SELENOSIS IN NORTH-WESTERN QUEENSLAND ASSOCIATED WITH A MARINE CRETACEOUS FORMATION

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SUMMARY

Selenosis in north-western Queensland was shown to be associated with the Tambo Formation of Cretaceous marine clay limestone shales.

This association was studied as a 3-stage programme. Stage 1 was a detailed investigation in a restricted 70-ac area. Stage 2 was an examination of adjacent areas. Stage 3 was a broad observational traverse of the northern portion of the incriminated Formation.

A highly selenized "poison strip" within a 70-ac enclosure was located on an extensive outcrop of the Tambo Formation. Disorders in livestock were associated with recent intensification of land use. The resultant redistribution of selenium-bearing soils made only a minor contribution to the increased toxicity of the whole enclosure. Cultivation for pasture improvement was the major contributor by encouraging the spread of both introduced and native selenium-accumulating plants to formerly barren but highly seleniferous localities. *Neptunia amplexicaulis* **and** *Acacia cana* **were shown to be major selenium-accumulating species.**

Despite other large areas of exposed seneliferous outcrops in this locality and significant selenium levels in almost every specimen, whether of rock, soil, plant or animal origin, disorders of livestock attributable to selenium excess were rare, outside the "poison strip", and of a most moderate nature.

Seleniferous outcrops of the underlying Formation were found at intervals throughout a 200-mile traverse but were extensive only in the Hughenden-Richmond area. Overlying soils representing vast areas of open grasslands were shown to be selenium-bearing. Under extensive grazing management no known endemic disorders occur that could be attributed to a dietary excess of selenium.

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I. INTRODUCTION

A specific disorder in horses, later known as "alkali disease", was first described in the U.S.A. by Madison (1860). As settlement intensified on the semi-arid plains, this disorder and similar disorders in cattle and pigs occurred and were associated with discrete localities. Franke (1934) postulated the presence of a rare toxic element in grains affecting pigs, and Robinson (1935) demonstrated the presence of selenium. The toxicity of the grain was shown to be due to its selenium content (Franke and Potter 1935). The term "alkali disease" is now used to designate chronic selenium poisoning.

Acute poisoning of livestock associated with "poison strips" and a syndrome in cattle known as "blind staggers" occurred, particularly in Wyoming. The identification of these disorders as the acute and a specialized sub-acute form of selenium poisoning was reported by Beath, Eppson, and Gilbert (1935).

Chronic selenium poisoning has since been reported from Mexico (Williams, Lakin, and Byers 1940), Canada (Williams *et al.* 1941), Colombia (Ancizar-Sordo 1947), Ireland (Walsh, Fleming, O'Connor, and Sweaney 1951), Israel (Volcani, Bondi, Lewin, and Newmark 1956) and Australia (Knott, McCray, and Hall 1958). Some exposure of livestock to selenium in South Africa has been reported by Brown and de Wet (1962).

Acute selenium poisoning associated with a "poison strip" was reported from Australia by Knott and McCray (1959). This report, based largely on the analytical findings on a limited number of animal and plant specimens from the Richmond district in north-western Queensland, demonstrated the presence of a major selenium-accumulating plant species and of common pasture grasses of high selenium content on a localized acutely toxic area of the "poison strip" type. In this area both acute and chronic selenium poisoning had occurred but both only recently.

Subsequent information supplied by the owner of the affected property indicated that the occurrence of selenosis within the 70-ac enclosure embracing the acutely toxic area had followed pasture improvement within and earth-moving both within and adjacent to this enclosure.

Although topographical and geological knowledge of the acutely toxic area was limited, it was known that the Tambo Formation, a marine Cretaceous Formation, underlies much of the undulating downs of north-western Queensland, including the Richmond district. The gross geology of this formation resembles that described by Trelease and Beath (1949) for a seleniferous Formation in eastern Wyoming.

The present study had a threefold objective—a detailed investigation of the recent origin of an acutely toxic strip, an examination of areas adjacent to this strip, and a broad survey on a 200-mile traverse transecting an area underlain by the Tambo Formation.

II. METHODS

(i) *Field Investigations.*—The origin of the "poison strip" was studied by a visual assessment of topographical and geological factors, by examination of records on land use and livestock association and by the collection and analysis of rocks, soils and plants from within the area. Examination of adjacent area was made by recording the major topographical and soil type subdivisions and by collecting and analysing rocks and soils from suitable natural features and from areas of differing soil type. Samples of vegetation and specimens from livestock were also taken and analysed. The observational traverse was supported by collecting and analysing soils and plants from areas of extensive soil type and from areas of topographical or geological interest.

(ii) *Preparation of Samples.*—Rock and soil samples were air-dried, ground to pass a 0·04 in. opening sieve and subsampled. Plant samples were shade-dried in the field, hammermilled and subsampled in the laboratory and aliquots taken for selenium and for moisture determinations. Wool, hair and hoof analyses were made on the material as collected.

(iii) *Chemical Analysis.*—For analysis of rocks and soils, selenium was separated by hydrobromic acid-bromine distillation (Trelease and Beath 1949) and estimated by measuring the absorbance of selenadiazole formed from 3, 3′-diaminobenzidine. The estimation was essentially that of Watkinson (1960), except that the absorbance of the selenadiazole was measured at 420 mμ. In plants, the moisture loss was determined on 5-g samples dried for 5 hr at 105°C. Selenium was determined by the method of Trelease and Beath (1949). Selenium in wool, hair and hoof was determined by the method of Watkinson (1960), except that the absorbance of the selenadiazole was measured at 420 mμ.

III. RESULTS

(a) Investigation of the "Poison Strip" Area

Only the 70-ac enclosure embracing the known "poison strip" and its immediate surroundings were included in the investigation of factors influencing the recent occurrence of a seleniferous "poison strip" on a well-established grazing property.

