

juices exuded by the worm, in this case black. Underneath this, about the centre, are indications of the polygonal areas found anteriorly in *Arenicola*. A few papillæ are present here. Otherwise this specimen is very similar in surface characters to the type, specimen A.

Appendages. There are very few indications of appendages in this specimen, and they are similar in character to those in specimen A, but are only distinct on one side, the left, where they are distant. They are notopodial setæ without a doubt, but though only seen on one side there is no trace of neuropodial crotchets as in specimen A, and they may both therefore be regarded as viewed from the dorsal aspect.

ARCHARENICOLA, NOV. GEN.

An annulated Polychæte, with an impression of the cuticle bearing annuli of two sizes, possibly forming segments. The cuticular surface is covered in the type by epidermal papillæ, in the co-type by polygonal areas between the somites. The appendages are paired, on alternate annuli, consisting of capillary notopodial setæ. The head bears no appendages, but indications of a frilled prostomium. The impression is surrounded by a zone caused by exudations of the juices, as in the present-day *Arenicola*.

ARCHARENICOLA RHÆTICA, SP. NOV. (GENOTYPE).

Characters of the genus, based on specimen A (type) and specimen B (co-type).

Specimen A (Pl. XXI, Fig. 1). Horizon: Lower Rhætic—Black Shales. Locality: Glen Parva, Leicestershire.

Specimen B (Pl. XXI, Fig. 2). Horizon: Lower Rhætic—Black Shales. Locality: ? Spinney Hills, Leicestershire.

Both specimens are deposited in the palæontological collections of Leicester Museum, where they form the third type species of local origin.

I am greatly indebted to the discoverer of the type, Mr. A. J. S. Cannon, for the opportunity of seeing this and other Rhætic fossils of interest, and for much help in other ways. I have to thank Miss G. M. Woodward also for the care which she has taken in preparing the plate.

EXPLANATION OF PLATE XXI.

- FIG. 1. *Archarenicola rhætica*, sp. nov. Specimen A. Lower Rhætic: Glen Parva. Nat. size.
 ,, 2. *Archarenicola rhætica*, sp. nov. Specimen B. Lower Rhætic: ? Spinney Hill, Leicestershire. Nat. size.
 ,, 3, 4. Burrows of *Archarenicola rhætica*, in Black Shale, Glen Parva. Nat. size.

III.—NOTES ON LATERITE IN WESTERN AUSTRALIA.

By EDWARD S. SIMPSON, B.E., F.C.S., Geological Survey of Western Australia.

(Communicated by permission of the Government Geologist of Western Australia.)

THE following notes on the laterites of Western Australia are the outcome of a careful study of the series of articles contributed to the GEOLOGICAL MAGAZINE during the latter part of 1911 by Dr. L. Leigh Fermor, entitled "What is Laterite?" These deal with the

subject from the point of view of one having an intimate knowledge of Indian laterite, but not a first-hand acquaintance with those of other parts of the world. The present writer, during the last fifteen years, has devoted much time to the study of the laterite of extra-tropical Western Australia, both in the field and in the laboratory, and is therefore in a position to supplement some of the work of Dr. Fermor, whilst inclined to differ from him in some of his deductions.

Broadly speaking, the laterite of Western Australia may be divided into two classes—

(1) Primary Laterite (true laterite, high-level laterite), formed in situ out of soluble material derived from the weathering rock immediately underlying it.

(2) Secondary Laterite (laterite, low-level laterite), composed largely of the mechanically transported fragments of primary laterite.

The study of the latter being dependent on and of secondary importance to the study of the former, it is the primary laterites which have been most closely examined, and will be dealt with almost exclusively in this article.

Primary laterite in Western Australia, and probably elsewhere, is a product of normal processes of weathering, accompanied by abnormal conditions of rainfall and denudation. It is not necessarily confined to tropical areas: immense deposits in this State are extra-tropical. It is simply confined to areas underlain by suitable rocks, and subject to all three of the favourable conditions just mentioned.

By "suitable rocks" is meant rocks composed largely or wholly of metallic silicates, especially in this State, granite and greenstones of common types, as well as amphibolites, epidiorites, chlorite-schists, and other similar rocks.

By "normal processes of weathering" is meant the attack of the outcrops of such rocks with rain-water carrying atmospheric carbonic acid, the result being the formation of kaolin (crystalline $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$), halloysite (amorphous $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$), and quartz or hydrous silica, together with solutions of aluminium hydrate, titanium hydrate, ferrous carbonate, calcium carbonate, magnesium carbonate, manganous carbonate, etc.

