

RATIONAL DESCRIPTIVE CLASSIFICATION OF DURICRUSTS

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Abstract

The term *duricrust* appears to be extending itself to include calcareous, gypseous, and saline crusts, in addition to crusts composed dominantly of silica and/or of sesquioxides of iron and aluminium, with or without significant contents of dioxides of manganese or titanium. This latter group can be distinguished as duricrusts proper. Its nomenclature is highly confused, and its classification, in writings in the English language, defective. The relevant problems can be resolved, at least in considerable part, by the introduction, adaptation, and extension of modern terms current in tropical pedology, to give a descriptive classification free of genetic implications. When content of SiO_2 , Al_2O_3 , and Fe_2O_3 is used as a primary basis for the classification of duricrusts proper, plots on a ternary diagram justify the recognition of seven named types in the fersiallitic range.

The nomenclature and classification of duricrusts, as they have developed in English, are undeniably confused. On a far smaller and much less complex scale, the situation resembles that faced by the authors of the 7th Approximation to the comprehensive classification of soils (U.S. Department of Agriculture, 1960). Perhaps a more apt comparison would be with the difficulties in the classification of climate which Thornthwaite (1931, 1948) set out to resolve. Both in pedology and in climatology, the authors of the new classifications aimed at generally-applicable systems, relying on consistent criteria throughout, and introducing new terminologies which relate to precise definitions and which are free from the unwanted imprecision and associations of previous terminologies. Although it does not yet seem possible to do as much for the naming and classification of duricrusts, the dubious and at times misleading connotations of some of the terms in current use, plus serious deficiencies in what may be called the first approximative classification in English, point the need for an attempt to produce some kind of taxonomic order.

As is well known, the term *duricrust* was originated by Woolnough (1927) for application to surficial crusts in Australia. These had previously been variously described as laterite, lateritic bauxite, bauxitic laterite, bauxite, concretionary ironstone, surface quartzite, and Desert Sandstone, according to assumed content or origin and/or observed lithology and mineralogy. The names listed cannot however be regarded as even a first approximation to a rational classification of duricrusts. Those in the laterite-bauxite range, quite apart from the uncertainties about chemical and mineralogic constitution which they entail, fail to make the necessary distinction between chemistry and mineralogy on the one hand and physical characteristics on the other. The terms *lateritic*, *bauxitic*, &c., *crusts* would seem to be called for, even though thick and well-cemented crusts can grade laterally into thin surface litters or subsoil layers of fragments, pisoliths, and nodules, and may wedge out altogether. By no means all bauxites are sufficiently well cemented to form crusts, and many appear to consist of transported material as opposed to residues in situ. Laterite, on anything like a strict definition, need not be and usually is not indurated at all. The prevalent obstacles to arriving at a strict definition of laterite need not concern us here (for discussion, see for

example Prescott and Pendleton, 1952; Maignien, 1966), since the term does not enter into the proposed classification. It is however worth observing that Buchanan's original laterite of 1807 came from the mottled, not the uppermost, part of a deep-weathering profile; that the confused associations of the word *laterite* are such as to cause some workers to recommend its complete abandonment; and that the description of highly siliceous deep-weathering profiles in Australia as lateritic has led to highly unlikely hypotheses of their origin (for discussion of this last topic, see Langford-Smith and Dury, 1965).

What may be regarded as a first approximation to the classification of duricrusts originated with Lamplugh (1902, 1907) who introduced the terms *calcrete*, *silcrete*, and *ferricrete*. To these have subsequently been added *gypcrete* and *salcrete*. A parallel list replaces *-crete* by *-crust* (Table 1, cols. i. ii). It seems unnecessary here to identify the points of introduction or the original authorship of the additional terms: for present purposes, they may be accepted as in widespread use, their currency being taken as a guarantee that they are thought useful.