(i) *Topography and Geology.*—The enclosed area is part of an extensive system of ridges and elevated areas of laminated calcareous clay shales. These areas are often capped with limestone or gypsum but vary to softer shales with increased proportions of buff to yellow clays and include areas of grey-brown heavy clay soils in shallow depressions and in local wash areas. Exposed sandstone concretions are a feature of some areas. The whole complex of which the enclosure is characteristic is an elevated and exposed portion of the Tambo Formation. The enclosure is adjacent to the homestead and consists of a flat area of dark grey-brown clay soils forming a wide natural watercourse lying between two low, lightly timbered ridges of calcareous clay shales and includes all but the upper slopes of both ridges.

The topography of the area and the location of features and of boundaries with adjoining grazing paddocks are shown in Figure 1. Samples of rock and soil were taken from localities recorded in the alphabetical code in Figure 2 and their selenium levels are given in Table 1.

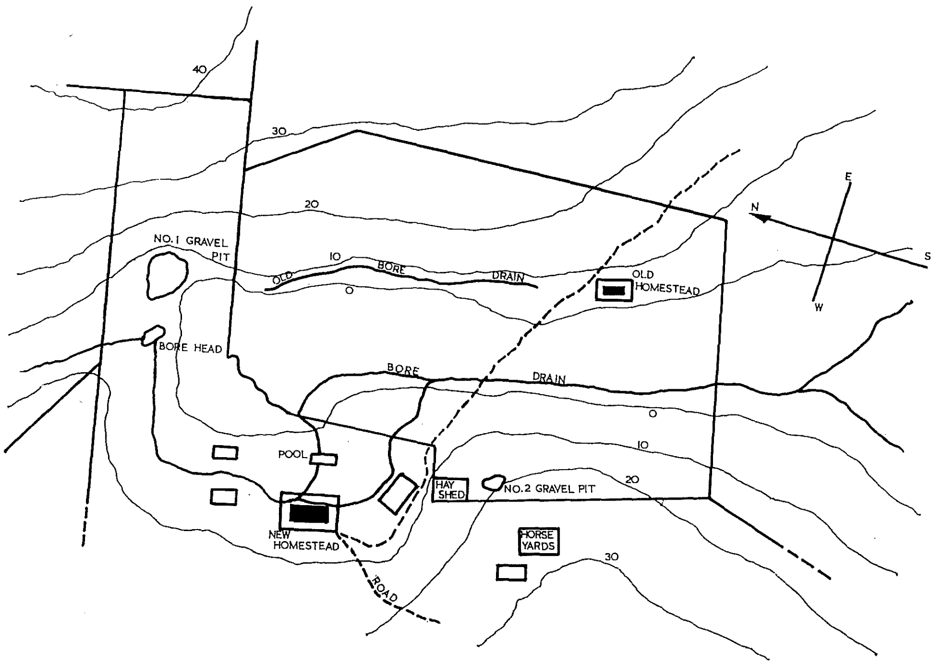

Fig. 1.—The "poison strip," showing the topography of the area and the location of features and boundaries.

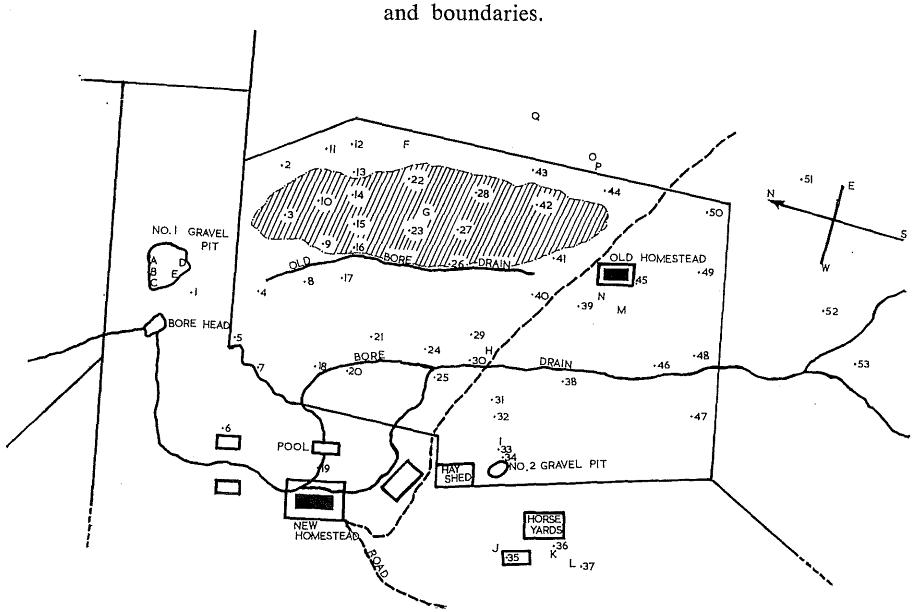

Fig. 2.—The "poison strip," showing the location from which soil samples (alphabetical code) and plant specimens (numerical code) were taken. Harrowed area indicated by hatching.

TABLE 1

SELENIUM CONTENT OF AIR-DRIED SOILS FROM THE "POISON STRIP" AREA

Map Reference	Description	Remarks	Selenium (p.p.m. Se)
A	Hard limestone shale	No. 1 gravel pit	24·6
B	Yellow lime gravelly clay	No. 1 gravel pit	2·7
C	White gritty clay loam	No. 1 gravel pit	2·5
D	Brittle lime laminates	No. 1 gravel pit	6·6
E	Brownish-yellow clay	Surface wash from No. 1 gravel pit	3·3
F	Yellowish-brown clayey lime gravel	0–6 in. above harrowed area	0·5
G	Brown clayey lime gravel	0–6 in. from harrowed area	3·2
H	Dark brown-grey clay	0–6 in. from flat area	32·2
I	Pale brownish-yellow clay	Surface wash from No. 2 gravel pit	3·4
J	Pale brown lime gravelly clay	0–12 in. homestead ridge	4·1
	Very pale brown lime gravelly clay	12–24 in. homestead ridge	4·5
	Very pale brown lime gravelly clay	24–36 in. homestead ridge	3·1
K	Yellowish-brown clayey lime gravel	0–6 in. homestead ridge	6·7
L	Yellowish-brown clay	Surface wash against obstruction	6·6
M	Dark-brown clay, strong crumb structure	0–6 in. from flat area	2·6
N	Dark-brown clay, strong crumb structure	0–6 in. from flat area	0·15
O	White salt deposit	Surface scrapings	8·2
P	Reddish-brown clayey lime gravel	0–6 in. beneath scraped area	1·7
Q	Precipitated lime mass	In fault in sandstone boulder	2·5

