COMMONWEALTH OF AUSTRALIA

MINISTRY OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN No. 8

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OCHRE DEPOSITS, RUMBALARA, NORTHERN TERRITORY

by

C. J. SULLIVAN and A. A. OPIK

(With Appendices by Irene Crespin and W. R. Browne)

Issued under the authority of the Rt. Hon. R. G. Casey,
Minister for National Development
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Minister: THE RT. HON. R. G. CASEY

Secretary: J. E. S. STEVENS

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Director: H. G. RAGGATT

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This Bulletin was prepared in the Geological Section

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Summary

Rumbalara railway siding is 831 miles by rail north of Adelaide, South Australia, and 120 miles by rail south of Alice Springs, Northern Territory. The ochre deposits (Plate 1) are situated in desert country, 15-20 miles north-east of the siding.

No permanent water supply has been developed in the vicinity of the mines.

Numerous mesas in the district are capped by siliceous laterite (grey billy), and are composed of approximately 150 feet of horizontally-bedded, leached shales and sandstone containing numerous fossils of Lower Cretaceous age. These beds, for which the name Rumbalara Shale is proposed, rest unconformably on the eroded surface of flat-lying, current-bedded sandstones of which the age has not been determined; it is proposed that the sandstone beds be called the De Souza Sandstone.

The ochre occurs in beds 1 to 4 feet thick; the best grade consists of soft, friable, golden-yellow material, free from grit and with good paint-making properties.

Throughout the deposits the ochre occurs at the same stratigraphic horizon—at the base of the Lower Cretaceous—and appears to be of sedimentary origin.

Excluding 1943 and 1944, annual production during 1940-1948 averaged 500 tons; in 1943 and 1944 production was 1,345 and 1,439 tons respectively.

The deposits are very extensive, but prospecting carried out to date indicates that only some of them contain ochre equal in grade to that being mined. However, although there are virtually no proved reserves, the field is probably capable of supplying Australia's requirements of yellow ochre for many years.

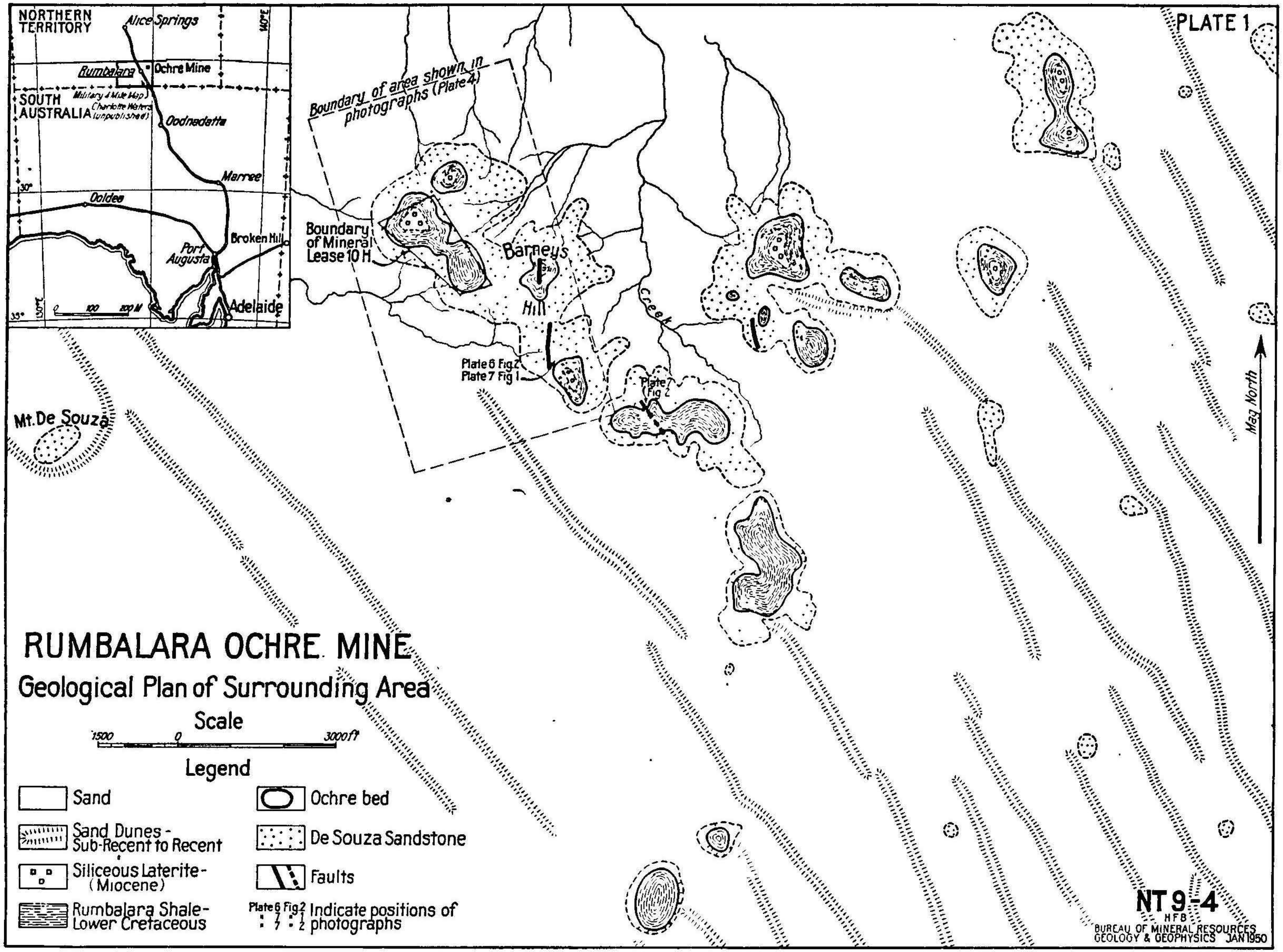
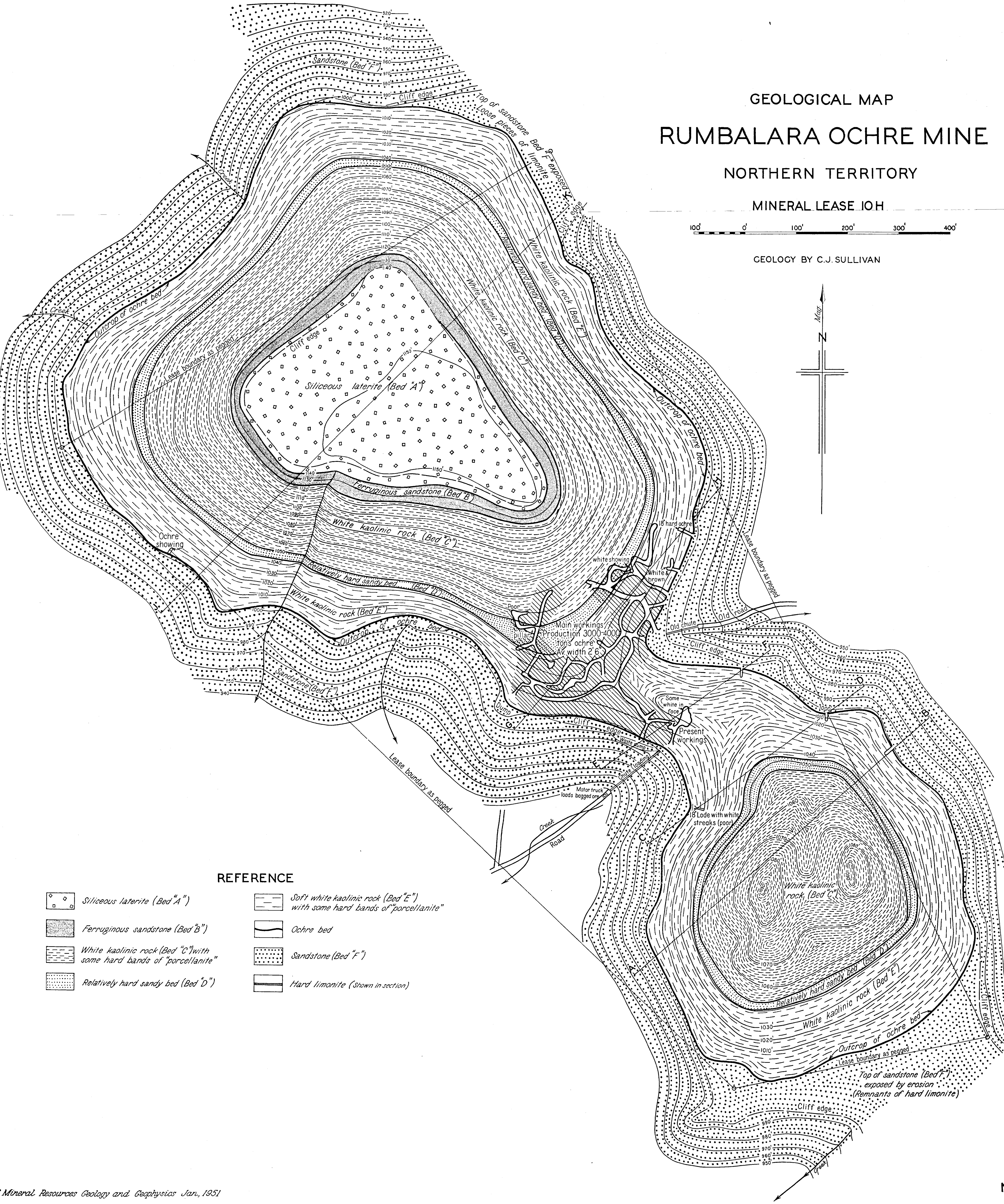