Terms in *-crete* and terms in *-crust* are not wholly interchangeable. As Wopfner and Twidale (1967) point out, it is appropriate to distinguish between well-cemented and massive gypcrete and loosely-cemented to powdery and impure gypseous crusts. Furthermore, the various *-cretes* can occur outside the range of *-crusts*: ortstein for instance can be regarded as a form of ferricrete. A weakness of applying *-crete* to the material of duricrusts is that the element refers merely to agent of cementation and not necessarily to major bulk content. Thus, while calccrusts are assumed to be composed largely of calcium carbonate (under analysis, 90% or more is common), calcretes need not be. A ready example is provided by the calcite-cemented outwash gravels in the north of the London Basin, where most of the material involved consists of silica in the form of flint. A general defect in both lists is that they make no provision for highly aluminous duricrusts, presumably because a quite small iron content in the ferricrust range can result in a strong hematitic coloration (*cf.* however Maignien, 1958, who distinguishes between aluminous and ferruginous laterites). At the same time, the separation of silcrusts from ferricrusts is useful, as recognising the occurrence of highly siliceous duricrusts, and as superseding the block term *lateritic*.

It is probably too late to debate whether or not calccrusts, gypcrusts, and salcrusts should be classed as duricrusts at all, since the term *duricrust* appears to be extending itself to embrace them: there is no purpose in trying to turn back a linguistic tide. Equally, the force of usage is probably strong enough to prevent the substitution of *calcrete*, the logical accompaniment of *calccrust*, for the original *calcrete*. There can however be no objection to styling crusts in the silcrust-ferricrust range of the first approximation *duricrusts proper* (*cf.* Table 1).

The difference of origin between duricrusts proper and other types of crust needs constantly to be borne in mind. The latter are associated with subhumid to arid climates, whether those of the present or those of the past. Many of them have strong affinities with evaporites, even when they do not result directly from the drying of pluvial lakes or from the evaporation of playas or of emergent saline groundwater. However, the name *evaporation crusts* is not entirely suitable: for example, Coque (1962) has identified crusts formed of wind-laid gypsum. Again, calccrusts can alternatively originate as calcareous soil horizons, including calcareous duripans (7th Approximation, 55-59). The fact that crusts of this subtype form mainly below the level of the ground surface is no necessary obstacle to their classification as crusts, since duricrusts proper originate, at least in very large part, in precisely the same manner. Gypsic, and for that matter natric and salic soil horizons also (7th Approximation, 45-46, 59-60) seem at most to rise to the status of fragipans (*ibid.*, 56-57) not resisting

stripping sufficiently to constitute crusts : in the present context, therefore, they may be disregarded. In respect of calccrusts, it is not proposed here to review the controversial aspects of the origin of soil carbonate, or to discuss the various names which it has been given (e.g., caliche, kunkar, travertine). The term *calcsiltitic crust*, mentioned here in anticipation of an outline of the second approximation, is provisionally inserted in the classification as connoting calccrust or other surficial limestone such as calcarenite, which has undergone silicification. Investigation is required both into the status of this type and into its place in the classification of silicified limestone in general.

Duricrusts proper are called, by a number of authors, *weathering crusts*, but this usage is not wholly defensible. The major extent of duricrusts proper admittedly seems to be associated with deep-weathering profiles, of which the duricrusts form part; but scarpfoot, detrital, and valley-bottom crusts are well documented from numerous areas (cf. de Swardt, 1964; Maignien, *op. cit.* 1966), where they can either be associated with deep weathering or merely result from the cementation of colluvium, terrace deposits, and valley fills, constituting the forms widely called detrital laterites (or lateritites) and groundwater laterites. Much obviously depends on the highly variable interplay of weathering, vegetation, climate, erosion, and time. In this connection, attention may be drawn to a potential source of specific confusion. With some writers, *primary laterites* are those of a residual erosion-platform, *secondary laterites* those formed below the level of a wasting duricrust cap, and formed from material fallen or leached from it; with others (e.g., Mohr and van Baren, 1954), *primary laterite* is the material formed next to weathering bedrock. Confusion of a different kind afflicts the description of duricrusts which do form parts of deep-weathering profiles. Whitehouse (1940) uses *pallid* and *mottled zones* for Walther's earlier German names *bleichzone*, *fleckenzone*; it has become quite general in Australian accounts of the duricrust to identify the layer above the mottled zone as the *indurated zone*, so that deep-weathering profiles are customarily subdivided into pallid, mottled, and indurated. However, the linguistic structure of this subdivision is obviously inconsistent, and can be misleading. In some profiles, the mottled zone is partly or even wholly cemented, and can be both thicker and better cemented than the layer next above; in consequence, it must be classed as part of the duricrust.

