment covering an extensive area for sampling

Fig. 8. Example of QA environment of a modern drain displaying buried lags uncovered by recent erosion

4. LAG MORPHOLOGY

I. RIMS

Rims are defined here as the accretionary or degraded crusts consisting of single or multiple, concentric, laminated bands, separated from the core of the lag by a distinct boundary. Rims may be formed around lags, due to mineralogical degradation or cyclic precipitation (Figs. 9, 10 and 11) of shells in nodular bauxite [27], Fe-crusts in ferricretes [28], cutans (incomplete, thin bands) and concentric-multiple rinds [16, 19, 25, 7]. Rims surrounding lag clasts display morphologies ranging from thin simple (Figs. 5 and 6) to complex and multiple-bands (Figs. 9 and 10) with incorporated fragments (Fig. 12). Three rim types were classified based on polished sections and SEM studies:

Fig. 9. A well-rounded, complex magnetic, massive pisoid lag, with concentric rim partially eroded away (field of view is 3.5 mm)

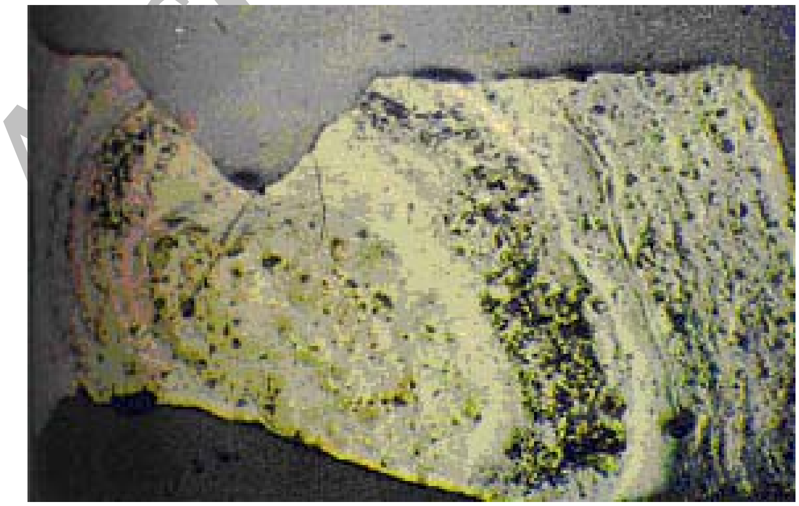


Fig. 10. A well rounded, non-magnetic massive, concentric multiple rim broken down by criss cross cracks (field of view is 3.5 mm)

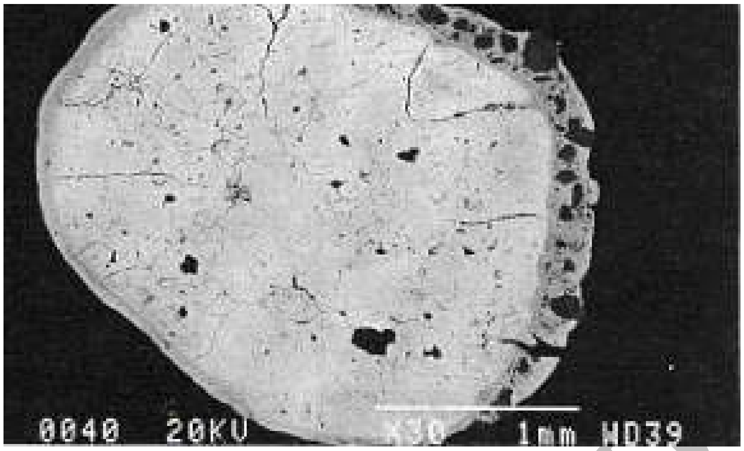


Fig. 11. A well-rounded, magnetic massive lag with an asymmetrical simple rim development (field of view is 3.5 mm)

Fig. 12. A well-rounded, magnetic massive, single rim lag displaying incorporated fragment in the core area. (field of view is 3.5 mm)

a) Single Rims

This type is usually composed of maghemite, hematite and/or goethite skin (Figs. 11 and 13). Maghemite rims were exclusive to the magnetic lag, hematite in both magnetic and non-magnetic lag and goethite, generally restricted to non-magnetic lag. The colour of rim varies according to the dominant Fe-oxide mineral present; deep brown for maghemite, red or reddish brown for hematite and yellowish for goethite. In magnetic lag and in the more ferruginous non-magnetic lag, a well-developed varnish exists on the rim surfaces. The single rim may cover the whole lag (Fig. 14) or may be partially eroded (Figs. 11 and 13) or not formed, depending on the environment (Fig. 12).

SEM and microprobe analysis of rims and ferruginized surfaces of rocks from the Antarctic [29] indicated the composition include Fe-oxides, kaolinite and quartz, with significant Al-substitution and Mn depletion in goethite rims with elevated levels of Ti and K. Single or incomplete rims are more commonly observed in lags from DP and DI landforms associated with non-magnetic or weakly magnetized lag (Fig. 15), and were rare in the DB unit.

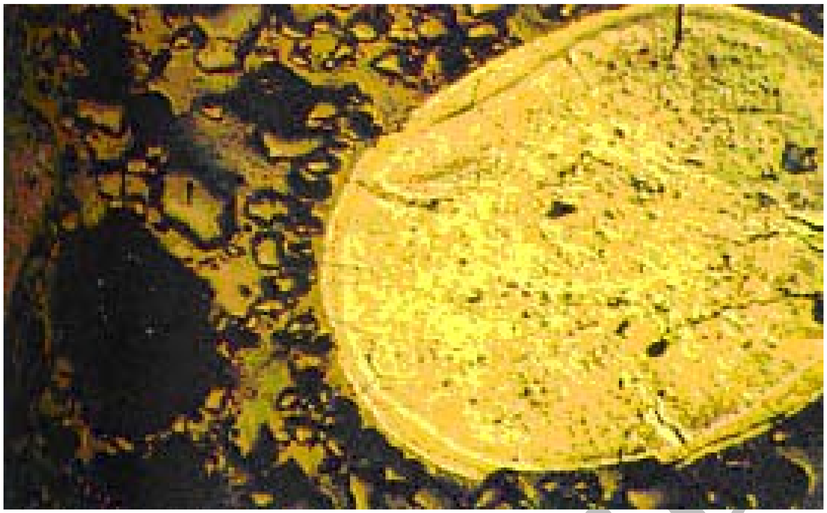


Fig. 13. A well-rounded, magnetic massive lag with a symmetrical simple rim development (field of view is 3.5 mm)