(ii) *Land Use and Vegetation*.—The district was taken up for extensive grazing about a century ago and the present sheep grazing property reselected 50 years later. During the next 40 years improvements were restricted to fencing and the provision of water by systems of bore drains radiating from artesian bores. The 70-ac enclosure (Figure 1) was fenced in 1921 and the first of several major disturbances of the clay shales of the area occurred in 1951. The slopes of the eastern ridge above the old bore drain were cleared of brush and harrowed to a depth of 18 in. and two gravel pits were developed. During the next seven years both pits were enlarged, a pool was constructed and in 1959 the upper flat area was ploughed and *Sorghum almum* planted.

When visited in 1960, the flat area of grey-brown heavy clay soils ploughed the year before carried an uneven stand of *Sorghum almum* interspersed with grasses, largely *Cynodon dactylon* (couch grass) and a wide variety of other miscellaneous species with the legume *Neptunia amplexicaulis* (Figure 3) predominating. The unharrowed upper slopes of the eastern ridge of calcareous clay shale were largely bare but carried scattered timber, mainly *Acacia cana* (boree) (Figure 4) with a few *Atalaya hemiglauca* (whitewood) and *Grevillea parallela* (beefwood) trees. *Enneapogon avenaceus* (ridge grass) was the most common of a variety of miscellaneous plant species. The lower slopes cleared, harrowed and planted with *Cenchrus ciliaris* (buffel grass) in 1951 carried regenerating brush, mainly *Acacia farnesiana* (mimosa) and young *Acacia cana* as well as grasses. The western ridge was also largely bare but a variety of plant species were present in areas where topsoil had washed against obstructions. The southern slopes and the southern end of the flat area carried stands of *Acacia cana* and *Neptunia amplexicaulis,* with *Sesbania aculeata* (sesbania pea) along the bore drain.

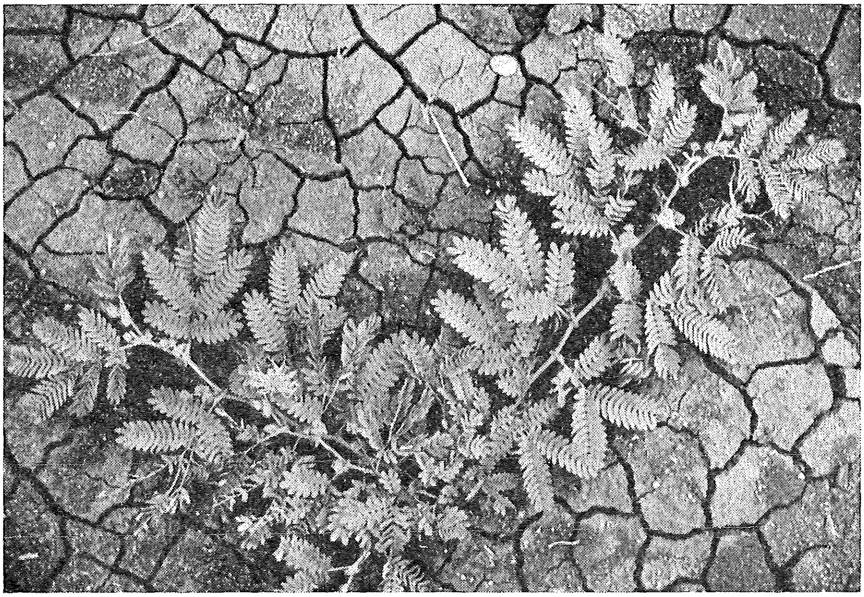

Fig. 3.—*Neptunia amplexicaulis*—a young specimen.

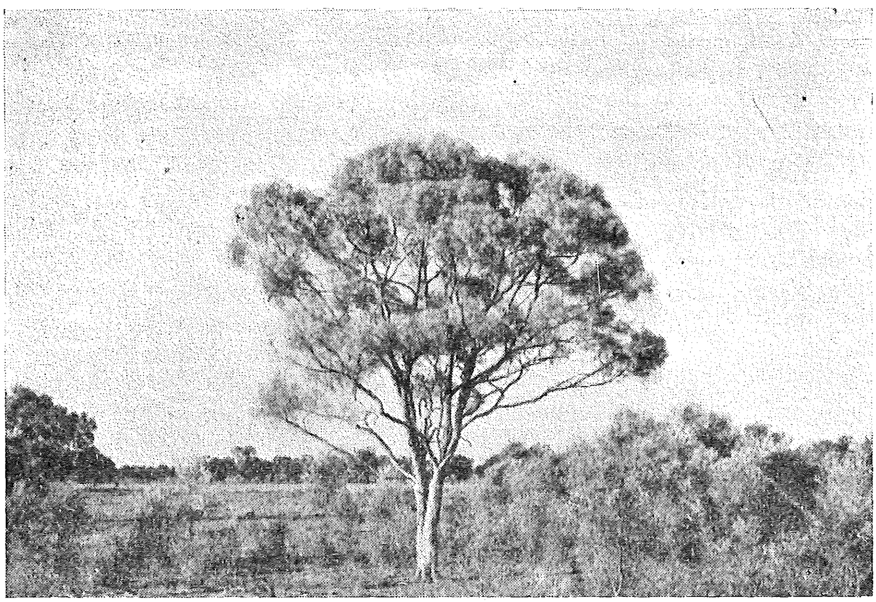

Fig. 4.—*Acacia cana*—a mature tree with seedlings.