The Second Approximation

In the construction of this rational-descriptive classification, the following principles have been observed :-

1. The basis of classification is bulk content, by weight.
2. Names are indicative of bulk content.
3. Names carry no genetic implications.
4. Mineralogy is disregarded.

Application of these principles results in a more detailed classification of duricrusts than has hitherto been available in English. The writer is of course aware of the work of d'Hooe (1954), Maignien (*op. cit.* 1958), and others on the classification of laterite, which has been published very largely in French (for a summary review, see Maignien, *op. cit.* 1966, 112-113). He is also aware of the considerable advances in genetic interpretation and classification which are involved. However, it can be suggested, without the least hint of derogating this work, that certain geomorphic purposes can be well served by a descriptive, as opposed to a genetic, classification. Particularly is this so in Australia, where duricrusts are widespread and extensive, but where the mechanisms of their

Table 1. Classification of Duricrusts.

i		ii		iii	iv	v
First Approximation		Second Approximation				
Cementing Agent		Classification By		Dominant Content B	Essential Chemistry (list <i>not</i> exclusive)	Typical Crystalline Minerals (list <i>not</i> exclusive)
		Dominant Content A				
↑ duricrusts proper ↓	↑ ←silcretes→ ↑ ferricretes ↓	↑	↑	silitic crust	SiO ₂	quartz
		↑	↑	siallitic crust	SiO ₂ , Al ₂ O ₃	quartz (aluminous compounds often amorphous to cryptocrystalline)
		↑	↑	fersilitic crust	Fe ₂ O ₃ , SiO ₂	hematite, quartz
		↑	↑	fersiallitic crust	Fe ₂ O ₃ , FeOOH, SiO ₂ , Al ₂ O ₃ , nH ₂ O, + AlOOH	hematite, goethite, quartz, gibbsite, + boehmite
		↑	↑	ferrallitic crust	Fe ₂ O ₃ , FeOOH, Al ₂ O ₃ , nH ₂ O, AlOOH	hematite, goethite, gibbsite, boehmite
		↑	↑	ferritic crust	Fe ₂ O ₃ , FeOOH,	hematite, goethite
		↑	↑	fermangitic crust	Fe ₂ O ₃ , MnO ₂	hematite, pyrolusite/psilomelane
↓ calcrete ↓	↓ calccrust ↓	↓	↓	tiallitic crust	TiO ₂ , Al ₂ O ₃ , nH ₂ O	rutile/anatase, gibbsite
		↓	↓	allitic crust	Al ₂ O ₃ , nH ₂ O, AlOOH	gibbsite, boehmite
		↓	↓	calcitic crust	CaCO ₃	calcite
		↓	↓	calcsilitic crust	CaCO ₃ , SiO ₂	calcite (silica often chalcedonic, etc.)
		↓	↓	gypsitic crust	CaSO ₄ .2H ₂ O	gypsum
↓ salcrete	↓ salcrust	↓	↓	halitic crust	NaCl (usually impure)	rock salt

formation remain in doubt, not to say in dispute. And particularly also is this so in respect of writings in English, where linguistic precision is less highly esteemed, and less carefully cultivated, than in writings in French.