PLATE 1
NORTHERN TERRITORY
Alice Springs
Rumbalara
Ochre Mine
SOUTH AUSTRALIA
Military 4 Mile Map)
Charlotte Waters (unpublished)
Oodnadatta
Marree
Ooldea
Broken Hill
Port Augusta
Adelaide
140°E
30°
35°
100
200 M
Boundary of area shown in photographs (Plate 4)
Boundary of Mineral Lease 10 H
Barneys
Hill
Creek
Plate 6 Fig 2
Plate 7 Fig 1
Plate 7 Fig 2
Mt. De Souza
Mag North
RUMBALARA OCHRE MINE
Geological Plan of Surrounding Area
Scale
1500
0
3000 ft
Legend
Sand
Sand Dunes - Sub-Recent to Recent
Siliceous Laterite - (Miocene)
Rumbalara Shale - Lower Cretaceous
Ochre bed
De Souza Sandstone
Faults
Plate 6 Fig 2 Indicate positions of photographs
NT 9-4
HFB
BUREAU OF MINERAL RESOURCES GEOLOGY & GEOPHYSICS JAN 1950


GEOLOGICAL MAP
RUMBALARA OCHRE MINE
NORTHERN TERRITORY
MINERAL LEASE 10 H
GEOLOGY BY C.J. SULLIVAN
Siliceous laterite (Bed "A")
Ferruginous sandstone (Bed "B")
White kaolinic rock (Bed "C")
Relatively hard sandy bed (Bed "D")
White kaolinic rock (Bed "E")
Sandstone (Bed "F")
Outcrop of ochre bed
Lease boundary as pegged
Cliff edge
Top of sandstone Bed "F" exposed
Loose pieces of limonite
Ochre showing
Creek
Main workings
Production 3000-4000 tons ochre
Av. width 2'6"
Present workings
Old chute
Old road
Dump
Motor truck loads bagged ore
18" Lode with white streaks (poor)
18" hard ochre
White & brown
white showing
Some white in face
Poor
pillar
Road
Top of sandstone (Bed "F") exposed by erosion (Remnants of hard limonite)
REFERENCE
Siliceous laterite (Bed "A")
Ferruginous sandstone (Bed "B")
White kaolinic rock (Bed "C") with some hard bands of "porcellanite"
Relatively hard sandy bed (Bed "D")
Soft white kaolinic rock (Bed "E") with some hard bands of "porcellanite"
Ochre bed
Sandstone (Bed "F")
Hard limonite (Shown in section)