The numerical code in Figure 2 gives the location from which plant specimens were taken for chemical analysis and the selenium levels are given in Table 2.

TABLE 2

SELENIUM CONTENT OF PLANTS FROM THE "POISON STRIP" AREA

Map Reference	Botanical Name	Common Name	Remarks	Selenium (p.p.m. Se D.M.)
1	*Cenchrus ciliaris* ..	Buffel grass	—	6·9
2	*Neptunia amplexicaulis*	A native sensitive plant	Above harrowed area ..	2211·6
3	*N. amplexicaulis* ..	A native sensitive plant	In harrowed area ..	1373·5
	Cenchrus ciliaris ..	Buffel grass		55·2
4	*Neptunia amplexicaulis*	A native sensitive plant	—	43·3
5	*N. amplexicaulis* ..	A native sensitive plant	—	25·7
6	*N. amplexicaulis* ..	A native sensitive plant	—	164·4
7	*Cynodon dactylon* ..	Couch grass	In ploughed area ..	11·1
	Flaveria australasica ..	Speedy weed		18·4
	Sorghum almum ..	—		6·8
	Neptunia amplexicaulis	A native sensitive plant		321·9
8	*Sorghum almum* ..	—	In ploughed area ..	5·3
	Cajanus cajan	Poona pea		30·7
9	*Cenchrus ciliaris* ..	Buffel grass	In harrowed area ..	77·6
10	*Neptunia amplexicaulis*	A native sensitive plant	In harrowed area ..	4334·0
11	*N. amplexicaulis* ..	A native sensitive plant	Above harrowed area ..	3569·0
12	*N. amplexicaulis* ..	A native sensitive plant	Above harrowed area ..	691·5
13	*N. amplexicaulis* ..	A native sensitive plant	Above harrowed area ..	4147·0
14	*Cenchrus australis* ..	Hillside burr grass ..	In harrowed area ..	71·1
15	*Neptunia amplexicaulis*	A native sensitive plant	In harrowed area ..	1915·3
16	*Acacia cana*	Boree	—	1121·4
17	*Sorghum almum* ..	—	—	21·0
	Neptunia amplexicaulis	A native sensitive plant	—	404·4
18	*Chloris barbata* ..	Purple-top chloris ..	—	104·8
19	*Solanum esuriale* ..	Quena	—	<0·5
20	*Dactyloctenium radulans*	Button grass	—	16·2
21	*Neptunia amplexicaulis*	A native sensitive plant	—	87·2
22	*Acacia cana*	Boree	—	901·8
23	*Aerva persica*	Kapok bush	In harrowed area ..	115·8
24	*Neptunia amplexicaulis*	A native sensitive plant	In ploughed area ..	1323·6
	Cynodon dactylon ..	Couch grass		163·0
	Chloris barbata ..	Purple-top chloris ..		21·2
25	*Neptunia amplexicaulis*	A native sensitive plant	In local wash area ..	3519·3
26	*Amaranthus interruptus*	A native amaranth ..	In harrowed area ..	65·6
27	*Acacia salicina* ..	Doolan	In harrowed area ..	173·7
28	*Acacia farnesiana* ..	Mimosa	In harrowed area ..	79·4
29	*Neptunia amplexicaulis*	A native sensitive plant	From edge of ploughed area	1957·3
	N. anplexicaulis ..	A native sensitive plant		2485·7
	N. amplexicaulis ..	A native sensitive plant		3949·0
	N. amplexicaulis ..	A native sensitive plant		1143·2
30	*N. amplexicaulis* ..	A native sensitive plant	From edge of ploughed area	4164·0
	Cynodon dactylon ..	Couch grass		263·3
31	*Chloris virgata*.. ..	Feathertop Rhodes grass	In wash of pit	24·4
	Neptunia amplexicaulis	A native sensitive plant		47·2
	Enneapogon oblongus ..	Bottle-washer grass ..		<0·5
	Digitaria ctenantha ..	—		<0·5
	Eragrostis setifolia ..	Neverfail grass ..		<0·5
	Urochloa panicoides ..	Urochloa grass ..		<0·5
32	*Neptunia amplexicaulis*	A native sensitive plant	—	390·4