Classification by bulk content raises no problems in the range of crusts other than duricrusts proper. Calcrusts of the calcitic kind commonly run at more than 90% CaCO_3 , and often exceed 95%. The proportion of gypsum in gypcrusts is similarly high. Salcrusts are probably often impure, but surficial occurrences consisting dominantly of rock salt are at least known. Moreover, the allocation of names in this range produces no difficulty (Table 3, col. iii).

Within the range of duricrusts proper, difficulties at once appear when attempts are made at mineralogical definition, partly because of the variations produced by varying degrees of hydration, partly because of the problems of classifying clay minerals, partly because of the dubiety of mineralogical identification in part of the range, and partly because iron compounds convert to hematite when sufficiently heated, as in analytical practice. These various causes of trouble are sufficiently well known to require no further discussion here (see, among the very numerous available references, Oades, 1963; Maignien, *op. cit.* 1966), and the mineralogical contents listed in Table 1 are intended merely as the roughest of approximations to actuality.

Particular emphasis may suitably be placed, for purposes of classification, on bulk content of silicon (as SiO_2), of aluminium (as Al_2O_3), and of iron (as Fe_2O_3). These fractions commonly supply more than 85%, and indeed more than 95%, of the total weight of a duricrust sample, exclusive of combined H_2O . This latter characteristically ranges from about 5% to about 25% of the whole. Locally, enrichment by manganese (as MnO_2) or by titanium (as TiO_2) can run up to 20% of the total weight, combined water again excepted. Manganese enrichment is typically associated with low terrace or valley-bottom situations, titanium enrichment with highly leached, residual aluminous duricrusts, the contrast in situation appearing to correspond to a contrast in relative mobility. But the relative proportions of SiO_2 , Al_2O_3 , and Fe_2O_3 in the majority of duricrusts proper appear to be controlled by an interplay of factors among which relative mobility is only one. Among the most obvious of the others are the constitution of weathering bedrock, the hydrologic, pedologic, biotic, and climatic environments, and the duration of time (*cf.* Jenny, 1941). By observation, the relative proportions of silicon, aluminium, and iron are highly variable, ranging up to 99% SiO_2 in some crusts, and up to well above 80% Al_2O_3 or Fe_2O_3 in others. It seems necessary, therefore, to provide descriptive names which allow for the possible sevenfold dominant combinations. Such names are listed in Table 1, col. iii.

The names are compounded from the *si* of silica, *al* of aluminium, *fe* of ferrum, and the *ti* of titanium. Manganese, for the sake of euphony, is made to supply the element *mang*. The resulting terms of course derive ultimately from the practice of Suess who, in the late 1800s coined the words *sal* (*sial* with later writers), and *sima*, and more nearly from the practice of pedologists. Del Villar (1937, p. 32) for instance appears originally to have applied the names *allitic* and *siallitic* to soil series; *ferritic*, *ferrallitic*, and *fersiallitic* now have wide currency among tropical pedologists, especially in Africa, thanks to the work and writings of Aubert, da Costa, d'Hoore, Duchaufour, Maignien, Rougerie, and others. As before, it seems enough to accept the currency of these terms without treating their origin as a problem in historicism (see, however, Aubert, 1954, and references in Maignien, *op. cit.* 1966). Their applicability in the classification of duricrusts appears to be self-demonstrating. The term *fermangitic*, *tiallitic*, and *silitic* are thought to be original to the present paper, but it would be in no way surprising if they had already been invented by others: the terms *allitic* and *siallitic* had