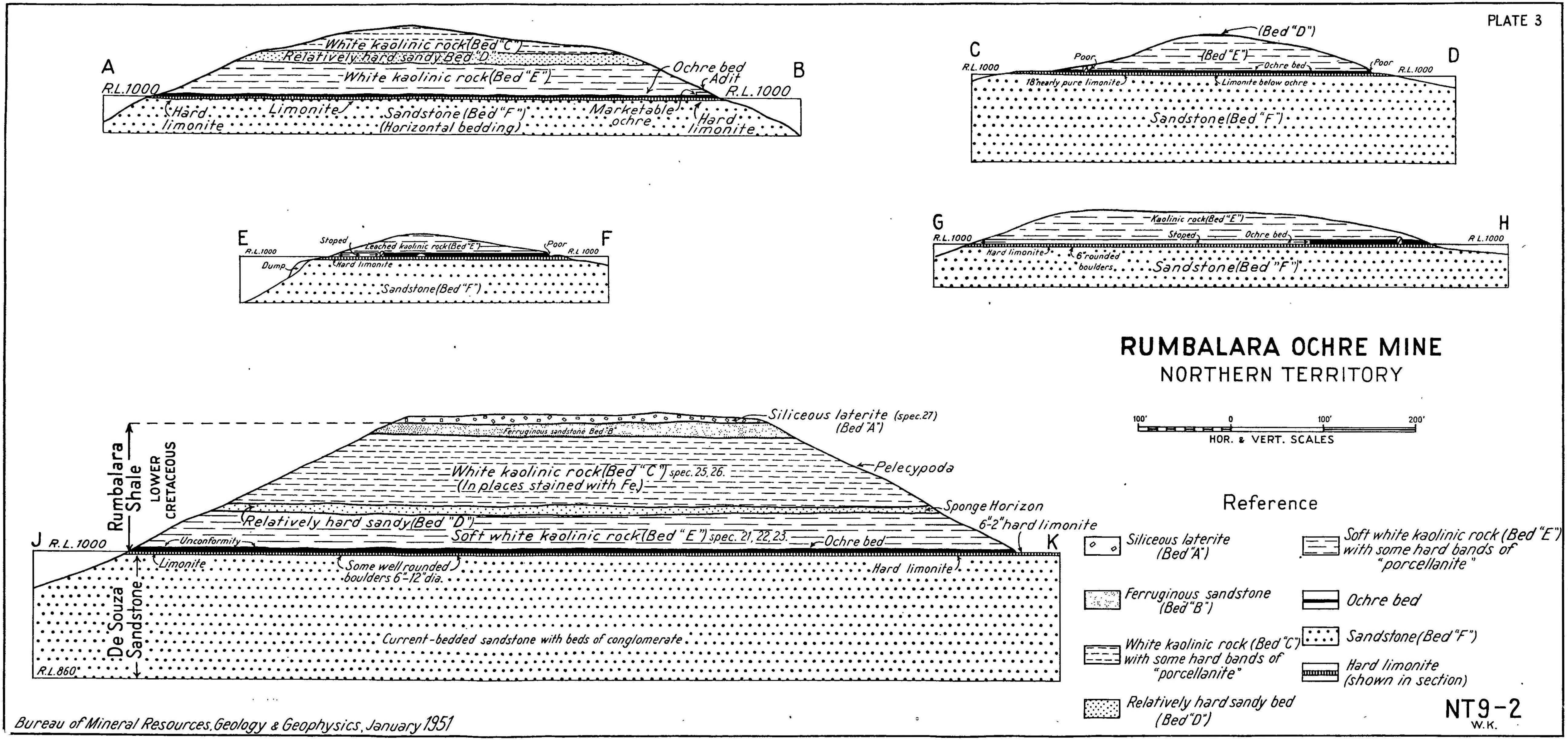


PLATE 3
A
B
R.L.1000
R.L.1000
White kaolinic rock (Bed "C")
Relatively hard sandy Bed "D"
White kaolinic rock (Bed "E")
Ochre bed
Adit
Hard limonite
Limonite
Sandstone (Bed "F") (Horizontal bedding)
Marketable ochre
Hard limonite
C
D
R.L.1000
R.L.1000
(Bed "D")
(Bed "E")
Poor
Ochre bed
Poor
18" nearly pure limonite
Limonite below ochre
Sandstone (Bed "F")
E
F
R.L.1000
R.L 1000
Stoped
Leached kaolinic rock (Bed "E")
Poor
Dump
Hard limonite
Sandstone (Bed "F")
G
H
R.L.1000
R.L.1000
Kaolinic rock (Bed "E")
Stoped
Ochre bed
Hard limonite
6" rounded boulders
Sandstone (Bed "F")
RUMBALARA OCHRE MINE
NORTHERN TERRITORY
100'
0
100'
200'
HOR. & VERT. SCALES
J
R.L.1000
K
Rumbalara Shale
LOWER CRETACEOUS
De Souza Sandstone
Siliceous laterite (spec.27) (Bed "A")
Ferruginous sandstone Bed "B"
Pelecypoda
White kaolinic rock (Bed "C") spec. 25, 26.
(In places stained with Fe)
Sponge Horizon
Relatively hard sandy (Bed "D")
6"-2' hard limonite
Soft white kaolinic rock (Bed "E") spec. 21, 22, 23.
Unconformity
Ochre bed
Limonite
Some well rounded boulders 6"-12" dia.
Hard limonite
Current-bedded sandstone with beds of conglomerate
R.L.860'
Reference
Siliceous laterite (Bed "A")
Ferruginous sandstone (Bed "B")
White kaolinic rock (Bed "C") with some hard bands of "porcellanite"
Relatively hard sandy bed (Bed "D")
Soft white kaolinic rock (Bed "E") with some hard bands of "porcellanite"
Ochre bed
Sandstone (Bed "F")
Hard limonite (shown in section)
NT9-2
W.K.
Bureau of Mineral Resources, Geology & Geophysics, January 1951

INTRODUCTION

Situation and Access.—Rumbalara is a small siding on the Adelaide-Alice Springs railway line and is 831 miles by rail north of Adelaide and 50 miles north of the South Australian border. It is 120 miles by rail, and 143 miles by road, south of Alice Springs. The road is now (1949) almost impassable for heavy vehicles because of the difficulty of negotiating the Depot Sandhills, 100 miles south of Alice Springs. The ochre mine is 35 miles by road north-east of the siding although the distance to the mine is not more than 20 miles in a direct line (compass survey); the road follows a devious route in order to avoid the sandhills as much as possible. The deposit being worked is on the edge of the Simpson Desert and it is very difficult for a motor vehicle to travel off the beaten track.

Time Spent in Area.—C. J. Sullivan visited the area in mid-1943 with the object of assessing the possibilities of the area for the production of ochre, then required for the manufacture of camouflage paint. The plans accompanying this bulletin were compiled from surveys made during the visit. C. J. Sullivan re-visited the area in January 1944.

A. A. Öpik, accompanied by G. F. Joklik, inspected the area from 23rd to 28th May 1949; they collected fossils and made a number of geological observations. The physiographic and palaeontological information given in this bulletin is the work of A. A. Öpik, as is also the recognition of the probable sedimentary origin of the ochre deposits.

Previous Literature.—The only previous reports dealing specificially with the Rumbalara area are those by Sullivan (1944, 1946). Several general papers containing relevant stratigraphic and palaeontological information are mentioned elsewhere in this bulletin.

History.—The existence of the ochre deposits in this locality was known to the natives before the coming of the white man; the ochre was highly prized by them for the decoration of their bodies and weapons. It was in special demand for ceremonial occasions and was traded over long distances. Natives still visit the locality and take away a few pounds of the ochre.

Production of Ochre.—The Australasian United Paint Company Limited of Adelaide holds the mining leases in the area and takes the entire output. The company supplies transport and mining equipment to a party that mines and delivers the ochre to the railhead on a contract basis. Recorded production to 31st December 1949 is given in Table 1.

Relative Importance of Rumbalara Deposits.—The annual consumption of ochre and pigment clays in Australia is estimated at 4,000 tons, of which about half is imported. Average domestic production from 1945 to 1949, inclusive, was as follows:—

New South Wales (red, yellow and umber)	1,000 tons per year
Tasmania (red)	23 tons per year
Western Australia (red and yellow)	629 tons per year
Northern Territory (yellow)	491 tons per year
Total	2,143 tons per year

The principal deposits worked in N.S.W. are in the Dubbo district (yellow ochre), Gulgong district (mixed), and Glen Innes district (red ochre); the largest production is from Dubbo. Red ochre is produced at Spalford, Tasmania, and in the Ophthalmia Range, Western Australia. The Rumbalara deposits are the only ones being worked in the Northern Territory; they provide the best quality yellow ochre available in Australia and, for this reason and on account of their size, they are of greater economic importance than past production indicates.

TABLE 1

RECORDED PRODUCTION OF OCHRE TO 31st DECEMBER 1949

Year*	Ochre Long Tons	Value £
1939	35	104
1940	535	1,606
1941	378	1,200
1942	661	2,151
July to December 1942	390	1,265
1943	1,345	4,800
1944	1,439	5,090
1945	554	2,079
1946	496	1,983
1947	570	2,564
1948	448	2,373
1949	605	3,024
Total	7,456	28,239

* Ending 30th June 1939-42; 31st December 1943-49.

PHYSIOGRAPHY

The topography of the Rumbalara district is illustrated by the stereoscopic pair of aerial photographs reproduced as Plate 4, by the oblique aerial photograph (Plate 9), and in the photographs—Plate 5, figure 1; Plate 8, figures 1 and 2.

As may be seen from the photographs, groups and chains of mesas rise above a plain ridged with desert sand dunes trending north-west. The tops of the mesas are 250 to 400 feet above the level of the plain and are believed to represent a Miocene surface* of peneplanation evidence of which is widespread in Australia (Woolnough, 1927; Noakes, 1949b.). The mesas have been protected from erosion by a capping of siliceous laterite,† or grey billy (called siliceous duricrust by Woolnough), which was probably once overlain by a ferruginous zone and a zone of surface soil, now removed by erosion.

Coincidence of part of the present surface with the Miocene surface is evident in places where the grey billy is preserved—for example, on the tops of the mesas in the central part of the Rumbalara Hills and on some slopes on the western and northern borders of the area. The billy occurs also in valleys and on low hills—for example, at "Hell's Gate" on the road from Rumbalara siding to the Ochre Mine. The distribution of the siliceous laterite indicates that the topography of the area in Miocene time was gently undulating.