The abnormal conditions of rainfall tending to produce laterite are such that the weathering rocks and any products are alternately saturated with water and then again completely desiccated.

A slow rate of denudation is essential.

Primary laterite is a true efflorescence, that is, a deposition on the surface of the ground of substances dissolved by underground water, brought to the surface by capillarity, and there deposited as solid matter owing to aeration and evaporation of the water.¹

Primary laterite in Western Australia, wherever sunk through, is found to overlie an almost pure pipeclay, and this in turn a crystalline rock. Dr. Fermor holds kaolinization to be a process incompatible with laterite formation.² In Western Australia the processes are

¹ *Vide* E. S. Simpson, Bull. 6 of the Geol. Surv. of Western Australia, pp. 39, 78, 79. Published 1902.

² GEOL. MAG., 1911, p. 459.

contemporaneous and inseparable from one another. Dr. Fermor writes thus:—

“When a rock breaks down into a *clay* hydrated aluminium silicate is to be regarded as the pure end product, all oxides being removed in solution. When a rock is converted into laterite, on the other hand, the reverse holds; aluminium and other silicates are decomposed, and the silica is removed in solution, presumably in the colloidal form, whilst the oxides of iron, aluminium, titanium, and manganese, which were relatively soluble under the clay-forming conditions, are relatively insoluble under laterite-forming conditions. The oxides of calcium, magnesium, sodium, and potassium are apparently soluble under both sets of conditions. I do not propose to advance here any reasons to account for these two diverse modes of alteration of rocks. . . .”

Such an apparently paradoxical postulate seems to require detailed explanation on the part of the author. Surely Dr. Fermor is putting the cart before the horse when he speaks of the concentrated accumulation of lateritic material as due to the leaching away of the non-lateritic products of weathering. The formation of an ordinary efflorescence of salt on the surface of salty ground, or of an efflorescence of gypsum or potassium vanadate on the surface of a brick are phenomena identical with the formation of laterite, but one does not explain them by saying that in the one case the insoluble sand and clay of the soil is dissolved away, leaving an accumulation of insoluble salt, or that in the other case the baked clay of the brick is dissolved away, leaving an accumulation of gypsum or vanadate of potash.

The same remarks indicate the absurdity of referring to a laterite as a true residual, or as a replacement of a rock, i.e. a deposit accumulating in the actual space originally occupied by the solid rock which has yielded the materials which compose the laterite. The primary laterites of Western Australia are deposited, like other efflorescences, outside the surface of the parent rock. Two typical sections are shown in the accompanying figure (p. 402).

Reverting to the question of the distribution of rainfall favourable to the formation of laterite, the extra-tropical portion of Western Australia may be divided into two provinces. One of these lies within 50 to 100 miles of the western coast, where the average annual rainfall is between 20 and 40 inches, distributed between well-defined wet and dry seasons. Typical laterite localities in this area are Mundaring and Greenbushes, the rainfall of which are—

	Mundaring. Inches.	Greenbushes. Inches.
Average annual rainfall . . .	41	37½
Average November to March . .	2½	3
Average April to October . . .	38½	34½

The other province includes the Eastern Goldfields, and has no defined annual wet and dry seasons. The average rainfall is between 7 and 12 inches, one-quarter of which frequently falls in a single day, the usual intervening climatic conditions being intensely arid. As typical examples, Mulline, with an average of 11·2 inches, had a fall of 3·3 inches on one day in 1907; Coolgardie, with an

average of 9·4 inches, recorded nearly 4 inches in two closely following days of the same month. These are typical, not abnormal, rainfall conditions.