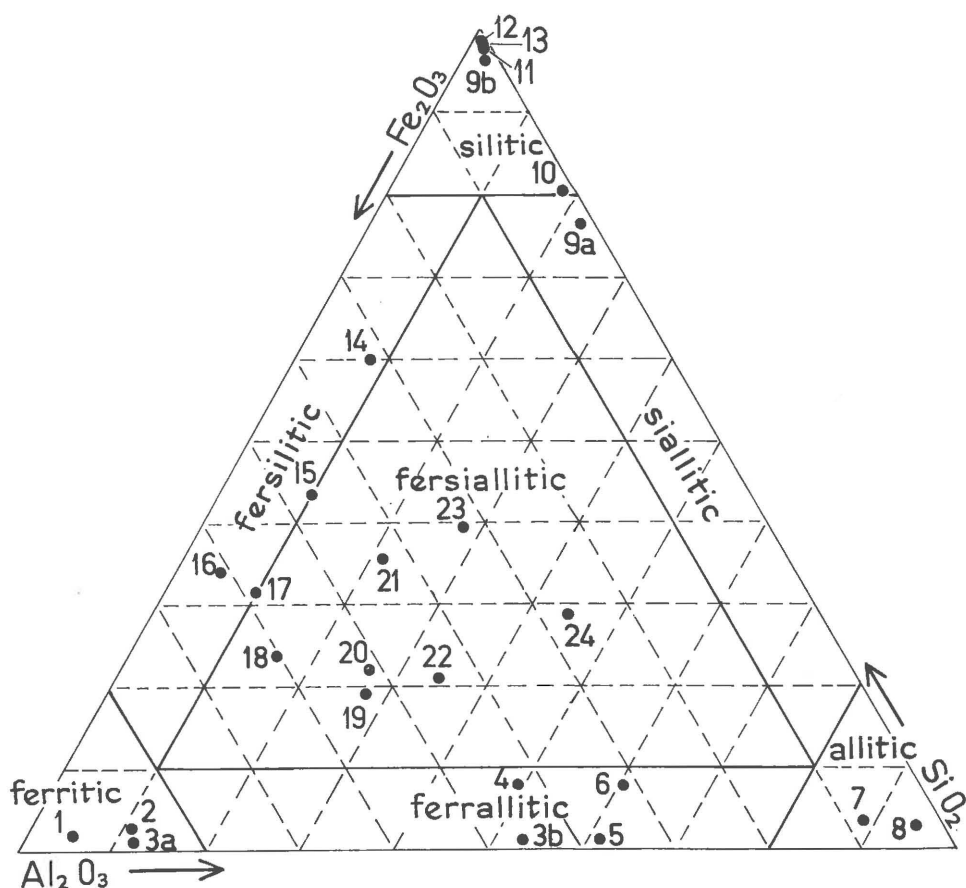


Figure 1. Ternary diagram, showing points for the data in Table 2, and suggesting boundaries among the seven types of duricrust in the total fersiallitic range.

already been formed before the writer located them in del Villar (*op. cit.*). All three of *fermaginitic*, *tiallitic*, and *silitic* appear to be necessary, especially the last. In respect of it, one could argue that the *l* should be doubled, by analogy with the usage in *allitic*, producing the form *sillitic*, but this form appears to be potentially misleading, so that *silitic* is to be preferred.

To draw up a list of classificatory names related to proportional content, before criteria of content have been established, may at first seem a reversed exercise in logic. However, the facts are that some names for different kinds of duricrust already exist, and that, as has just been pointed out, names developed in pedology can readily and usefully be adapted to the descriptive identification of duricrusts. The development of language, even of technical language, is little susceptible of control. Nevertheless, it remains to show that the names proposed can be justified by the results of analysis.

Analyses of crusts in the siliceous-aluminous-ferruginous range can readily be made to provide the data for a ternary diagram, when the percentages of SiO_2 , Al_2O_3 , and Fe_2O_3 are recalculated so that their sum = 100 (Table 2, Fig. 1). The potential range is, needless to say, any combination among and up to $\text{Si,Al,Fe} = 100$. However, if, as in Figure 1, the 80% limit of a single constituent is used to separate off *silitic*, *allitic*, and *ferritic* crusts, then the margins of the

Table 2. Percentage Contents of SiO_2 , Al_2O_3 and Fe_2O_3 in selected duricrust samples.
For sources and locations, see Appendix.