At present erosion of the Rumbalara Hills is proceeding very slowly—so slowly that the steep slopes of the mesas cannot have been developed during the present cycle of erosion. Moreover, there is only a little talus at the foot of the hills and all outcrops of the country rock are deeply impregnated by limonite which forms a resistant shell.

Viewed from the air, the hills are bald and dark. Some white patches can be observed; most of these are talus but some are outcrops of Rumbalara Shale exposed by slides.

TABLE 2

STAGES IN DEVELOPMENT OF PRESENT TOPOGRAPHY

4. Recent	Conservation of the mesa-topography, of the limonite shell and of the siliceous laterite. Dunes mainly fixed.
3. Sub-Recent	Invasion by dunes of the Simpson Desert after cessation of erosion between Stages 1 and 2.
2. Pleistocene or Pliocene	Development of the hard limonite crust (2 to 4 ft. thick).
1. Post-Miocene	Dissection of the Miocene surface and development of the mesa-topography.

* Evidence in the Rumbalara area shows that this surface is post-Cretaceous and comparison with other parts of Australia suggests that it is Miocene.

† In this bulletin the term laterite is used to cover the whole profile of rock altered by lateritization. The divisions of the lateritic profile are distinguished, from the surface downwards, as: soil, ferruginous zone, mottled zone, and pallid zone. Silicified material may occur in either the pallid or mottled zones and, more rarely, in the ferruginous zone. It is formed by impregnation of leached parent rock by opaline silica and the products can be divided into two general classes: where the host rock is sandy material or sandstone, a glassy hard quartzite—commonly called billy or grey billy—results and, where shales or clays are impregnated, a fine, hard rock, which has been called porcellanite (Noakes, 1949b), is produced.

The present mesa-topography was developed before invasion by the sands of the Simpson Desert. At "Hell's Gate," 10 miles east of Rumbalara siding, the sand—some of which is still mobile—covers the siliceous laterite. Around the mining area, the flanks of some of the hills abutting on the desert are buried by huge dunes, some of which are fixed by vegetation. In these places the outcrops with the limonitic shell are buried by the dunes; therefore the impregnation by limonite is older than the sub-Recent invasion by the dunes.

The stages suggested above in the development of the present topography are summarized in Table 2.

STRATIGRAPHY AND PALAEONTOLOGY

GENERAL.—The sequence of beds at Rumbalara is illustrated in the accompanying plans and sections, the complete succession being shown in Section J-K, Plate 3. Sediments of two ages are exposed in the mesas of the ochre

TABLE 3

STRATIGRAPHIC SEQUENCE IN RUMBALARA AREA

Bed	Lithology	Thickness (feet)	Formation	Remarks
"A"	Siliceous laterite (grey billy). Specimen No. 27*	10		Leached rocks of the mottled and pallid zones of the Tertiary laterite (Browne, Appendix 3).
"B"	Ferruginous sandstone (leached)	14	Rumbalara Shale	
"C"	Soft white kaolinic rock with hard bands of porcellanite very similar to bed "E". Specimens No. 25 and 26	76		
"D"	Relatively hard, sandy bed with some iron staining	8		
"E"	Soft, white kaolinic rock, apparently formed by leaching, with hard bands of porcellanite. Specimens No. 21, 22, 23	38		
	Yellow ochre	1.5 to 4		
	Hard limonite. Specimen No. 15. The limonitic layers form a distinctive bed containing some quartzite boulders	1 to 1.5	De Souza Sandstone	
"F"	Red and grey cross-bedded sandstone and grit with some conglomerate; in places, these beds contain much hematite and limonite. Specimen No. 19	140 (may extend well below 140 feet)		

* Specimen numbers correspond with those in Appendix 3.

field: (1) Lower Cretaceous shales and sandstone, and (2) cross-bedded sandstones of unknown age and unconformably underlying the Lower Cretaceous sediments. The name Rumbalara Shale is proposed for the predominantly fine-grained beds that are typically exposed at the Rumbalara Ochre Mine (M.L.10H). The underlying sandstone is named the De Souza Sandstone, from Mount De Souza — a steep conical hill 1.5 miles west of M.L.10H — on which this formation is typically exposed (Plate 9).

The beds mapped in the Rumbalara area, in descending stratigraphic sequence, are shown in Table 3.

A representative collection of specimens was examined petrologically by Dr. W. R. Browne, of Sydney University, and his report is given in Appendix 3.

Rumbalara Shale — Lower Cretaceous.—Fossils were found at Rumbalara, for the first time, by A. A. Öpik in 1949. Beds B, C, D, E and the productive ochre bed at the base constitute the Rumbalara Shale and are of Lower Cretaceous age. These beds contain fossil species similar to those described by Etheridge (1902), Whitehouse (1925), and others, from the Rolling Downs, near Roma, Queensland (Appendix 2). The ochre is the lowest fossiliferous bed. In the soft white kaolinic rock of Bed E, poorly preserved fragments of lamellibranchs were observed; Radiolaria were also found in this bed. In Bed D, which is a soft white sandstone where fresh, but dark brown and hardened on exposed surfaces, the sponge *Purisiphonia* is represented—in some places in abundance. The bedding planes of the sandstone are pierced by hollow tubes representing pockets of *Rhizocorallum*; similar pockets cover the top face of the sponge horizon. Bed C, the overlying white kaolinic bed, yielded most of the lamellibranchs collected; assemblages of *Pseudavicula anomala* (Moore) appear just above the sponge horizon.

At Barney's Hill, on the exposed floor of the sponge horizon, a piece of fossilized wood was found.

The lamellibranchs, crinoid stem-joints and gastropods are preserved as moulds and interior casts only; the shell substance has vanished. The sponges are preserved exceptionally well, all details of the structure being retained. Large specimens of *Purisiphonia clarkei* occur — some more than fifteen inches across — showing the confluence of many individuals to form small bioherms. *Purisiphonia* n.sp. is represented by single conical individuals with a pointed base, whereas *P. clarkei* has a rounded base with an elliptical cross section.

Rhizocorallum (U-shaped pockets dug along the bedding planes with U-shaped digging markings on the walls) is very abundant and some specimens are more than two feet long and five inches wide. This is the youngest known *Rhizocorallum*; previously the genus had been recorded only from the Cambrian to the Triassic. Small crystals of micaceous hematite are abundant on the sponge horizon and in places have been accumulated by the sponges in their canals. The hematite, therefore, is a component of the sediment and was not formed during later mineralization.

Unconformity at Base of Cretaceous.—In many places the ochre band, which is the basal bed of the Cretaceous, contains numerous well-rounded boulders and pebbles of hard sandstone lithologically similar to the sandstones underlying the Cretaceous (the natives call the boulders emu eggs and believe the ochre to be the yolk). The presence of the conglomerate suggests a break in sedimentation. The surface of the underlying De Souza Sandstone shows low elevations and depressions and cuts the cross-bedded sandstone beds; the unconformity is obviously erosional.

De Souza Sandstone.—On the surface the De Souza Sandstone is dark brown because it is covered by a thick crust rich in limonite. In fresh outcrops the Sandstone is soft, white to reddish, and is generally cross-bedded and micaceous. In many places the Sandstone is interbedded with grits and conglomerates showing current bedding; most of the pebbles are of quartz. Ripple marks are rare.