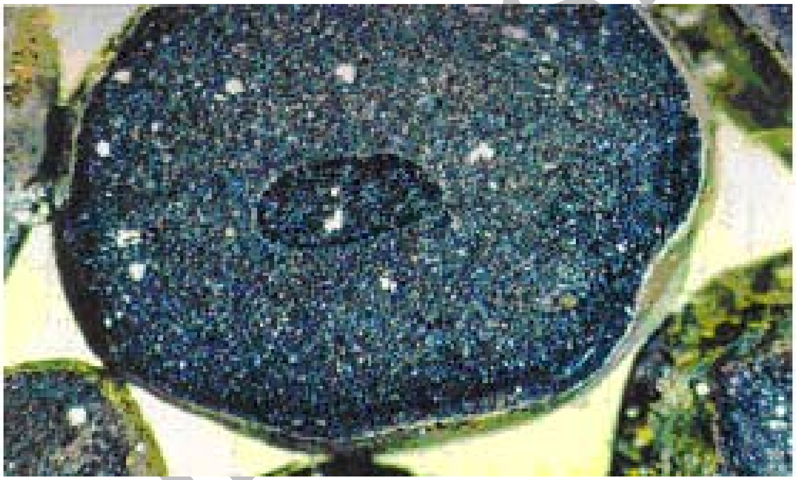


Fig. 14. A thin, single rim developed around a large, magnetic quartz-rich core. Covering the whole lag (field of view is 3.5 mm)

Fig. 15. Simple rim covered non-ferruginized-magnetic primary lags (light color) and ferruginized lag (dark color). Note the rough, non-polished lag surface and lithic texture (field of view is 10 cm)

b) Concentric Rims

This type of rim is composed of circular or ellipsoidal, single or multiple concentric bands around a core of primary (Fig. 10) or secondary indurated colluvial lag (Figs. 9 and 10). Generally 2-5 bands were more common in a lag range of between 0.5 mm- 6 mm in thickness. Such rims are generally composed of highly ferruginized clays, hematite, maghemite, goethite and quartz resulting in light and dark bands or irregular zones. Dehydration cycles result in the cracking of concentric rim, both crossing the bands and along the bands (Figs. 9 and 10). Concentric rims are more commonly observed in clasts from DI and QA geomorphic units, associated with highly ferruginized magnetic lag, and were almost unseen in the DB unit.

c) Complex Rims

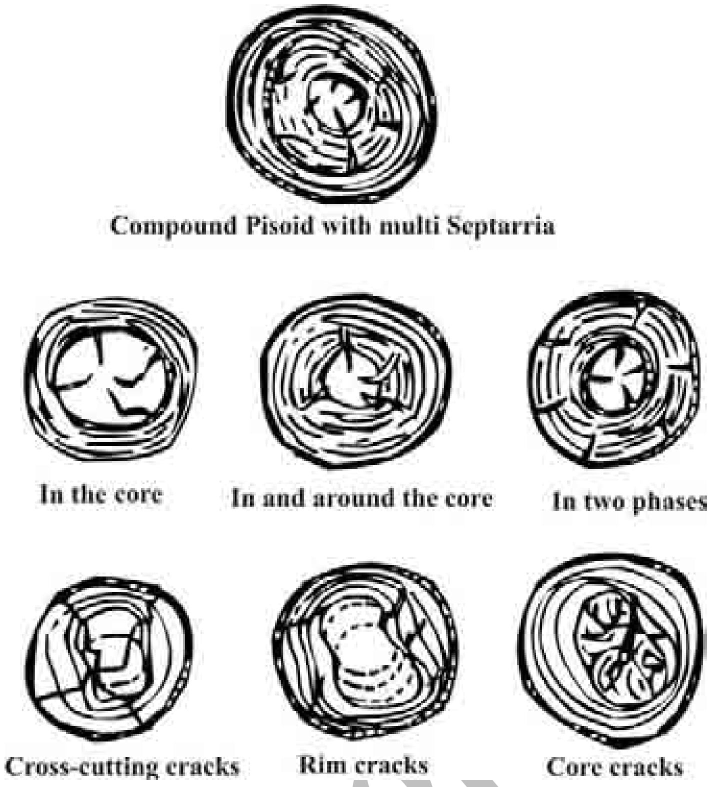
This type of rim is composed of discontinuous, alternating, single or multiple discordant bands of varying thickness and composition (Fig. 16). Bands were crossing each other in various angles and with directions ranging between 5 -70°. The fabrics suggest the formation of this type of rim in alternating erosional and depositional environments. Reprecipitation or formation of new rims after partial fragmentation of older rims also results in the formation of complex rims. This type of rim is formed in both magnetic and non-magnetic lags, but is more common in the magnetic lag of DI landforms.

Fig. 16. Rim cracks developed in a concentrically complex rimmed lag around a quartz rich, magnetic simple pisoid lag (field of view is 3.5 mm)

II. Lag Septaria (lag Cracks)

Septaria are the system of internal cracks developed in materials such as lateritic material or lag [17], (Fig. 17). Cracks are well developed in both core (Figs. 11, 18 and 19) and rim areas (Figs. 9 and 12) and along the boundary of the lag (Fig. 13). Replacement of hematite or goethite along fractures in the rim or core of lag are commonly observed, as they are more susceptible to dehydration and volume loss (Figs. 9, 16 and 18).