TABLE 2—continued

SELENIUM CONTENT OF PLANTS FROM THE "POISON STRIP" AREA—*continued*

Map Reference	Botanical Name	Common Name	Remarks	Selenium (p.p.m. Se D.M.)
33	*Cynodon dactylon* ..	Couch grass	From lip of pit	15·6
34	*Neptunia amplexicaulis*	A native sensitive plant	From pit	39·4
35	*N. amplexicaulis* ..	A native sensitive plant	—	133·8
	Malvastrum spicatum	Malvastrum	—	6·2
	Rhynchosia minima ..	—	—	34·4
36	*Neptunia amplexicaulis*	A native sensitive plant	—	152·3
	Polonisia viscosa ..	Tick weed	—	19·7
37	*Neptunia amplexicaulis*	A native sensitive plant	In local wash area ..	870·4
	Glossogyne tenuifolia ..	Native cobbler's peg ..		31·6
38	*Neptunia amplexicaulis*	A native sensitive plant	—	319·5
	Cynodon dactylon ..	Couch grass	—	45·0
39	*Neptunia amplexicaulis*	A native sensitive plant	—	934·6
	N. amplexicaulis ..	A native sensitive plant	—	798·3
	N. amplexicaulis ..	A native sensitive plant	—	610·7
	N. amplexicaulis ..	A native sensitive plant	—	1165·3
	Cynodon dactylon ..	Couch grass	—	125·8
	Sesbania aculeata ..	Sesbania pea	—	55·4
40	*Sorghum almum* ..	—	—	15·8
	Sorghum almum ..	—	—	14·6
41	*Eragrostis setifolia* ..	Neverfail grass ..	—	49·3
	Enneapogon avenaceus	Ridge grass	—	7·9
	Cassia occidentalis ..	Coffee senna	—	11·1
	Nerium oleander ..	Oleander	—	9·9
42	*Neptunia amplexicaulis*	A native sensitive plant	From top of harrowed area	307·2
	Setaria oplismenoides	Native pigeon grass ..		23·0
	Cenchrus ciliaris ..	Buffel grass		53·9
43	*Neptunia amplexicaulis*	A native sensitive plant	From above harrowed area	438·2
44	*N. amplexicaulis* ..	A native sensitive plant	From above harrowed area	227·3
45	*N. amplexicaulis* ..	A native sensitive plant	—	111·1
46	*N. amplexicaulis* ..	A native sensitive plant	—	114·0
	Sesbania aculeata ..	Sesbania pea	—	22·5
47	*Neptunia amplexicaulis*	A native sensitive plant	—	30·3
48	*N. amplexicaulis* ..	A native sensitive plant	—	165·8
49	*N. amplexicaulis* ..	A native sensitive plant	—	58·3
50	*N. amplexicaulis* ..	A native sensitive plant	—	61·1
51	*N. amplexicaulis* ..	A native sensitive plant	In grazing paddock ..	41·5
52	*N. amplexicaulis* ..	A native sensitive plant	In grazing paddock ..	114·3
53	*N. amplexicaulis* ..	A native sensitive plant	In grazing paddock ..	40·1

(iii) *Livestock History*.—The area was enclosed in 1921 and used to maintain a horse and two or three milking cows. After 1951 it was used intermittently as a holding paddock. The association of livestock with this area has been:—

1921–1951: No abnormality reported in cows or horses: one horse had been in the paddock for 15 years.

1951: An introduced mare sloughed all four hoofs and was withdrawn. The cows remained apparently normal.

1954: A stallion almost died three weeks after introduction and sloughed hoofs. The cows remained normal.

1955: The stallion was again badly affected, and sloughed its hoofs before being withdrawn. The cows remained apparently normal.

1956: Five racehorses were introduced; one died in four weeks, three died subsequently after sloughing hoofs. The surviving horse and the cows were withdrawn. The cows were said to be in poor condition although receiving supplementary feed.

1957: One bull and 13 sheep died within 24 hr of being introduced to the paddock.

1960: Three mares and a yearling foal were introduced for 1-hr periods on three consecutive days. The yearling died on the fourth day. Three weeks later all mares were lame. One mare aborted, lost all body hair but retained its mane and tail hair.

The selenium contents of samples from livestock associated with the "poison strip" are given in Table 3.

TABLE 3

SELENIUM CONTENT OF TISSUES FROM ANIMALS IN THE "POISON STRIP" AREA

Specimen	Remarks	Selenium (p.p.m. Se on "as received" basis)
Hoofs	From horses lost in 1956	1·0, 0·8, 1·2
Liver	From sheep lost in 1957	24·7
Kidney	From sheep lost in 1957	7·0
Mane hair	From yearling horse lost in 1960	24·1
Body hair	From affected mare 1960	140·6
Hoof	From aborted equine foetus 1960	7·1
Faeces	From affected mare 1960	5·9

(b) Examination of Areas Adjacent to the "Poison Strip"

This examination was confined largely to the major topographical and soil type subdivisions elsewhere on the affected property but included features of interest on two adjoining properties.

(i) *Topography and Soil Type*.—The affected property comprises 42,000 ac of grazing land. It is divided almost equally between exposed clay limestone shales of the Tambo Formation and overlying brown-soil downs. The western part of the property consists largely of open brown-soil downs, timbered along the watercourses but includes an outcrop of Tambo Formation along the northern boundary. The eastern part of the property, including the homestead area, consists of elevated, broadly undulating, timbered calcareous clay shale ridges totalling 18,000 ac in extent. Small areas of grey-brown heavy clay soils occur in local depressions. A portion of this system of timbered ridges is illustrated in Figure 5. The exposed Tambo Formation merges with the timbered brown earths along the line of the Flinders River to the south and joins quite sharply with the undulating brown-soil downs to the north. Portion of this junction is shown in

Figure 6. In addition, small, sharply defined ridges of exposed limestone shale occur as crests in the undulating downs. Figure 7 illustrates this type of outcrop, while the laminated nature of the clay limestone shales is illustrated in Figure 8. The Tambo Formation examined elsewhere on the property was similar to the 70-ac enclosure more intensively investigated.

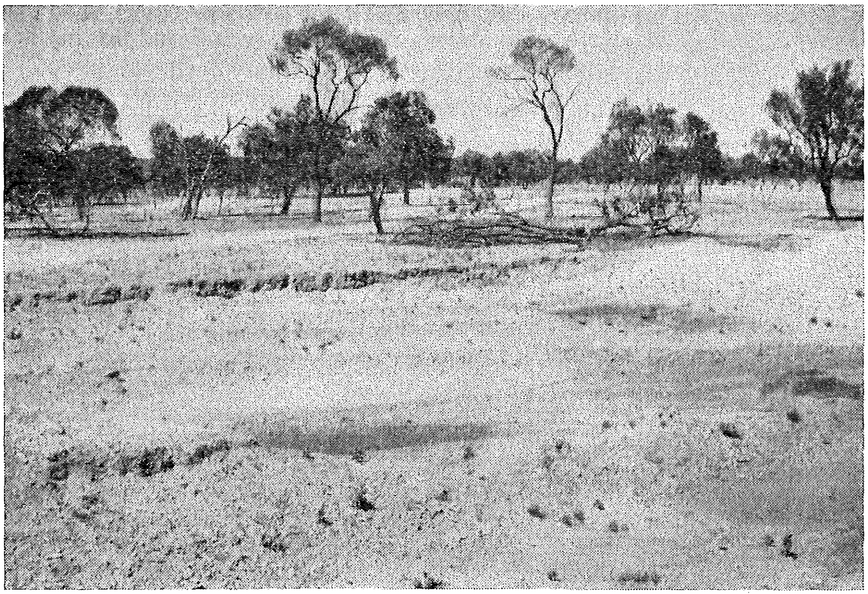

Fig. 5.—Exposed Tambo Formation occurring as timbered broadly undulating ridges.