The only fossils observed in the De Souza Sandstone are occasional *Scolithus*-like vertical pipes. A piece of rock collected from the grey billy covering the Sandstone is closely perforated by these pipes. Pipe rocks of this type are very common in sandstones of the Larapintine — probably Middle Ordovician — of the Macdonnell Range area, and A. A. Öpik had the opportunity of seeing specimens in the collections of the Adelaide University. The presence of pipe rock in the De Souza Sandstone therefore suggests an Ordovician age for this Sandstone. However, on the southern border of the Macdonnell Ranges, in the so-called Pertnjara conglomerate of post-Larapintine age, derived Ordovician fossils and pipe rocks are recorded (Madigan, 1932). As the pipe rocks found in the Rumbalara area may also be derived, their presence cannot be regarded as conclusive evidence that the De Souza Sandstone is Ordovician.

The De Souza Sandstone, which is unfolded, may perhaps represent an Ordovician facies on the stable southern border of the "Amadeus Lake Sunkland" (Chewings, 1935).

It is possible, also, that this formation can be correlated with part of the "Finke Series" (e.g., in the sense used by Ward, 1925), the age of which has not been definitely established. The "Finke Series" is said to be horizontal and, according to Ward, it overlies gently-folded Ordovician sandstone in the Percy Hills, north of the Rumbalara area. South of Rumbalara, at Mount Daniel, the "Finke Series" is covered by Cretaceous sediments; at Crown Point and Yellow Cliff, near Finke Station — the type localities for the "Finke Series" — tillites and glacial sediments are described in detail by David and Howchin (1924). The authors, as well as Ward, consider that a Permo-Carboniferous age for the glacial part of the Series is possible. Chewings (1935) suggests, tentatively, that the Series may be Jurassic or Permo-Carboniferous. David and Howchin discuss the evidence for the glacial origin of the beds and give a full history of the discovery and previous research. In the De Souza Sandstone of the Rumbalara area no evidence of glaciation could be found.

It is still uncertain whether the De Souza Sandstone is a member of the "Finke Series" and the age of the Sandstone cannot be determined until the relationships between the Ordovician, the "Finke Series" and the Finke glacial beds are established.

STRUCTURE

No folding is observed in the Rumbalara area: the formations are all horizontal. A few minor faults are present, the strike in general being northerly (Plate 7, figure 2); slickensiding is very common in places and is apparently connected with the faults. Although the throw does not exceed 6-9 feet, the faults have an important bearing on the mining of the ochre, as they may displace the ochre bed by as much as its thickness. The faults are younger than Lower Cretaceous and older than the present mesa-topography; their relation to the grey billy could not be established. The northerly strike of the faults corresponds to the direction of minor faults and slickensides observed by A. A. Öpik in the Macdonnell Ranges, near Alice Springs and in the Jervois Ranges. The cracks in crushed zones around the faults in the ochre mining areas are filled with crenulated anhydrite-gypsum replacements.

THE OCHRE

COMPOSITION AND QUALITY.—High quality Rumbalara ochre is bright golden-yellow, has a hardness of 2, powders readily, and yields a fine-grained product relatively free from grit. It has a high staining strength* and yields paint of good colour and opacity. The material utilized to date normally contains 45 to 55 per cent. Fe_2O_3. Apart from ferric hydroxide, the ochre consists mainly of kaolin, but some fine grains of quartz and a few flakes of muscovite may be present. The ochre is porous and absorbs moisture; when placed in water it emits a hissing sound.

A report by the Munitions Supply Laboratories on ochre from M.L.10H reads as follows:

"*Yellow Ochre ex Rumbalara (from Australasian United Paint Co.)*
G.C.B.45/3054.

Composition

Fe_2O_3	44.1%
Acid insoluble	42.2%
Volatile matter	1.48%
Further loss on ignition	11.02%
Water soluble	0.63% (Chlorides: 0.13%; Sulphates: nil)
Acidity or alkalinity of water extract	pH = 5.55

* The staining (or tinting) strength of a mineral pigment is the ability of the pigment to impart colour to other materials. It is normally tested by mixing one part of the pigment and ten parts of zinc oxide with linseed oil. The resulting colour is compared with that produced by a standard pigment, similarly treated. Sometimes colour charts are used as standards of comparison.

Properties

Specific gravity $\frac{15^\circ C.}{15^\circ C.}$	=3.33
Oil absorption	42%
Colour (in raw linseed oil)	
Lovibond	4.2 red 12.7 yellow 0.9 blue
Munsell	8 YR 5/10
B.S.C.	Somewhat whiter and more yellow than No. 14 "Golden Brown"

Conclusion

It is understood that this material is used extensively as a paint pigment. It is considered to be a good grade of yellow ochre, although the amount of soluble chlorides and the slight acidity would render it unsuitable as an ingredient in special anti-corrosive paint formulations."

A considerable quantity—perhaps 60 per cent.—of ochres and near-ochres found in the district does not reach the high specifications outlined above; some of the material contains too much kaolin and some, though rich in limonite, is hard and/or gritty.

The ochre occurs as a well-defined lithological unit at the base of the Lower Cretaceous sequence. It forms a band 1.5 to 4 feet thick, the average thickness being 2.5 feet, and is, in general, underlain by a band of hard, dense limonite 1 to 1.5 feet thick. The limonite contains about 60 or 70 per cent. Fe_2O_3, but in the past it has not been mined as it was not acceptable to the paint companies. However, advice received recently indicates that some, at least, of this material may be utilized.

The line of demarcation between the ochre and the overlying white kaolinic rock is fairly sharp except in a few places where the white rock is stained with iron oxide for 1 to 4 inches above the top of the main ochre bed.

Origin.—The mode of origin postulated for the ochre is of considerable importance in an assessment of the productive possibilities of the field. Until the time of C. J. Sullivan's visit (1943-1944), most of the output had been obtained from M.L.10H, below a deeply eroded portion of the hill where the surface is only 10 to 30 feet above the workings (Plate 2, and Plate 5, fig. 2). The manager considered that mineable ochre was confined mostly to this section and that the material under the higher hills was low-grade. Such distribution would suggest that the formation of the ochre was related to the present topography. However, in 1944 Sullivan considered it quite likely that the ochre did extend below the high portions of the mesas and that its formation was related to the Miocene peneplanation and lateritization.

W. R. Browne (Appendix 3) suggests that the iron content of the ochre may have been derived from the ferruginous zone of a laterite profile of which the grey billy formed a part.

As a result of his 1949 visit, A. A. Öpik writes as follows:

"The lateral and vertical distribution of the ochre bed has not been determined by the present surface or by the Miocene peneplanation; the bed is intersected by both surfaces in many places. In some places, the outcrops of the ochre bed are covered directly by siliceous laterite; in other places, the limonitic coating is present. Therefore, the formation of the bed cannot be explained by an infiltration of iron-bearing solutions from the surface.

"The main ochre bed occurs over a large area and is everywhere at the same stratigraphic horizon, but other small ochre deposits are present in the kaolinic rocks. The main ochre bed has all the features of a sediment; it is the basal bed of the marine Cretaceous in this area, and is a sedimentary iron ore. The ochre is probably a bacterial sediment formed by Cretaceous micro-organisms comparable to the Recent *Leptotrix ochracea.*"

ORE RESERVES

M.L.10H.—The possibility of obtaining further supplies of ochre from this lease is indicated, to some extent, by Plate 2. The area shown as having been stoped produced approximately 4,000 tons of ochre to July 1943; from July 1943 to June 1949 an additional 2,500 tons were obtained from the lease. In the section mined it has been found that about 50 per cent. of the material in the ochre bed is sufficiently impregnated with iron oxide to be utilized as ochre. On the basis of this figure it is estimated that, if the ochre extends below the higher sections of the hills, there may be 25,000 to 30,000 tons of commercial ochre remaining in the lease.