The lags display primary fabrics, or with higher sand proportions, contain no cracks or very weak cracking (Figs. 11 and 13), due to siliceous, and are resistant to volume loss. Pisoid may contain cracks up to 5% of their volume, with a generally higher proportion in the core, compared to the rim of lags (Fig. 18). They display different morphology including wavy, straight, curly, dendritic, circular (around the lag), and radial. Crack development in general, results in exhumation and breaking down of coarse lag to finer lag fractions. Overall, three main crack types were identified:



Compound Pisoid with multi Septarria

In the core

In and around the core

In two phases

Cross-cutting cracks

Rim cracks

Core cracks

Fig. 17. Schematic representation of some types of septaria observed in lag (after Boulange, 1984)

Fig. 18. Core cracks developed in a primary siltstone fabric and filled by Fe-oxides in a magnatic lag (field of view is 3.5 mm)

a) Rim Cracks

This type of crack is developed in the lag rims and does not extend to the core (Figs. 9 and 13). As for the core cracks, this type of crack may be totally or partially filled by reprecipitated Fe-oxides, clays or carbonates and dolomites. A large proportion of the rim cracks were open, implying recent cracking of the rims. Some cracks have formed parallel to laminations, but in general, cracks that cross the laminations are prominent (Figs. 12 and 13).

b) Core Cracks

These cracks are mainly developed in the inner, massive core of composite lag and indicate the younger rims have not been subject to dehydration processes (Figs. 11, 18 and 19). The crack morphology varies from radial, concentric, roughly parallel to irregular, and generally filled by reprecipitated Fe-oxides and dolomite. Core cracks were well developed in areas with higher amounts of clay and iron oxides (Fig. 19), but not well developed in clasts dominated by quartz and silicified grains (Figs. 14 and 20).

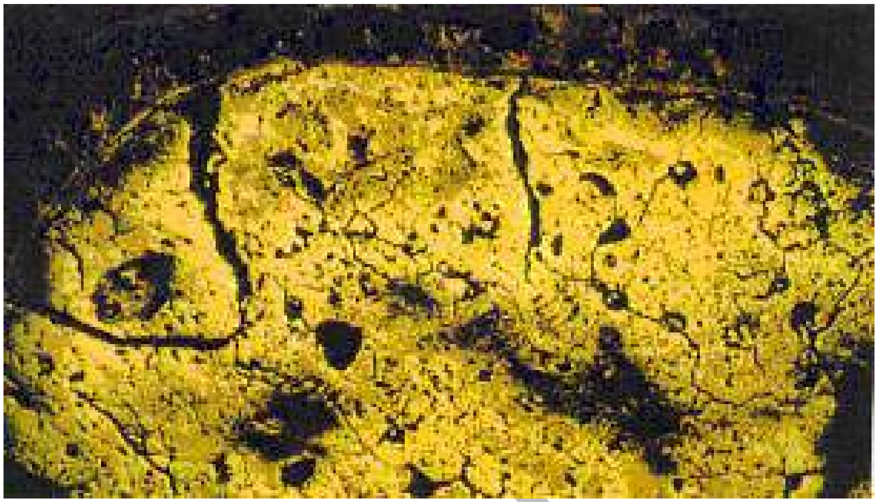


Fig. 19. Simple massive pisoid lag, in which the massive maghemite core contains prominent radial cracks (field of view is 3.5 mm)

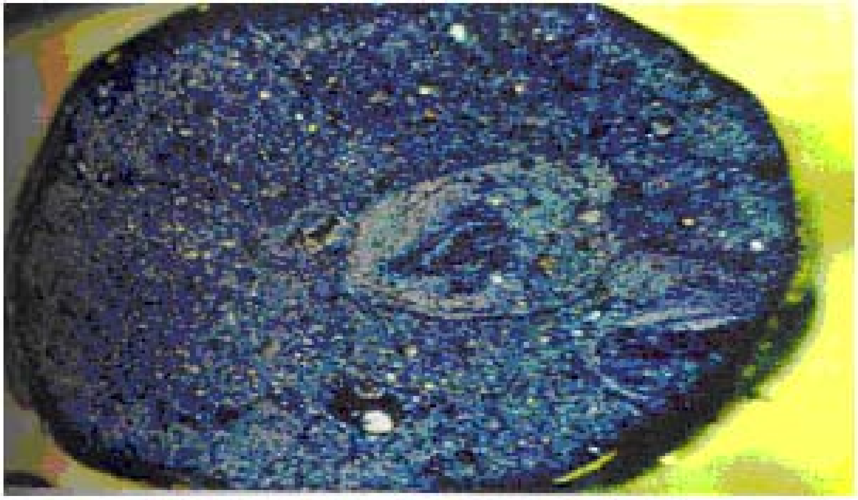


Fig. 20. Magnetic simple pisoid lag dominated by quartz grains preventing septaria development in the core (field of view is 3.5 mm)

c) Cross-Cutting Cracks

This type of crack develops across the entire grains (rims and cores). It is indicative of rim formation prior to commencement of core dehydration, followed by general dehydration within the particle (Figs. 10 and 169). Morphologically they are straighter (Fig. 10) and radial to irregular (Fig. 12), indicative of a more complex history of septaria development. This type may lead to the free-flow of fluids within the lag, resulting in both dissolution and reprecipitation of Fe-oxides (Fig. 12) and may affect the trace element composition in lag.

5. LAG CLASSIFICATION

I. Petrological Classification

The petrological and internal textures of lag, saprolite and rocks indicate that parent material and a variety of secondary processes influence the mineralogy and morphology of the lag. The following classification is based on petrology and mineralogy of parent rock types.

a) Weathered Siltstone Lag

Lag clasts with internal fabrics, mineralogy and the presence of closely spaced foliation similar to typical siltstones occur throughout the study region (Figs. 15 and 6). XRD analysis indicates kaolinite and iron oxides form the dominant minerals, but quartz, sericite, hematite, goethite and maghemite commonly dominate the lags with yellow to brown and red colours (Figs. 6 and 15). Silty lags were generally elongated to platy within the DP and DB units, but were far more rounded in the DI and QA units and highly varnished, accompanied by the presence of a rim of variable thickness (Figs. 6 and 15).

b) Weathered Sandstone Lag

Morphologically they are mainly irregular, rough surfaced, and less polished with a greater degree of rounding in finer-grained clasts (Figs. 4 and 5). Quartz occurs as a primary and secondary mineral with kaolinite cements replaced by iron oxide as dominant minerals. The lithic and ferrolithic lag are texturally similar to the fresh, unweathered sandstone forming the resistant sandy ridges in the region (Fig. 5), suggesting a very close relationship with or derivation from sandstone bedrock. Genetically some quartz rich lag appears to be formed by the cementation of loose quartz, maghemite or hematite.

c) Quartz lag

Quartz lag includes a small portion of the non-magnetic lag. They are well-rounded, suggesting significant fluvial transport and derivation from weakly weathered lithologies (Fig. 21).

d) Calcrete (Dolcrete) Lag

Calcrete and dolcrete lags with rounded, nodular or fractured morphologies are commonly abundant in arid and semiarid regions (Fig. 22). Secondary carbonates are also present in ferruginous lag clasts; in-filling cracks and fractures, alone or in association with goethite and hematite.

e) Silcrete lag

Silcrete is a minor component (< 1%) of lag. Two types of silcrete lag are recognized. The first is an irregularly shaped, silcrete set in an amorphous or finely crystalline quartz groundmass. The second is yellowish-brown with smooth, cuspate surfaces and sub-conchoidal fractures. Occasionally brecciated fabrics remained from the older stream beds (Figs. 15 and 23).