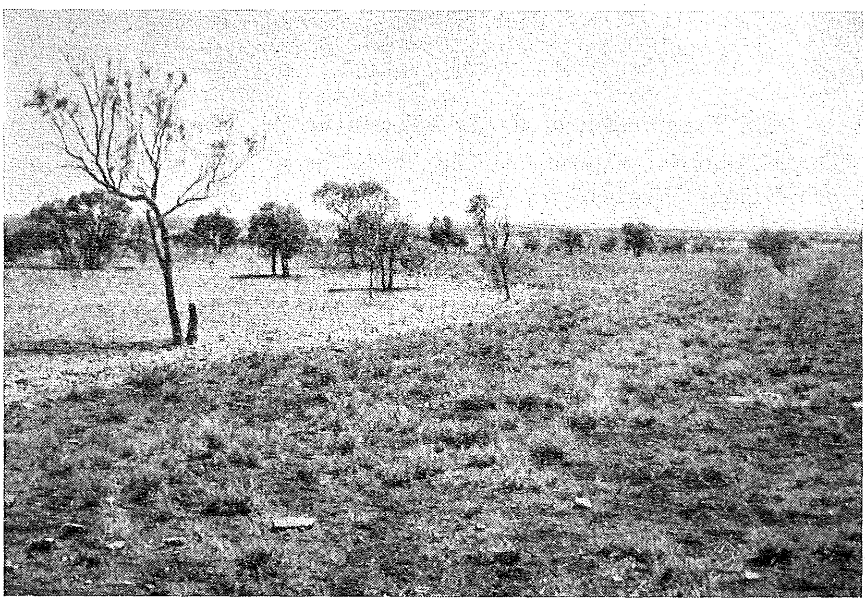

Fig. 6.—Exposed Tambo Formation merging with undulating brown-soil downs.

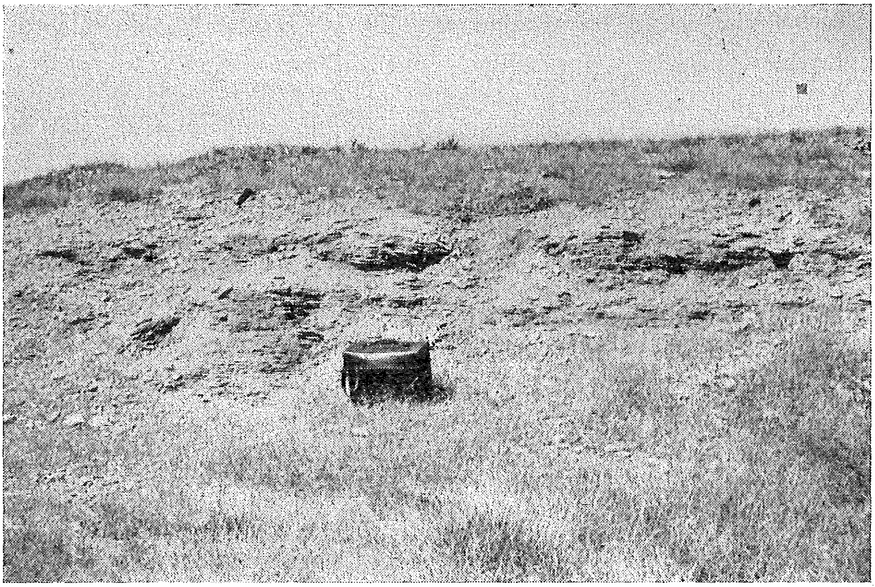

Fig. 7.—Exposed Tambo Formation occurring as a crest in the undulating brown-soil downs.

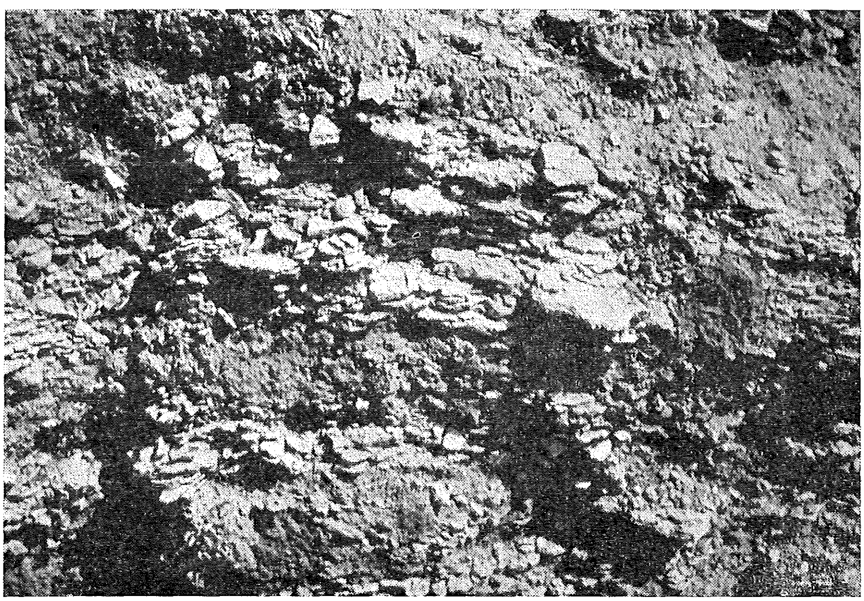

Fig. 8.—Detail of Tambo Formation, showing laminated limestone shale and clays.