It is emphasized that the mining operation is a very small one and that at no time has there been any attempt to explore the deposits systematically and to prove reserves. The amount of proved ochre is thus negligible. However, there is every reason to expect that substantial additional supplies could be obtained from this lease. In July 1943 a small party was carrying out work preliminary to the resumption of production from M.L.10H.

THE KENDA DEPOSITS, M.L.25H.—These deposits, situated approximately 12 miles south-west of M.L.10H, were briefly inspected by C. J. Sullivan in 1943. There are two mesas, each as large as the ochre-bearing area on M.L.10H. The hard limonite layer that underlies the ochre is extensively developed in this area, and there are substantial deposits of the softer material which, in this district, is regarded as the ochre proper.

In 1943 one or two small cuttings had been made but, for the most part, samples could be collected only from the outcrops. One of the samples (No. 28) was reported on as follows by Minerals Pty. Ltd. of Sydney:

> "Sample No. 28: Per cent Fe_2O_3, 47.64. It is intermediate in colour between ochre from M.L.10H and that from New South Wales. It could be used as a pigment."

Another sample from this locality (No. R.1123) was examined by the Paint Section of the Munitions Supply Laboratories, Maribyrnong, Victoria; the report reads:

"*Yellow Ochre R.1123 ex Rumbalara.* G.C.B.45/3048.

Composition

Fe_2O_3	48.4%
Acid insoluble	41.3%
Volatile matter	0.92%
Further loss on ignition	10.12%
Water soluble	0.24% (Chlorides: 0.04%; Sulphates: nil)
Acidity or alkalinity of water extract	pH = 5.4

Properties

Specific gravity $\frac{15°C.}{15°C.}$	= 2.99
Oil absorption	Not determined
Colour (in raw linseed oil)	
Lovibond	4.4 red 11.3 yellow 0.6 blue
Munsell	8YR 5/10
B.S.C.	Somewhat whiter and more yellow than No. 14 "Golden Brown"

Conclusion

Although insufficient material was available to obtain a truly representative sample, it appears that the material is worthy of further investigation."

The company obtained 300 tons of ochre from this lease in 1949 and reported it to be equal in quality to that obtained from M.L.10H. However, the company has not continued working this deposit and has re-commenced mining on M.L.10H.

AREA IN GENERAL.—A chain of ochre-bearing mesas in the Rumbalara district extends over a distance of at least 20 miles (Plate 9). The limonite-rich horizon at the base of the Cretaceous is clearly present in each mesa and forms a dark band which may be seen from a considerable distance. Most of these numerous mesas undoubtedly contain some ochre of commercial grade, but the quality of such material has not been determined.

During recent years, the Australasian United Paint Company has carried out a limited amount of testing by means of short adits and the results have, in many instances, been disappointing. Also, it may be worthy of note that over a long period the natives obtained their ochre requirements from the mesas now held as M.L.10H, and not from the other ochre deposits in the district.

It is concluded that there are probably very substantial quantities of yellow ochre in the Rumbalara Hills — sufficient to supply Australia's requirements for many years. However, much systematic prospecting will be required before reserves can be determined. The grade of the ochre appears to vary considerably; this variation is, to some extent, due to the fact that the ochre is of sedimentary origin.

It seems probable that some of the hard limonite underlying the soft ochre could be utilized as a pigment at the cost of a little additional expenditure in grinding.

At present (1949) the ochre-mining industry at Rumbalara is extremely small and large-scale expenditure is not warranted. However, if the time should arrive when a more substantial output is required, attention should be paid to the possibility of producing from the area, not so much the highest grade and most easily treated material, but a standard blend of average but stable quality. Such constancy of quality is highly prized in the paint manufacturing industry, and it can be maintained over a long period only by mining average-grade material from a deposit of substantial size.

MINING METHODS

In 1943-44, most of the mining at Rumbalara was carried out by natives under white supervision. First an adit 6 feet high and 4 feet wide was driven into the hill, the base of the ochre forming the floor of the adit. The ochre was picked out, but the harder ground above it sometimes required a light charge of explosive. The natives stoped out laterally from the drives, taking only the thickness of the ochre and leaving small pillars to support the rcof; all work was done from a sitting position. The ochre was shovelled into the drives where it was bagged in double wheat sacks. It was then transported by wheelbarrow to the dump at the head of a chute constructed on the steep slope of the mesa. The chute, 120 feet long, discharged into motor trucks at a point 80 feet below the dump. By this method the natives produced ochre at the rate of 120 tons per man per year and also disposed of about the same amount of waste — a substantial productive eflort.

The laws governing the employment of natives have been changed since 1948 and, because natives may not now be employed underground, the company has provided jack hammers and a compressor which will be operated by white men. In 1949, however, only two men were working on the field.

WATER SUPPLY

The water supply at Rumbalara is not satisfactory; water has to be brought by rail to Rumbalara siding from Finke siding, 40 miles south, and carted by motor truck to the mine. The Railway Department charge is 30/- per thousand gallons for water delivered at Rumbalara siding.

In 1944, the Mines Branch, Northern Territory Administration, attempted to develop a water supply and sank a bore at a point 20 chains east of Rumbalara siding. Water was encountered at a depth of approximately 400 feet and the bore was continued to 432 feet. At the time the bore was completed the water was reported to contain 3,550 p.p.m. — or 245 grains — of sodium chloride per gallon. The flow, based on a continuous pumping test for 24 hours, was reported to be 600 to 1,000 gallons per hour. It is reported, however, that the water has since become much more salty and it is not now used for any purpose. The Railway authority had previously sunk a bore to a depth of 600 feet near the railway siding, with somewhat similar results.

The owners of the Engoordina (Horseshoe Bend) Station, on which the ochre deposits occur, have not found water in this section of their property; the Cretaceous beds are thin, and are preserved only on the mesas and, where tested, the underlying De Souza Sandstone contains only saline water. Supplies required for the station are obtained from the sandy bed of the Finke River.

In 1943, Sullivan selected a site for a trial bore with the object of obtaining comparatively fresh, shallow water. A broad depression, running westward from a chain of low hills, crosses the road from Rumbalara siding to M.L.10H at a point 17 miles from the mine; approximately three-quarters of a mile west of the road, the depression occupies a gap through a second line of hills. The site was selected on the upstream side of this gap, with a view to obtaining shallow groundwater. However, this prospect was not drilled, the site near the railway station being chosen instead, with the results described above.

ACKNOWLEDGMENTS

A. A. Öpik expresses his appreciation of the assistance rendered during his visit by Mr. A. F. de Souza, manager of the ochre mine.

Plates 4 and 9 are reproductions of aerial photographs, published with the permission of the Royal Australian Air Force.

Canberra.
15th March, 1951.

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EXPLANATION OF PHOTOGRAPHIC PLATES

PLATE 4

Stereoscopic pair of aerial photographs showing the ochre-bearing mesas, M.L.10H, Rumbalara Ochre Field, Northern Territory; scale 1500′ to 1″ (R.A.A.F. Official Photograph).

PLATE 5

Fig. 1.—Ochre-bearing mesas from Mount De Souza; sand dunes in middle distance.

Fig. 2.—Section through Rumbalara Shale at Ochre Mine (M.L.10H). The harder, dark bed dividing the white kaolinic sediments into an upper and lower portion is the sponge horizon (Bed D). The men are standing at the level of the ochre bed.

PLATE 6

Fig. 1.—The floor of the sponge bed (D) at Barney's Hill, M.L.10H (see Plate 1), showing several pockets of *Rhizocorallum*. The hammer is 15 inches long.

Fig. 2.—De Souza Sandstone at a hill south-east of the mine, M.L.10H (see Plate 1). The sandstone is limonitized on the surface.