Fig. 21. Well-rounded, fractured, coarse-grained quartz lags, displaying extensive transportation

Fig. 22. Coarse calcret exposed at drainage bed, which later on results in the formation of calcret lag following the weathering in the arid environment

Fig. 23. Moderately rounded silcrete lags with smooth cuspate surface and brecciate fabrics in some lags (field of view is 10 cm)

II. Morphological Classification

Based on the studied morphology, interpretation of relict lithic fabrics, Fe-oxide textures and chemical composition, three major categories of lag are recognized.

a) Lithic lag

Lag of this category are blocky, have a rough surface and display the fabric of the parent material, including bedding, stylolites, sutured grain boundaries, cleavages and cross-cutting quartz veins. They are presumably derived directly from outcropping sedimentary bedrock (Figs. 4 and 15), and range from grey to yellow in colour with less than 20% Fe oxides.

b) Ferrolithic lag

Lag are dominated by more than 20% Fe-oxides (mainly maghemite and hematite), and clays with little or no discernible primary lithological fabric (Figs. 11, 13, 14 and 20). Their colour varies from red to dark brown, depending on the degree of ferruginization (Figs. 4, 6 and 15). Morphologically they occur in two main types; as simple (Figs. 14 and 18) and complex massive lag (Figs. 9 and 13). Both types normally have polish or varnish forming a distinct dark brown skin of maghemite or hematite up to 1 mm thick, irrespective of grain shape and size. Parental fabrics are not preserved and are replaced by massive interlocking grains of hematite, maghemite, quartz and kaolinite. Core in massive lag is generally composed of silty or fine clay materials in both magnetic and non-magnetic lag. Maghemite appear to be the main core Fe-oxide composition in magnetic massive lag, whereas hematite is the only iron-oxide in the core of the non-magnetic one. Massive lag clasts normally are bounded by a concentric or a complex system of rim from single to multiple (3-5) bands and the thickness from μm to mm fractions.

c) Pisoid Lag

True pisolites are generally secondary concretions of Fe-oxides with minimal amounts of inclusions of sand particles or weathered lithic fragments [30]. The rounded ferruginous lags in the Cobar region are somewhat different, typically composed of ferruginized, cemented silt or sand size or lithic fragments with quartz and polished or varnished veneer. The term "pisoid" has therefore been used for this type of lag (Figs. 24 and 25), despite differences in internal morphology. This category includes Fe-oxide rich lag with only a subtle trace of primary rock fabrics and a well-developed surface polish or varnish. Individual clasts are dark colored (red or very dark brown), with a polished smooth surface. Rims vary in thickness from less than 20 μm to more than 1 mm and may comprise up to 60% of a clast. On the basis of the core structure of the pisoids, two sub-categories are classified:

Fig. 24. SEM image of a secondary, well rounded and ferruginized pisoid lag (as seen in the Pictures 1 and 2 at surface),in DI geomorphic unit (field of view is 5mm)

Fig. 25. Pisoid type magnetic (maghematized) lag with highly polished and varnished surface, from surface above the sample site in picture 21(attracted by a hand magnet)

d) Simple Pisoid Lag

This type contains a single polished clast with or without a distinct rim (Figs. 16 and 20). At one end of the range are massive hematite, maghemite and goethite with sparse, silt-sized quartz grains. At the other end of the range of simple pisoid lag are cores with a matrix of variably crystalline hematite, goethite and maghemite between silt and sand-sized quartz grains.

e) Composite Pisoid Lag

This sub-category includes lag composed of two or more clasts with a silty or sandy matrix or colloform hematite (Figs. 9, 26, 27 and 28). Individual clasts display textures ranging from poorly preserved lithic clasts to simple pisoids associated with cross-cutting veins and patches of crystalline hematite. In general, a complex array of cracks with partial replacement of the rims by maghemite is developed. The cores of both types generally occupy more than 80% of the total lag volume.

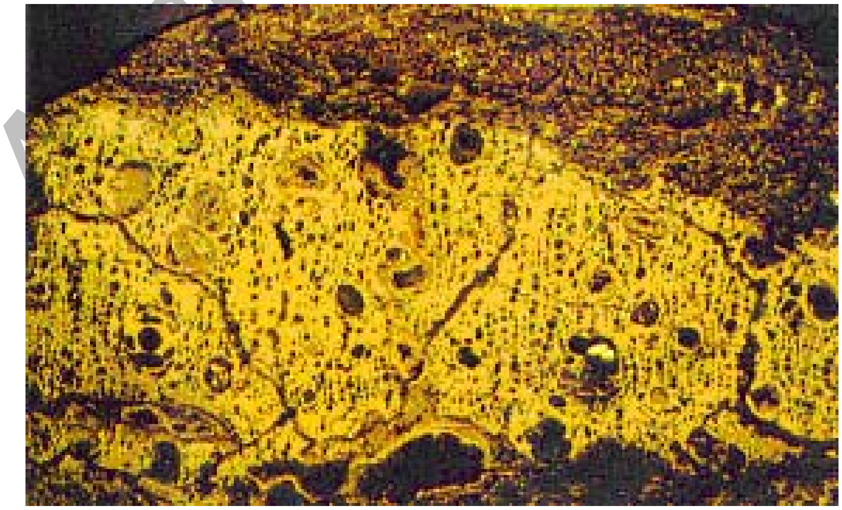


Fig. 26. A well rounded non-magnetic, complex pisoid lag with a patchy rim fabric and a core of fossilized wood (Iron- oxide replacement) with cellular structure (field of view is 3.5 mm)