Samples of rock and soil similar to those from the enclosure were taken. To provide samples of the various strata in the Tambo Formation, advantage was taken of a 15-ft deep erosion gully on the property and of an extensive gravel pit outside the affected property but adjacent to it. Samples were also taken from the timbered brown earths adjacent to the Flinders River and from a 25-ft deep vertical bank where recent flood erosion had exposed a calcareous shaly shelf in the new river channel. Additional samples were taken from the undulating brown-soil downs and from a ridge rising sharply from these downs on an adjoining property. This ridge of white calcareous clay was underlain with yellow-brown clays. Its steeper eroding slopes consisted of friable platy calcareous clay of all shades from white to red.

Figure 9 shows the relative distribution of the exposed Tambo Formation and the overlying brown soils, the boundaries and subdivisions of the affected property and the location of adjoining properties. The alphabetical code gives the location of soil or rock samples taken from these areas. The selenium content and descriptions of these samples are given in Table 4.

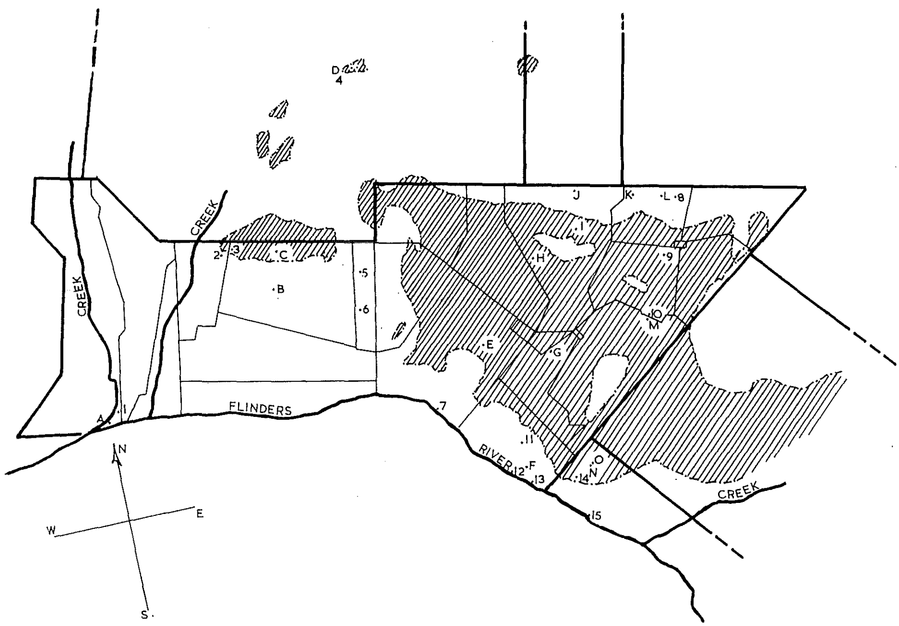

Fig. 9.—The affected property, showing the distribution of the exposed Tambo Outcrop (hatched areas), the location of features, subdivisions and boundaries, and the location of soil samples (alphabetical code) and plant specimens (numerical code).

TABLE 4

SELENIUM CONTENT OF ROCKS AND AIR-DRIED SOILS FROM AREAS ADJACENT TO THE "POISON STRIP"

Map Reference	Description	Remarks	Selenium (p.p.m. Se)
A	Dark grey brown heavy clay ..	0–1 ft (eroded river bank)	0 03
	Yellow brown heavy clay ..	1–3 ft (eroded river bank)	0·09
	Yellow brown silty clay ..	3–4 ft eroded river bank ..	0·11
	Yellow sandy clay loam ..	20 ft (eroded river bank)	0·05
	Yellowish white shale	25 ft (eroded river bank)	0·13
B	Very dark grey heavy clay ..	0–6 in. from stony downs	0·47
C	Pale brown clayey lime gravel ..	0–6 in. on Tambo outcrop	6·12
D	White calcareous clay	0–6 in. (exposed clay ridge)	0·7
	Yellow brown clay	From excavation site (exposed clay ridge)	4·8
	Limonitic concretion	From clay, excavation site (exposed clay ridge)	385·0
	Limonitic concretion	In sandstone, excavation site (exposed clay ridge)	176·0
	Yellow clay with platey structure	Eroding end .. .. (exposed clay ridge)	1·7
	Light red clay with platey structure	Eroding end .. .. (exposed clay ridge)	3·8
	Red clay with platey structure ..	Eroding end .. .. (exposed clay ridge)	2·7
	Brown earth with white wash ..	Wash from eroding end .. (exposed clay ridge)	23·7
E	Limestone shale	(from pit in Tambo outcrop)	28·9
	Yellow clay limestone shale ..	from pit in Tambo outcrop	1·0
	Yellow lime gravelly clay ..	(from pit in Tambo outcrop)	2·5
F	Dark brown clay loam	Near Flinders River	0·3
G	Brown heavy clay	Plain on Tambo outcrop	1·0
H	Dark brown heavy clay ..	0–6 in. (erosion gully, Tambo outcrop)	2·6
	Yellow brown heavy clay ..	2–3 ft (erosion gully, Tambo outcrop)	1·0
	Limestone shale	5 ft (erosion gully, Tambo outcrop)	1·1
	Yellow clay shale	6 ft (erosion gully, Tambo outcrop)	4·3
	Ironstone band	8 ft erosion gully, Tambo outcrop	3·3
	Red sandstone	10 ft (erosion gully, Tambo outcrop)	6·4
	Red clay shale	12 ft (erosion gully, Tambo outcrop)	2·1
	Yellow clay shale	14 ft (erosion gully, Tambo outcrop)	2·6
	Brittle yellow shale	15 ft (erosion gully, Tambo outcrop)	1·1
I	Pale brown clay lime gravel ..	0–6 in. (Tambo outcrop)	3·3
	Lime gypsum shale	6–12 in. Tambo outcrop	1·0
J	Dark yellowish-brown silty clay loam	0–6 in. undulating downs	1·4
K	Dark brown clay	0–6 in. undulating downs	1·1
L	Reddish-brown heavy clay ..	0–6 in. undulating downs, old cultivation	2·0
M	Reddish-brown heavy clay ..	Wash area, Tambo outcrop	1·0
N	Limestone shale	(Gravel pit, Tambo outcrop)	0·5
	White clay loam band	(Gravel pit, Tambo outcrop)	2·0
	Pale pink clay limestone ..	(Gravel pit, Tambo outcrop)	3·0
	Rouge band	(Gravel pit, Tambo outcrop)	96·2
	Rouge band	Gravel pit, Tambo outcrop	68·0
	Rouge band	(Gravel pit, Tambo outcrop)	67·1
	Pale pink shaley limestone ..	(Gravel pit, Tambo outcrop)	1·9
	Pink calcareous gravel	(Gravel pit, Tambo outcrop)	2·9
	Orange-red clayey gravel ..	(Gravel pit, Tambo outcrop)	73·5
O	Yellow brown heavy clay ..	Wash from pit to downs	2·3