PLATE 7

Fig. 1.—Fresh outcrop at the foot of the hill shown in Plate 6, Fig. 2. Current-bedded grits with cross-bedded aeolian sands on top. The limonitic coating has been removed by running water; the face shown is the bank of a small creek. The hammer is 15 inches long.

Fig. 2.—Fault, dipping west, striking nearly north. The white rock is the top of the lower kaolin bed (E); the dark rock above it is the sponge horizon (Bed D); the downfaulted continuation of the bed is seen on the right. The hammer is 15 inches long. (For position see Plate 1.)

PLATE 8

Fig. 1.—Morphology of the hills midway between Rumbalara siding and mine. The tops are horizontal. The distinct band about half-way down the slopes of the hills represents the top of the De Souza Sandstone, immediately below the ochre bed.

Fig. 2.—Morphology of the western border of the Rumbalara Hills. The inclination of the top of the mesa represents the gentle slope of the Miocene surface.

PLATE 9

Oblique aerial photograph (altitude 20,000′) showing topography of Rumbalara district, N.T. The top of the flat hills is mostly grey billy. On the slopes the white spots represent the talus of the Cretaceous Rumbalara Shales, with a few outcrops; the hard horizontal band is the top of the De Souza Sandstone. In the background are the sand ridges of the Simpson Desert. (R.A.A.F Official Photograph.)

PLATE 4

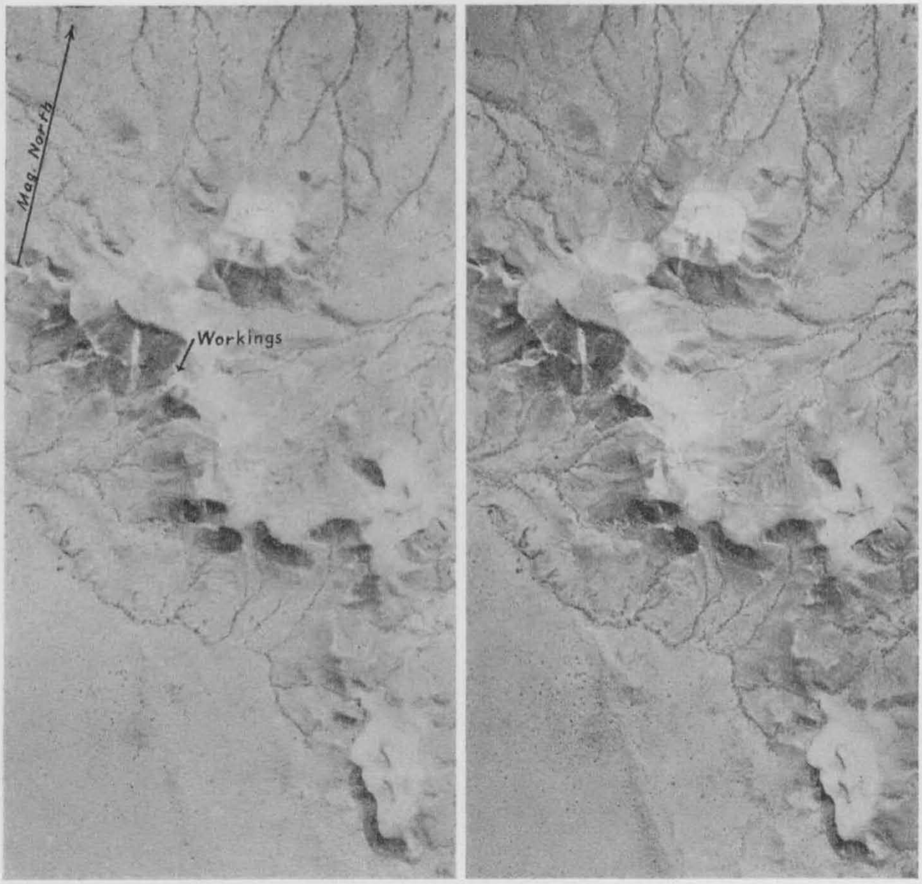

PLATE 5

FIG. 1

FIG. 2

PLATE 6

FIG. 1

FIG. 2

PLATE 7

FIG. 1

FIG. 2

PLATE 8

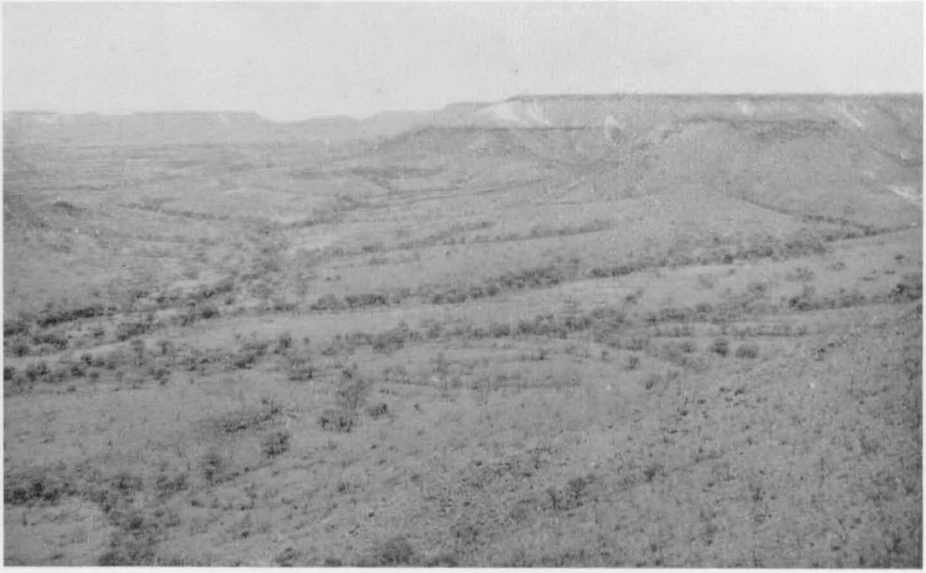

FIG. 1

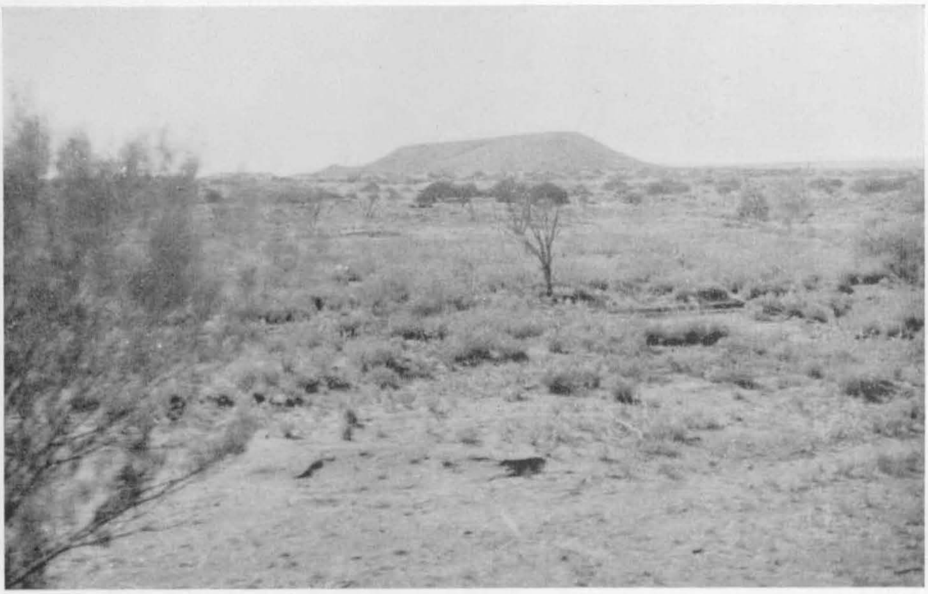

FIG. 2

PLATE 9

APPENDIX 1

NOTES ON MICROFOSSILS

By Irene Crespin

A microscopic examination was made of the hard rock in Bed E. This rock has the lithological characters of a "porcellanite," a rock type widely distributed in the Lower Cretaceous. In thin section the rock has a very fine siliceous matrix in which are siliceous bodies, regarded as Radiolaria, and fine siliceous spicules which most probably represent spines detached from the spinose forms of Radiolaria. Most of the Radiolaria, which are not very well preserved, are spherical in shape and belong to the Order Spumellaria. The commonest genus is *Cenosphaera,* but it was not possible to determine the form to which spines were attached. Another form, *Dictyomitra,* which belongs to the Order Nassellaria, was also noted.