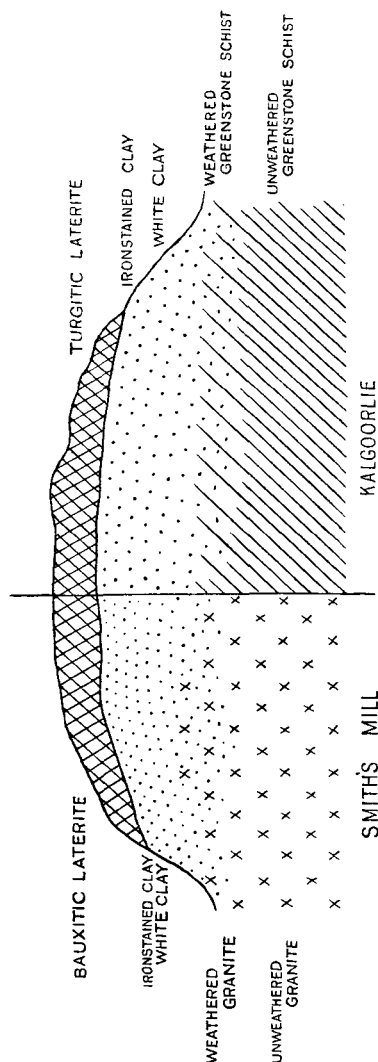


Diagram showing two typical examples of the mode of occurrence of primary laterites in Western Australia.

Although the climatic conditions in these two provinces are so very different, yet the result from the present point of view is identical, viz., short or long periods during which the surface rocks are saturated with meteoric water, alternating with long dry and hot periods, during which they are completely desiccated and the freshly-formed laterite

hardened. Such conditions seem to me to favour, if not indeed to be necessary to, the accumulation of laterite.

It would appear that the accumulation of laterite is a very slow process, and cannot take place where erosion is moderately rapid. It tends, therefore, to grow on well-defined peneplains, such as the 1,000 feet Darling Range peneplain, and on the upper very gentle slopes of valleys, where denudation is slow. Bare rock, clay, sand, and secondary laterite carrying sand and clay are found at lower levels. In Western Australia primary laterite is found chiefly between 500 and 1,500 feet above sea-level. Higher altitudes than 1,500 feet are rare within the extra-tropical parts of the State. They are usually devoid of laterite.

The climatic conditions favouring its formation and preservation having been dealt with, the details of its growth need elucidating. It has already been stated that laterite is an efflorescence resulting from normal weathering, the first stage in the process being the conversion of feldspars into kaolin and the partial saturation of the sub-surface water with carbonates of iron, manganese, lime, and magnesia, with hydrous silica, titania, and alumina, and finally with alkali salts. With the advent of dry weather this solution begins to evaporate at the surface, and as it evaporates further supplies are brought to the surface by capillary action. A slow but appreciable movement of water from below to the surface goes on till the weathered rock is desiccated. Mere contact of this water with the atmosphere is sufficient to precipitate all the iron and manganese as hydrated peroxides, two important laterite constituents. Evaporation increases the speed of this precipitation, and at the same time leads to the precipitation of all the other substances dissolved in the water. Alumina and silica in the proportions Al_2O_3 to 2SiO_2 are co-precipitated as colloidal halloysite (lithomarge of Fermor), $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$. An excess of silica over this proportion seldom if ever occurs in the water, an excess of alumina is precipitated as hydrate, probably primarily as gibbsite, $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$. Titanium is precipitated as metatitanic acid, $\text{TiO}_2 \cdot x\text{H}_2\text{O}$. During the growth of the laterite small amounts of sand and clay become mechanically included.

All the important constituents of laterite are thus accounted for. But in addition to these the evaporating water must have deposited at the same time alkali salts and carbonates and sulphates of lime and magnesia, compounds occurring only in traces in normal primary laterite. The history of the rock is evidently not yet complete. It must be continued over the dry season, during which the typical laterite materials are rendered practically insoluble by consolidation and desiccation, into the succeeding wet season. The soluble alkali, lime, and magnesia salts are then soon taken up by the rain-water and carried off in the streams. The laterite has then reached its final composition.

In structure West Australian laterites are almost always pisolitic, the typical form of an amorphous substance slowly growing by precipitation from solution. The nodules vary in size from that of a pin's head up to about 1 inch in diameter, the average being one-eighth to one-quarter of an inch. The spaces between the nodules

are partly filled with similar material to the nodules, partly unfilled. Rarely (e.g. Lone Hill, Kalgoorlie) some of the more ferruginous laterites are devoid of concretionary structure, whilst still containing numerous visible pores.

The composition of some typical laterites is given in the accompanying table:—

COMPOSITION OF WEST AUSTRALIAN PRIMARY LATERITES.