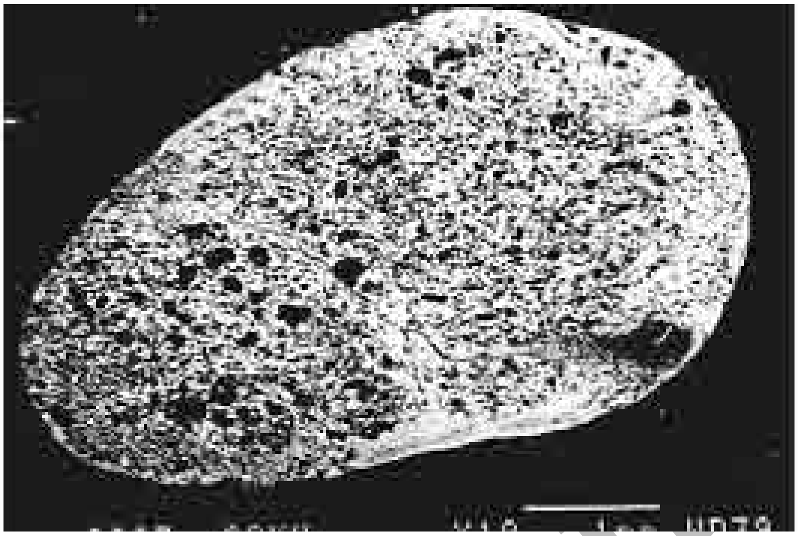


Fig. 27. A well rounded magnetic, complex pisoid lag with sporadic maghemite- hematite, occupied two core clasts cemented together along a crack (field of view is 3.5 mm)

Fig. 28. An ellipsoidal multi stage rim, complex and secondary pisoid lag formed over a widely varying time periods (field of view is 3.5 mm)

f) Detrital (Non-ferruginous Lag)

This is a miscellaneous category of lag including clasts without discernible lithic fabrics. The several sub-categories recognized include vein quartz, silcrete, and calcrete as explained previously.

III. Textural Classification

Based on the texture and original lithologies, lag may be broadly divided into three categories; primary, secondary (pisoid type) and detrital.

a) Primary Lag

The primary lag has a rough, blocky, lithic morphology, which predominantly evolved in erosional landforms (Figs. 4, 5, 6 and 15). The similarity in petrographic and geochemical characteristics to adjacent bedrock and extremely irregular surfaces indicate derivation of this lag type from underlying or adjacent bedrock. Fe content of the margins of original rock clasts oxidize to hydrous Fe-oxides, eventually converting to hematite and promoting further break-up of the blocks. It may display indications of mobilization and reprecipitated Fe oxides during weathering, producing concentric Fe zonation. The final product is a primary lithic and ferrolithic lag.

b) Secondary (Pisoid) Lag

The secondary type includes a smoother pisoid lag, with a well-developed varnish or polished surface (Figs. 16, 18, 19 and 20), suggesting both a secondary origin and subsequent transportation. Two types of pisoid lag are recognized based on internal textures (a) simple pisoid lag; containing a single core of primary or secondary particles, surrounded by single or multiple concentric bands; and (b) composite pisoid lag; which are well rounded, irregularly rimmed, varnished and internally bear a complex texture, structure and septaria [31]. Exhumation and subsequent disaggregation along incipient cracks of rocks with later polishing, forms composite pisoid lags. Similar patterns for the derivation of nodular textures in bauxitic conglomerates have been proposed in the Ivory Coast [17 and 32] and in north Queensland [33].

c) Detrital lag

This type contains no discernible (sedimentary) lithic fabrics, and includes clasts formed from the remnants of vein quartz, silcretes, calcretes and dolcretes derived from topographic inversion. The variation in smoothing and roundness indicates a range of transportation (Figs. 25 and 29), through palaeodrainages. Silcrete and calcrete predominantly occur in DI and QA landforms, whereas vein quartz is more prominent in silicified ridges of the DB and DP erosional landforms.

Fig. 29. pisoid type magnetic (with limonite on surface) lag from 5m. Bellow the surface with diminishing polish and varnish after being buried by humid soil (attracted by a hand magnet)

IV. Magnetic Classification

Independent of the origin and petrology, lag can be divided into two magnetic and non-magnetic fractions, which have a very close genetic relation to the lag evolution. It is also very simple to separate two main categories of this class in the field by using a simple hand magnet.

a) Magnetic lag

A large proportion of pisoid and composite lag rich in maghemite are magnetic (Figs. 21 and 22). Geochemical analysis has indicated that magnetic lags tend to attract anomalous concentrations of Fe, Pb, Ni, Co and other heavy metals. The hematite and goethite have been converted to maghemite, allowing ready separation of lag into magnetic and non-magnetic fractions.

b) Non-Magnetic Lag

Most of the lithic, ferrolithic and detrital lag, including quartz, silcrete and calcrete lags fall in this category (Figs. 4, 6 and 15). Unlike magnetic lags that tend to be enriched in heavy metals, non-magnetics are enriched in Cu, Zn, As, Mn and other base metals.

6. DISCUSSION

I. Lag Mineralogy and Morphology

The morphology of the lags described suggests a complex history of precipitation and distribution of Fe oxides in response to surface conditions. Due to low solubility, Fe^{3+} will precipitate in normal pedogenic environments in arid regions to form amorphous to poorly crystalline, but highly stable goethite (α-FeOOH). Therefore, goethite is generally the most prominent Fe-oxide in weathered soil profiles [34, 35], controlled by temperature, moisture content, pH, organic mater and the amount of Al present [36]. The level of Al substitution affects crystal morphology, stability and dissolution characteristics of hematite [37, 38], and results in the accumulation of goethite in cool and humid regions, but hematite in more arid environments [39, 36], or both in clay fractions, ferricretes and saprolites [9, 40, 41]. Low pH and high Si concentrations increase Al solubility in humid environments and result in more Al substitution, twice as much Al for Fe in goethite [40, 42, 43, 28, 44].

Hematite, goethite and quartz are the most abundant minerals in DB and DP units and contain elevated elements such as Cu Zn and Mn. In the DI unit, maghemite is dominant due to strong ferruginization, transformation of hematite to maghemite and contains a higher level of heavy metals such as Pb, Fe, Co and Ni.