This Radiolaria-bearing rock is widely distributed in the Lower Cretaceous of Australia, but Rumbalara is the first locality in which it has been found associated with a rich mega-fossil assemblage which contains many species described from the Lower Cretaceous beds near Roma, Queensland.

The first record of a similar radiolarian rock was made by Hinde (1893), from Fanny Bay, Darwin, Northern Territory, and since then it has been discovered at several localities in the Northern Territory and in North-west Australia. A similar rock was recently examined from the opal deposits at Coober Pedy, South Australia.

REFERENCE

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APPENDIX 2

LIST OF MEGA-FOSSILS

By A. A. Öpik

The sequence of beds is shown on Plates 1, 2, and 3 and in Table 3.

LOWER CRETACEOUS

- Bed D. (Sponge horizon)
  - *Purisiphonia clarkei* Bowerbank
  - *Purisiphonia* n.sp.
  - *Rhizocorallum* n.sp.
- Bed E. (Upper kaolinic rock)
  - *Cyrene* sp.
  - *Fissilunula* cf. *clarkei* (Moore)
  - *Maccoyella reflecta* (Moore)
  - *Panope* cf. *rugosa* (Moore)
  - *Pecten* (*Camptonectes*) sp.
  - *Pseudavicula anomala* (Moore)
  - *Tatella maranoana* Etheridge
  - *Tatella* cf. *maranoana* Etheridge
  - Large indeterminate lamellibranchs
  - Indeterminate gastropods
  - Pentacrinite stem-joints
- Horizon unknown
  - Silicified wood

ORDOVICIAN

- Bed A, Boulders
  - *Scolithus* sp.

APPENDIX 3

PETROLOGICAL REPORT ON SPECIMENS FROM RUMBALARA

By W. R. BROWNE*

NOTES ON THE SPECIMENS

SPECIMEN No.†

27 A typical "grey billy" such as is found in many parts of the interior of Australia—"siliceous duricrust" of Woolnough. It is a quartzite composed of rounded and angular quartz grains in a very fine-grained siliceous paste or matrix. (Cape rock.)

25, 26 Soft kaolinic rocks such as are found in the leached zone immediately under duricrust. They have a hardness of a little more than 2 and are somewhat gritty from tiny grains of quartz of which there is more in No. 25 than in No. 26. An odd flake of muscovite is also present. No. 25 is stained pink by a small content of iron; No. 26 has a smaller iron content. There may be a little opal present in both specimens, but it cannot be identified with certainty.

21, 23 Are essentially alike—compact kaolin or lithomarge, with a hardness of 2. Like Nos. 25 and 26, they adhere to the tongue. Blowpipe tests gave identical results. Both rocks are infusible and react for hydrous aluminium silicate; some sulphate is also present, possibly derived ultimately from the decomposition of pyrite. A few tiny flakes of muscovite are seen and the microscope reveals a very small proportion of very tiny quartz chips. Though called "Kaolin," the rocks may perhaps contain some aluminium hydroxide, but no test was made for this.

22 Is an unexpected type. It looks very like Nos. 21 and 23, but some parts have a hardness of 3 and do not adhere to the tongue. Under the microscope all that can be seen—apart from tiny quartz chips—is an abundance of colourless rodlike or platy sections with moderate birefringence, but too small for determination in a matrix of feebly refracting material. Before the blowpipe, No. 22 is fusible to a milky glass and gives a strong reaction for sulphate and phosphate. Aluminium and a little water are present, but silica could not be detected and calcium is absent, so that the sulphur and phosphorus seem to be combined with aluminium. It would appear that this material is in streaks or layers through kaolin.

15, 16, Show clearly that the ochre is due to impregnation of the kaolin with ferric hydroxide, and the degree of impregnation is in-

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† These specimen numbers correspond with the numbers in Table 3.

17 creased in No. 15 which, like the others, retains the quartz chips and tiny mica flakes characteristic of Nos. 21 and 22. When Nos. 15, 16 and 17 are powdered and boiled with HCl to dissolve the iron, a white residue of insoluble kaolin is left. In other words, the rocks would all be classed as ochres.

19 In No. 19, a limonitic grit, the ferric hydroxide has impregnated an original kaolinic cement in which the quartz grains are set. Here, too, when the iron is dissolved from the cement a residue of kaolin remains.

INTERPRETATION

It is clear that the suite of specimens is part of a duricrust formation. Although sections of such formations are widespread in Australia, they do not appear to have been studied in any great petrological or chemical detail.

From his observations in Western Queensland, Dr. F. W. Whitehouse (1940) considers the complete typical sequence to be somewhat as follows:

(1) Laterite, nodular or pisolitic, grading down into

(2) The Mottled Zone, consisting of leached, kaolinic rock, often with iron oxide in stalactitic-looking masses or forming a kind of network, the interspaces of which are filled with kaolin. This passes down into

(3) The Pallid Zone, largely kaolinic, sometimes passing down into kaolinized sandstone.

A siliceous zone ("grey billy"), either in sheets or in large separate masses, frequently appears either in (2) or in (3). In many instances erosion has removed zone (1) and/or (2).

The laterite of zone (1) was, according to Woolnough (1927), formed in early to middle Tertiary time by upward leaching of the underlying rocks under special climatic and physiographic conditions, and by the deposition of aluminium and iron hydroxides. The leached rock underneath formed the kaolin of zones (2) and (3) and the silica released in the decomposition was deposited as "billy."

In the present instance, the kaolinic rocks, e.g. Nos. 21, 23, 25, etc., were derived from slightly micaceous shales and sandy shales, possibly Cretaceous beds like those so widespread in the Great Artesian Basin. The original laterite has disappeared, so that the surface-rock is "grey billy." The phosphate in No. 22 I can only surmise to have been derived from former layers of glauconitic shale or sandstone such as are fairly common among the Cretaceous shales. (It should be mentioned that faint reactions of potassium were obtained in Nos. 21, 15 and 17.)

CONCLUSIONS

The ochreous rocks, Nos. 16, 17, and 15, and the limonitic cement of No. 19 are due to impregnation, not replacement, of kaolin by ferruginous solutions, but where the solutions came from it would be hard to say. The laterite, which it is presumed was formerly present, was due to upward migration of solutions and the iron compound in it was probably of the usual red or reddish-brown colour, either hematite or one of the hydroxides. I think it very probable that the brown limonite of the ochres was produced in different circumstances, perhaps by downward percolation of surface-waters, and long after the kaolin was formed. It might have been deposited during the erosion of the laterite and mottled zone, the bulk of the iron having been derived from these; in that case the source-rock is no longer existent. I do not think that No. 25 is necessarily the source-rock, though it may have contributed some of the iron.

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