Sample No.		1	2	3a	3b	4	5	6	7	8	
After ignition loss	{	SiO ₂	2.0	3.1	0.9	1.0	7.5	0.5	7.2	3.1	2.4
		Al ₂ O ₃	4.7	11.0	11.0	49.5	48.0	57.6	58.6	80.4	79.3
		Fe ₂ O ₃	87.0	84.5	82.6	42.0	41.0	35.0	30.6	7.5	2.4
		Total	93.7	98.6	94.5	92.5	96.5	93.1	96.4	91.0	84.1
Recalculated to	{	SiO ₂	2.0	3.1	1.0	1.1	7.8	0.5	7.5	3.4	2.9
Al ₂ O ₃		5.0	11.2	11.6	53.5	49.7	61.9	60.8	88.4	94.2	
Fe ₂ O ₃		93.0	85.7	87.4	45.4	42.5	37.6	31.7	8.2	2.9	
$\Sigma = 100$											

Sample No.		9a	9b	10	11	12	13	14	15	16	
After ignition loss	{	SiO ₂	74.5	96.1	79.5	97.8	98.6	98.5	58.7	37.9	33.2
		Al ₂ O ₃	22.0	2.1	18.4	1.2	0.6	0.7	7.9	9.0	5.0
		Fe ₂ O ₃	2.1	1.1	1.1	0.8	0.3	0.6	31.6	40.7	60.2
		Total	98.6	99.3	99.0	99.8	99.5	99.8	98.2	87.6	98.4
Recalculated to	{	SiO ₂	75.6	96.8	80.4	98.0	99.1	98.7	59.8	43.5	33.7
Al ₂ O ₃		22.3	2.1	18.5	1.2	0.6	0.7	8.0	10.0	5.1	
Fe ₂ O ₃		2.1	1.1	1.1	0.8	0.3	0.6	32.2	46.5	61.2	
$\Sigma = 100$											

Sample No.		17	18	19	20	21	22	23	24	
After ignition loss	{	SiO ₂	28.1	23.3	18.9	19.4	34.5	19.8	36.5	28.5
		Al ₂ O ₃	9.1	16.1	27.1	23.6	21.1	32.8	26.2	44.5
		Fe ₂ O ₃	52.1	60.3	52.0	45.6	42.4	42.0	30.8	26.8
		Total	89.3	99.7	98.0	88.6	98.0	94.6	93.5	99.7
Recalculated to	{	SiO ₂	31.6	23.4	19.2	21.9	35.2	20.9	39.0	28.6
Al ₂ O ₃		10.0	16.1	27.7	26.6	21.5	34.7	28.0	44.5	
Fe ₂ O ₃		58.4	60.5	53.1	51.5	43.3	44.4	33.0	26.9	
$\Sigma = 100$										

remaining field can be separated off for siallitic, fersilitic, and ferrallitic duricrusts, the centre being allocated to fersiallitic crusts. It is in the nature of the geometry of the diagram that the subdivision cannot be wholly satisfying. Thus, allitic crusts, as defined, contain up to 20% $\text{SiO}_2 + \text{Fe}_2\text{O}_3$, and allow for $\text{SiO}_2 = 0\%$, $\text{Fe}_2\text{O}_3 = 20\%$, and vice versa, whereas the suggested delimitation of siallitic crusts reduces the permitted Fe_2O_3 content to a maximum of 10%. Corresponding effects are produced elsewhere. Nevertheless, the sevenfold subdivision of the fersiallitic range can be claimed to correspond far more closely to actualities than does the twofold subdivision of the first approximation. It may be provisionally suggested that the cutoff points for tiallitic and fermalitic crusts should also be placed, respectively, at 10% of TiO_2 and at 10% of MnO_2 .

Some of the data in Figure 1 have been recast, since some workers record quartz and other silica separately, while others give quartz as a part of total silica. Again, some of the original lists include water of combination, others exclude it: it is excluded from Table 2, the values being, where necessary, re-calculated accordingly. All values listed have been corrected to the first decimal place.