Locality.	Kalgoorlie. (1)	Kalgoorlie. (2)	Kalgoorlie. (3)	Kalgoorlie. (4)	Coolgardie.	Comet Vale.	Boogardie.	Smith's Mill.	Wongan Hills.	Mt. Baker.	Grosecerry
Fe ₂ O ₃ . .	78·38	75·41	79·41	62·67	80·02	79·01	73·81	10·02	19·08	35·54	3
Al ₂ O ₃ . .	9·92	12·29	5·97	12·76	4·32	?	?	46·70	44·66	31·14	3
Cr ₂ O ₃ . .	0·01	0·05	0·60	0·08	0·08	5·30	?	?	?	?	
V ₂ O ₅ . .	0·40	0·45	0·65	0·15	0·55	?	?	?	?	?	
MnO ₂ . .	0·07	0·41	0·07	0·35	0·13	?	?	?	?	?	
MgO . .	0·35	none	1·56	0·99	trace	?	?	trace	trace	trace	
CaO . .	none	none	none	none	none	?	?	trace	trace	0·16	
TiO ₂ . .	2·01	2·55	3·10	6·00	6·06	?	?	0·59	3·10	4·33	
SiO ₂ , Quartz SiO ₂ , Combined	2·67	1·77	2·52	2·73	$\left\{ \begin{array}{l} 0·76 \\ 1·77 \end{array} \right\}$	3·14	11·46	17·17	5·96	13·74	$\left\{ \begin{array}{l} \\ \end{array} \right\}$
P ₂ O ₅ . .	trace	trace	trace	trace	trace	0·18	0·05	trace	trace	trace	ti
H ₂ O . .	6·00	7·05	6·89	14·46	7·06	?	2·86	25·37	27·02	15·40	14
	99·81	99·98	100·77	100·19	100·75	?	?	99·95	99·82	100·31	10

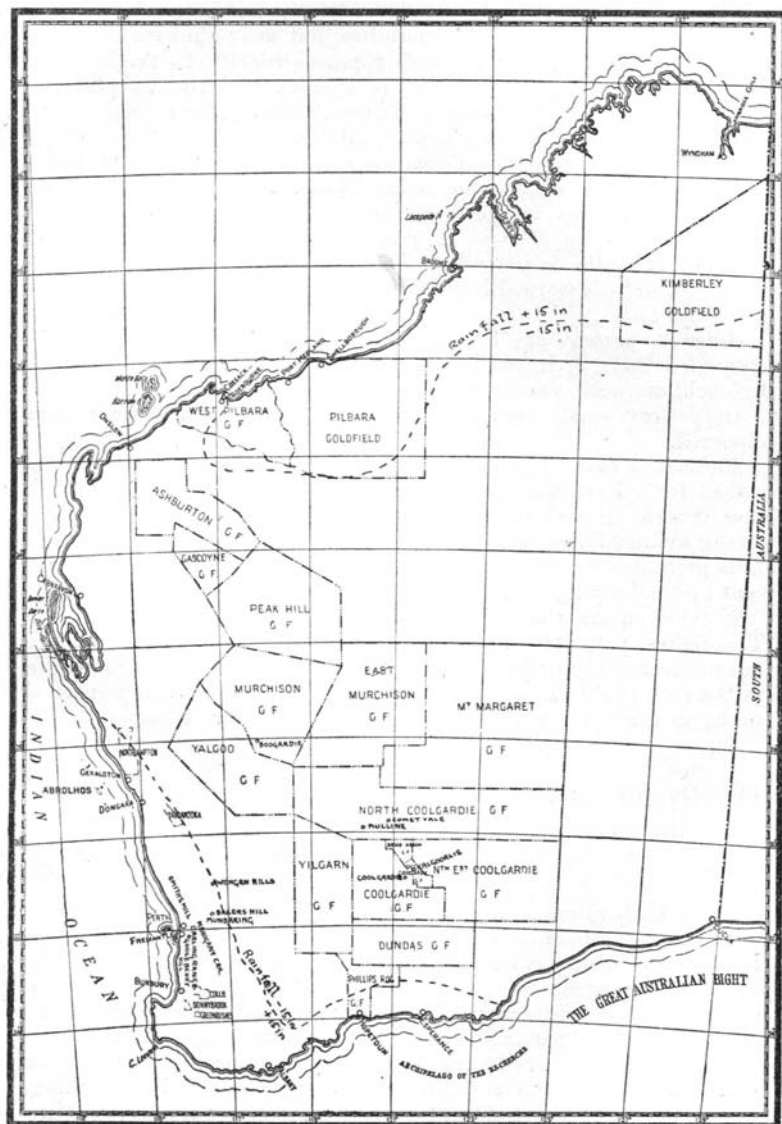
These analyses, though so many of them are incomplete, are an assistance in unravelling the mineral composition of the laterite.