Septaria develops in clay or Fe-oxide rich materials due to volume changes caused by dehydration during alternating wet and dry seasons or climatic variations and water-table fluctuations [32]. Dehydration during the dry season may convert goethite to hematite, resulting in volume changes and leading to septaria development [1]. All cracks may contain colloform hematite and are a locus for subsequent clast dissolution and disaggregation. Core cracks are developed after the formation of lag and before rim formation starts. Rim cracks are likely to be the result of recent dehydration processes started immediately after the present rim formation during a more arid period and could indicate the rims are younger stages of the lag formation. The high proportion of unfilled rim cracks indicates recent formation at surface. Cross-cutting cracks have formed after rim formation stages due to climatological changes.

II. Formation of Lag

X-ray mineralogy indicates that, the magnetic mineral forming magnetic lag is maghemite (γ-Fe_2O_3) not magnetite [3-5]. It is the cubic form of Fe_2O_3 and isostructural with magnetite [45], more common in subtropical and tropical environments, but very rare in cooler humid regions [39, 46, 47, 48, 49 and 50].

The presence of maghemite in oolitic limestone, [51] and oxidic soils of old land surfaces [36, 40 and 47] has also been attributed to aerial oxidation of magnetite, dehydration of lepidocrocite (γ-FeOOH) or goethite [46, 52] and the thermal transformation of Fe-oxides in the presence of organic materials during bush fires (300-800°C) [53]. The conversion of maghemite to hematite and yellow goethite crust at the surface of buried lags has also been observed [3]. XRD analysis of < 2 mm B-horizon soil of the sample sites indicates an absence of maghemite, implying rapid maghemite degradation in the finer fractions of soil or buried lag [3, 54].

The various stages involved in lag formation, lag development and evolution start at places where weathering leach happens and accumulates iron-oxides to form parts of a profile, resulting in profile mottling. The development of the fractures breaks down the permeable lithologies and mottled zones to various sizes of blocks. Precipitation of calcite and dolomite, in radial or concentric fractures forming within the mottled zone, facilitates the liberation of the clast from the top of the weathered profile to the environment. Erosional landforms are covered by coarse lithic and non-magnetics derived locally from bedrock, and depositional landforms are dominated by the pisoid type.

Cyclical wetting and drying of the surfaces of such clasts result in transitions between goethite and hematite, eventually leading to zonation within the outer layers of the clast. Dehydration may cause the core or rim of the clast to crack, depending on the relative proportions of clays, Fe-oxides, quartz, and the time of dehydration. The evolution of such a lag type is common of non-magnetic lag in erosional landforms in the weathered profile.

Lag evolution may also evolve the recementation of weathered material within the overburden, including lithorelics, aeolian, sand and other transported materials. This produces secondary lag with massive fabric, where clay or iron oxides are dominant, and a sandy core with ferruginous rims, where sand is prominent. Formation of cracks and in-fill by Fe-oxides may gradually convert such secondary lags to massive pisoids. The formation of this lag category is more favoured in depositional and intermediate landforms.

Final liberation of clay-coated clasts may convert to the secondary lag types through intense ferruginization and calcrete development [55]. The distinctive polish on the pisoid lag is comparable to the desert varnish on gibber plains [56] and would appear to form near or at the surface.

Although the process of magnetization remains enigmatic, maghemite formation by bushfires [39, 57 and 58] or possibly by chemical reactions may develop in all lag categories. This results in formation of a strongly magnetic pisoid lag in depositional landforms and weaker magnetic ferrolithic and lithic clasts in erosional landforms.

7. CONCLUSIONS

Lithic lag is a remnant of a weathered profile and unlike soil, bears a more lithic texture, more dependent on local parent rocks, and therefore its composition reflects the real nature of covered sources. Magnetic lag is normally secondary in origin and more widespread in the regional scale.

Lag, for its larger size, cannot be transported too far from its source and is related to surrounding landforms. Its composition is more reliable for detecting real covered anomalies, especially in arid regions where aeolian sediments and soil may be much more contaminated.

Lag could easily be employed as a suitable sampling medium for discovering concealed deposits of covered environments such as deserts, forests and even farms. It may be replaced for the conventional -200 mesh ill nature soil samples at these regions.

Rims, wherever formed around lag, reflect the digenetic processes after emplacement in the open environment and may change the geochemical composition.

Septaria may accelerate dehydration and result in volume loss and affect composition in secondary lag compared to primary non-magnetic, which are silicified and less susceptible to dehydration and have a more stable composition.

Based on the characters described, lag samples must be differentiated according to the landforms, magnetic characters and the origin of the lag types. Magnetic character could be employed for separating primary and secondary lag from each other, which are in very close harmony with morphological classification. Mixed magnetic and non-magnetic sampling may lead to higher and more exaggerated anomalies for elements such as Pb, Cr, Co and Ni produced by magnetic or more oppressed anomalies produced by non-magnetic lag. Due to broad and wider distribution of the magnetic lag in the field and secondary origin (simple or complex pisoids), it could be easily used as a regional sampling medium.

Magnetic lag is able to delineate regional targets, but to locate the source of deposits; a non-magnetic type must be sampled in the follow-up stages. Mixing magnetic with nonmagnetic lag or sampling nonmagnetic lag at the first sampling stage will result in losing anomalies with weak surface expression. Partitioning magnetic and non-magnetic lag (a magnet even in the field can easily differentiate these two types), therefore, is highly recommended prior to chemical analysis in detecting concealed deposits of arid and non-arid regions.