The selected information in Table 2 is meant to show that all seven types of duricrust named within the total fersiallitic range can be matched by actual examples. This proves to be so, even during a swift preliminary sorting through the literature. The one near-exception concerns the siallitic type, for the Australian deep-weathering profiles which include highly siliceous duricrusts appear characteristically to be highly siliceous throughout, the silica content in the crust running above 80% and not infrequently at about 98%. Thus, Joplin (1963, Tables W_{2a}, W₄, pp. 384 - 386, 393) lists some twenty analyses of grey billy (=silcrust) and silcrete, in which the SiO_2 content is at least 95% in all cases. It has however been thought preferable to rely here on the analysis of samples which have been studied in the specific context of duricrusting, and for which the precise location in the profile is known. In some deep-weathering profiles which include highly siliceous crusts, the Al_2O_3 content fails to increase significantly until the pallid zone is reached; its increase there is presumably referable to the layer silicates of kaolin and allied clay minerals. Results from some profiles which have been sampled and analyzed in detail fail to suggest that the increase in Al_2O_3 content with depth is in any way orderly; but they do leave open the possibility that at least some siallitic crusts result from the cementing of the mottled zone, and the weakness (or weakening) and stripping of the superjacent layer.

A more general consideration is that the identification of silitic, fersilitic, and siallitic crusts, however marginal these last may appear in the classification, shows that the relative mobility principle $\text{Si} > \text{Fe} > \text{Al}$ is but one control over constitution. The least aluminous fersilitic sample, the very slightly ferruginous siallitic sample, and the most highly ferritic and silitic samples of those plotted in Fig. 1 all come from fossil crusts, and from interfluvial sites where relatively great removal of the more mobile constituents might have been looked for. The identification in the literature of the deduced types of duricrust proper which are listed in Table 1 is at the same time a confirmation of the efficacy (in this context) of the deductive process, and a suggestion of possible directions for further investigation in the future.

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APPENDIX

Location of Samples: Proximate Sources of Analytical Data. Among the sources, Barshad is Chap. 1 in Bear (ed.) (1964); the other publication references are to Maignien (1966) and Mohr and van Baren (1954).

Sample No.	Location and Proximate Source
1.	Coolgardie, W. Australia (Barshad, p. 126).
2.	Kaloum Peninsula, Guinea (Maignien, p. 38).
3a, 3b.	Eagle Mountain, Guyana (Mohr and van Baren, p. 134).
4.	Mt Bougourou, Guinea (<i>idem.</i> , p. 151).
5.	Sarata, Bombay, India (Barshad, p. 126).
6.	Iles de Loos, Guinea (Maignien, p. 38).
7.	Ile de Roume, Guinea (Mohr and van Baren, p. 151).
8.	Bihar, India (Barshad, p. 126).
9a.	Near Quilpie, Qld, Australia: surface (unpublished).
9b.	Same profile as 9a, c. 5ft below surface, but still above mottled zone (unpublished).
10.	Near Thargomindah, Qld, Australia (unpublished).
11.	Near Wilcannia, NSW, Australia (unpublished).
12.	Near Thargomindah, Qld, Australia (unpublished).
13.	Near Roma, Qld, Australia (unpublished).
14.	Near Gulgandra, NSW, Australia (unpublished).
15.	Siam, from structure (Mohr and van Baren, p. 378).
16.	Near Mitchell, Qld, Australia (unpublished).
17.	Siam, field sample (Mohr and van Baren, p. 378).
18.	Near Miles, Qld, Australia (unpublished).
19.	Mamou, Guinea (Barshad, p. 126).
20.	Cheruvannar, India: Buchanan's original 1807 site (<i>idem.</i> , p. 126).
21.	Dahomey (<i>idem.</i> , p. 126).
22.	Tumatumari, Guyana (Mohr and van Baren, p. 140).
23.	Yarikita Hill, Guyana (<i>idem.</i> , p. 143).
24.	Near Charleville, Qld, Australia (unpublished).

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