The iron is undoubtedly present as limonite, 2 Fe₂O₃ . 3 H₂O, in many of them, e.g., Kalgoorlie (4), Smith's Mill, and Wongan Hills. Turgite, 2 Fe₂O₃ . H₂O, is, however, just as common, particularly in laterites from the interior, such as Kalgoorlie (1), (2), and (3), and Coolgardie. Its presence, suspected from the results of the analyses, was readily confirmed by the decrepitation of the mineral when heated in a closed tube. Goethite, Fe₂O₃ . H₂O, and hæmatite are probably present at times. Wherever the laterite overlies greenstone an iron hydrate is the predominant constituent.

Solutions of these laterites in a mixture of sulphuric and hydrofluoric acids, prepared in a neutral atmosphere, are invariably capable of reducing potassium permanganate solution, usually in two distinct stages. For example, the Coolgardie laterite quoted above instantaneously reduced permanganate equal to 0·80 per cent of ferrous oxide, and more slowly (about 3 seconds) a further amount equal to 0·54 per cent ferrous oxide. This consumption of permanganate may be due to the presence of ferrous oxide, vanadium trioxide, or organic matter. No definite interpretation is at present possible, but the writer is inclined to consider that it is in small part due to the presence of a little ilmenite or magnetite, but more largely

¹ 1·20 per cent at 105°.

to the presence of organic compounds of iron. In this connexion it is worth noting that a series of small springs flowing out from beneath



Map of Western Australia, showing localities where laterite has been observed, and referred to in Mr. E. S. Simpson's paper.

the laterite at Mundaring gives rise to a stream which, near the laterite, was found (in 1909) to contain ferrous iron (1.32 grains

per gallon) and organic matter, together with insufficient inorganic radicles to satisfy the basic radicles. This water apparently contained organic compounds of iron.

Alumina is present in all the laterites, but most abundant in those overlying granite and other less ferruginous rocks. In the Wongan Hills and Smith's Mill samples it appears to exist as gibbsite, $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, in other cases it is less hydrated, corresponding to bauxite, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$, or diasporite, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$.

Titanium oxide is always present in appreciable amounts, probably in the form of metatitanic acid, $\text{TiO}_2 \cdot x\text{H}_2\text{O}$, for which no mineralogical name has yet been suggested. Experiments on the Coolgardie laterite showed it was not present, except in traces perhaps, as rutile or ilmenite. The titanium compound was found to be insoluble in warm dilute hydrochloric acid but soluble in fuming sulphuric acid.

Silica is present as (1) quartz, or rarely felspar, mechanically entangled, and (2) in combination in a form decomposed by strong hydrochloric acid, probably halloysite.

Only very small percentages of manganese oxide have been observed.

Chromium oxide has been detected in every case where it was looked for. It varied from a trace to 5.30 per cent. In the latter case it was almost wholly present as chromic hydrate, soluble in strong hydrochloric acid. A small proportion was present as chromite. It is probable that where the percentage of Cr_2O_3 rises above 0.1 per cent the underlying rock is of an ultra-basic type.

Notable amounts of vanadium were detected whenever looked for. The highest proportion noted was 0.65 per cent, V_2O_5 (?), in a turgitic laterite from Kalgoorlie. The form in which this constituent occurs in the rock is not yet determined. This is only one of many unsolved problems connected with this deeply interesting formation.

IV.—ON THE ORIGIN OF CERTAIN CLAY-BANDS IN THE LIMESTONE OF THE CRICH INLIER.

By H. C. SARGENT, F.G.S.

Introductory.

IN the Carboniferous Limestone of the Crich inlier in Derbyshire, there are numerous clay-bands or partings interbedded with the limestone which appear to throw considerable light on the geological history of the area.

These clay-bands vary in thickness from about 3 feet down to the thinnest possible parting between two beds of rock. Some of those between the higher beds are undoubtedly contemporaneous detrital sediments¹ and appear to indicate shallow-water conditions; others, though consisting of sedimentary material, were probably deposited along solution planes subsequently to the formation of the limestone;

¹ Many, perhaps all, of the tuffs of Derbyshire are sediments, but, to avoid ambiguity, the use of the word in this paper is confined to detrital deposits, the waste of a land-surface.