REFERENCES

1. Balkay, B. & Bardossy, G. Y. (1967). Etude des processus elementaires de la lateritization sur laterites guineennes. *Bull. Hung. Geol. Soc., Budapest, 97*(1) 91-110.
2. Bates & Jackson. (1980). *Glossary of Geology*, second edition. American Geological Institute, Va. 751p.
3. Alipour, S., Cohen, D. R. & Dunlop, A. C. (1995). Characteristics of magnetic and non-magnetic lags in the Cobar Area, N.S.W. *17th International Exploration Geochemical Symposium.* Townsville Abstracts.
4. Alipour, S., Dunlop, A. C. & Cohen, D. R. (1995). Morphology of lag in the Cobar region, NSW, Australia. In: C. F. Pain, M. A. Craig and I. D. Campbell (Eds.), *Australian Regolith Conference '94. Broken Hill* (1). Abstracts.
5. Alipour, S., Dunlop, A. C. & Cohen, D. R. (1995). Morphology of lag in the Cobar region, NSW, Australia. *AGSO J. of Australian Geology and Geophysics, 16*(3), 253-262.
6. Robertson, I. D. M. (1989). Geochemistry, petrology and mineralogy of ferruginous lag overlying the Beasley Creek gold mine, Laverton, WA. *V. 1 and 2 CSIRO division of exploration geoscience, restricted reports 27R.*
7. Robertson, I. D. M. (1995). Interpretation of fabrics in ferruginous lag. *AGSO J. of Australian Geology and Geophysics, 16*(3), 263-270.
8. Carver, R. N., Chenoweth, L .M., Mazzucchelli, R. H., Oates, C. J. & Robbins, T. W. (1987). "Lag"- A geochemical sampling medium for arid regions. In: R. G. Garrett (Ed.), *Geochemical Exploration 1985. J. Geochemical Exploration, 28*, 183-199.
9. Davey, B. G., Russell, J. D. & Wilson, M. J. (1975). Iron oxides and clay minerals and their relation to colours of red and yellow podzolic soils near Sydney, Australia. *Geoderma, 14*, 125-138.
10. Smith, R. E. & Perdrix, J. L. (1983). Pisolitic geochemistry in the Golden Grove massive sulphide district, W. A. *J. Geochem. Explor., 18*, 131-164.
11. Smith, R. E. & Perdrix, J. L. (1982). Pisolitic laterite geochemistry for detecting massive sulphide deposits-as exemplified in the Golden Grove district, Western Australia. in R. E. Smith (Ed.) *Geochemical Exploration in Deeply Weathered Terrane, CSIRO Institute of Energy and Earth Resources, Division of Mineralogy, Floreat Park, W. A.*, 261-285.
12. Sherrington, G. H. & Gatehouse, S. G. (1979). Pea gravels as a guide to mineralization. In: abstract volume for *symposium on weathering in Australia and its implication for mineral exploration*. *Geol. Soc. Aust. (Abstract).*
13. Anand, R. R. & Smith, R. E. (1992). Regolith-landform evolution and geochemical dispersion in lateritic regolith about the Mt. Gibson gold deposits, Western Australia. *Exploration Research News, No. 6*, the CSIRO Division of Exploration Geoscience.
14. Mazzucchelli, R. H. & James, C. H. (1966). Arsenic as a guide to gold mineralization in laterite-covered areas of Western Australia. *Trans. Inst. Min. Metal., London, (Sect. B) Applied Earth Sci., 75*, 285-294.
15. Dunlop, A. C., Atherden, P. R. & Govett, G. J. S. (1983). Lead distribution in drainage channels about the Elura zinc-lead-silver deposit, Cobar, N.S.W., Australia. *J. Geochemical Exploration, 18*, 195-204.
16. Anand, R. R. & Smith, R. E., Innes, J., Churchwood, H. M., Perdix, J. L., & Grunsky, E. C. (1989). Laterite types and associated ferruginous materials, Yilgarn Block, W. A. *CSIRO/AMIRA laterite geochemistry project 240p, Exploration Geoscience Restricted report 60R.*

17. Bardossy, G. Y. & Aleva, G. J. J. (1990). *Lateritic Bauxites*. Elsevier, Amsterdam, 624 p.
18. Bourman, R. P. (1994). Towards distinguishing transported and in situ ferricretes: data from southeastern Australia. In: Pain, M. A. Craig and I. D. Campbell (Eds.), *Australian Regolith Conference* (7-8). Broken Hill, Abstracts.
19. Bourman, R. P., Milnes, A. R. & Oades, J. M. (1987). Investigation of ferricretes and related surficial ferruginous materials in parts of southern and eastern Australia. *Z. Geomorph. suppl. 64*, 1-24.
20. Milnes, A. R., Burman, R. P. & Fitzpatric R. W. (1987). Petrology and mineralogy of laterite in southern Australia and South Africa. *Chemical Geology, 60*, 237-250.
21. Milnes, A. R., Burman, R. P. & Nryhcote, K, H. (1985). Field relationship of ferricretes and weathered zones in southern South Australia: a contribution to' Laterite' studies in Australia. *Australian J. of Soil Res., 23*, 441-65.
22. Anand, R. R. (1995). Genesis and classification of ferruginous materials in the Yilgarn Craton: Implications for mineral exploration. *Explore, newsletter for the Association of exploration Geochemist* (3).
23. Anand, R. R., Smith, R. E. & Robertson, I. D. M. (1994). Classification and origin of laterites and ferruginous regolith materials in the Yilgarn Craton, Western Australia. In: C. F. Pain, M. A. Craig and I. D. Campbell (Eds.), *Australian Regolith Conference*. (2-3). Broken Hill, Abstracts.
24. Butt, C. R. M. & Anand, R. R. (1994). Terminology of deeply weathered regoliths. In: C. F. Pain, M. A. Craig and I. D. Campbell (Eds.), *Australian Regolith Conference* (11). Broken Hill, Abstracts.
25. Jonathan, D. A., Clark, J. R. & Lee, C. (1995). Classification, genesis and evolution of ferruginous surface grains. *AGSO J. Australian Geology and Geophysics, 16*(3), 213-221.
26. Senior, B. (1992). Regolith photogeology of the Cobar/Wrightville area, NSW. *Report to Dominion Mining Ltd*. 16 p.
27. Bardossy, G. Y. (1982). *Karst Bauxites*, Amsterdam, Elsevier, 441 p.
28. Nahon, D., Jancot, C., Karpof, A. M., Paquet, H. & Tardy, Y. (1977). Mineralogy, petrography and structures of iron crust (ferricretes) developed on sandstones in western part of Senegal. *Geoderma, 19*, 263-277.
29. Johnston, J. H. & Cardile, C. M. (1984). The characterization of the iron oxide phase in desert varnish from Antarctica using back scattered conversion electron and X-Ray Mossbauer spectroscopy. *Chemical Geology, 45,* 73-90.
30. Taylor, G. F. & Humphrey, C. (1990). Mineralogy and geochemistry of some regolith samples from about the Elura Mine- an orientation survey, *CSIRO, Division of exploration Geoscience, restricted report 148R*.
31. Bourman, R. P. (1993). Perennial problems in the study of laterite: a review. *Australian J. Earth Sciences, 40(4),* 337-401
32. Boulange, B. (1984). Aluminium in bauxite derived from granite (Ivory Coast): relative and absolute accumulation. *Treveaux de ICSOBA, Zagreb, 13*, 109-116.
33. Tilley, D. B., Morgan, C. M. & Eggleton, T. (1994). The evolution of bauxitic pisolites from Weipa, North Queensland. In: C. F. Pain, M. A. Craig and I. D. Campbell (Eds.), *Australian Regolith Conference* (58). Broken Hill, Abstracts.
34. Schwertmann, U. & Taylor, R. M. (1977). Iron Oxides. In J. B. Dixon, S. B. Weed et. al. (Eds.): *Minerals in Soil Environments. Soil Science Society of America, Madison*, 145-180.
35. Waychunas, G. A. (1991). Crystal chemistry of oxides and oxyhydrides. In: Reviews in Mineralogy, 25, Oxide Minerals: Petrologic and Magnetic significance .Lindsly, D. H. ed., *Mineralogical Society of America, Chesla*, 11-68.
36. Schwertmann, U. (1988b). Occurrences and formation of iron oxides in various pedoenvironments. *In: J. W. Stucki et al,. (Eds.), Iron in Soils and Clay Minerals. D. Reidel, Dordrecht*, 267-308.
37. Eggleton, R. A. (1987). The application of micro-beam methods to iron minerals in soils. In J. W. Stucki et al. (Eds.), *Iron in Soils and Clay Minerals. D. Reidel, Dordrecht*, 165-201.
38. Murad, E. (1987). Properties and behavior of iron oxides as determined by Mossbauer spectroscopy. In J. w.

Stucki et al, (Eds.), *Iron in Soils and Clay Minerals. D. Reidel, Dordrecht,* 309-350.

39. Fitzpatrick, R. W. (1988). Iron compounds as indicat*ors of pedogenic processes: examples from the southern hemisphere. In:* J.W. Stucki et al (Eds)*, Iron in Soils and Clay Minerals*. 351-396.
40. Fitzpatrick, R. W. (1978b). Occurrence and properties of iron and titanium oxides in soils along the eastern seaboard of South Africa. *Ph.D. Dissertation*, University of Natal. P. 211.
41. Taylor, R. M. & Graley, A. M. (1967). The influence of ionic environment on nature of iron oxides in soils. *J. Soil Sci., 18*, 341-348.
42. Schwertmann, U. (1985). The effect of pedogenic environments on iron oxide minerals. Adv. *Soil Sci., 1*, 171-200.
43. Ibanga, I. J., Boul, S. W. Weed, S. B. & Bowen, L. H. (1983). Iron oxides in petroferric materials. *Soil Sci. Soc. Am. J., 47*, 1240-1246.
44. Schwertmann, U. & Kampf. (1983). Oxides de ferro Jonens em ambientes pedogeneticos bracileiros. *Bras. Ci. Solo, 7*, 251-255.
45. Eggleton, R. A. & Fitzpatrick, R. W. (1988). New data and a revised structural model for ferrihydrite. *Clays and Clay Minerals, 36*, 111-124.
46. Bonifas, M. & Legoux, P. (1957). Presence de maghemite massive dans des produs d'alteration lateritique. Bull. Serv. *Carte Geol. Als. -Lor., 10*(7).
47. Coventry, R. J., Taylor, R. M. & Fitzpatrick, R. W. (1983). Pedological significance of the gravels in some red and grey earths of central North Queensland. *Aust. J. Soil Res. 21*, 219-240.
48. Fitzpatrick, R. W. (1974). Mineralo-chemical studies on soils and related material from pedosystem in the southeastern Transvaal. *M. Sc., Agric. Dissertation*, University of Natal. P. 154.
49. Taylor, R. M. & Schwertmann. U. (1974a). Maghemite in soils and its origin; I. Properties and observations on soil maghemites. *Clay Minerals, 10*, 289-298.
50. Taylor, R. M. & Schwertmann, U. (1974b). Maghemite in soils and its origin; II. Maghemite syntheses at ambient temperature and pH 7. *Clay Minerals, 10*, 299-310.
51. Kopp, O. C. & Lee, S. Y. (1987). An unusual occurrence of maghemite in soils developed on dolostones of the Knox Group, Oak Ridge, Tennessee. In: *proceedings for the international clay conference, Denver* (205-211). L. G. Schultz, H. van Olphen and F. A. Mumpton, (Eds.).
52. Schwertmann, U. (1988a). Some properties of soil and synthetic iron oxides. In J.W. Stucki et al. (Eds.), *Iron in Soils and Clay Minerals. D. Reidel, Dordrecht*, 203-250.
53. Walker, J., Raison, R. J. & Khanna, P. K. (1986). Fire, in "Australian Soils: The Human Impact", J. S. Russell and R. F. Isbell (Eds). *University of Queensland Press*, 342-346.
54. Walker, P. J. & Green, S. D. (1978). Soil Conservation Service of New South Wales, *Cobar district technical manua*l. Soil Conservation of New South Wales. 112-119.
55. Williams, M. A. J., De Deckker, P., Adamson, D. A. & Talbot, M. R. (1991). Episodic fluviatile, lacustrine and aeolian sedimentation in a late Quaternary desert margin, central western New South Wales. In: M.A.J. Williams, P., De Deckker, A. P. and Kershaw, (Eds). The Cainozoic in Australia: a reappraisal of the evidence). *Geol. Soc. Aust. Inc. Spec. Publ., 18*, 258-287.
56. Bourman, R. P. & Milnes, A. R. (1985). Gibber plains. *Australian Geographer, 16*, 229-32.
57. Xie, J. J. & Dunlop, A. C. (1993). Geochemical patterns for Zn and associated elements derived from iron oxide dissolution. *World Zinc'93*, Hobart, 302-306.
58. Xie, J. J. & Dunlop, A. C. (1993). Iron oxide dissolution patterns-Implications for geochemical samples containing relict iron oxides. *16th International Geochemical Exploration Symposium* (98-105). Beijing.