(ii) *Land Use and Vegetation.*—The property is largely devoted to sheep raising under extensive grazing conditions. Since 1951 agriculture on the "poison strip" area and some cultivation and pasture hay-making on the undulating downs near the north-eastern boundary of the property have occurred.

The extensive series of ridges making up the exposed Tambo Formation on this property are timbered with *Acacia cana, Acacia cambagei* (gidyea), *Atalaya hemiglauca, Grevillea parallela, Ventilago viminalis* (supplejack) and *Denhamia obscura* (Christmas bush). On the softer, moister localities *Eremophila mitchellii* (budda), *Ziziphus mauritiana* (China apple) and *Acacia farnesiana* are found also. The main grass is *Enneapogon avenaceus.* On the edges of the ridges, *Aristida arenaria* (kerosene grass), *Themeda australis* (kangaroo grass) and *Bothriochloa ewartiana* (desert Mitchell grass) grow in good seasons. Legumes, particularly *Neptunia amplexicaulis,* are found in the softer areas of the exposed Formation. The undulating downs is grassed with species of *Iseilema* (Flinders grasses) and *Dichanthium fecundum* (Gulf blue grass), with *Cynodon dactylon* along the bore drains, while *Astrebla squarrosa* (bull Mitchell grass) and species of *Aristida* (feathertops) predominate on the brown soils adjacent to the main watercourses. Watercourses carry *Eucalyptus microtheca* (coolibah) and other large gums. Plant samples taken for analysis during the examination of the grazing paddocks on the affected property were confined where possible to *Neptunia amplexicaulis,* but this species was not common on the open downs.

Table 5 gives the selenium content and other information concerning plant specimens taken during the examination of areas adjacent to the "poison strip". Sampling sites are defined by the numerical code in Figure 9.

TABLE 5

SELENIUM CONTENT OF PLANTS FROM AREAS ADJACENT TO THE "POISON STRIP"

Map Reference	Botanical Name	Common Name	Remarks	Selenium (p.p.m. Se D.M.)
1	*Neptunia gracilis*	A native sensitive plant	On brown earth, river bank	<0·5
2	*N. gracilis*	A native sensitive plant	From edge of Tambo outcrop	25·4
	N. monosperma	A native sensitive plant		1·4
3	*N. amplexicaulis*	A native sensitive plant	From pit in Tambo outcrop	21·4
4	*N. amplexicaulis*	A native sensitive plant	From clay ridge	4·9
	Medicago sativa	Lucerne		2·3
	Neptunia amplexicaulis	A native sensitive plant		13·9
5	*N. amplexicaulis*	A native sensitive plant	From stony downs	172·8
6	*Cynodon dactylon*	Couch grass	Near bore drain	28·1
7	*Neptunia amplexicaulis*	A native sensitive plant	From brown earth, river bank	32·4
	N. gracilis	A native sensitive plant		<0·5
8	*Dichanthium fecundum*	Gulf blue grass	In old cultivation	5·3
	Iseilema sp.	A Flinders grass		4·6
9	*Cynodon dactylon*	Couch grass	From bank of dam, on Tambo outcrop	14·9
	Sesbania aculeata	Sesbania pea		29·1

TABLE 5—continued

SELENIUM CONTENT OF PLANTS FROM AREAS ADJACENT TO THE "POISON STRIP"—continued

Map Reference	Botanical Name	Common Name	Remarks	Selenium (p.p.m.Se D.M.)
10	*Neptunia amplexicaulis*	A native sensitive plant	In wash area, Tambo outcrop	14·4
11	*N. amplexicaulis* ..	A native sensitive plant	From undulating downs	227·1
12	*N. amplexicaulis* ..	A native sensitive plant	From brown earth, river bank	19·3
13	*N. amplexicaulis* ..	A native sensitive plant	From brown earth, river bank	28·6
14	*N. amplexicaulis* ..	A native sensitive plant	From brown earth, near pit Tambo outcrop	4·8
	N. amplexicaulis ..	A native sensitive plant		18·2
	N. amplexicaulis ..	A native sensitive plant		36·5
	N. amplexicaulis ..	A native sensitive plant		19·7
	N. gracilis	A native sensitive plant		16·6
15	*N. amplexicaulis* ..	A native sensitive plant	From brown earth, river bank	141·6

(iii) *Livestock History.*—This well-managed and valuable property carries about 12,000–14,000 sheep, 100 cattle and 50 horses, and its carrying capacity, lambing percentages and fleece weights are equal to the district average. Because of the large area carrying edible scrub as top feed, this property is regarded as being safer in times of drought than those on the treeless downs. Apart from fleece shedding in about 5 in every 1,000 sheep, no abnormality occurs in the sheep flock, and cattle on the property show no abnormality. All horses were examined and about 10 cases of very moderate alkali disease were observed. Scant mane and tail hair and scaly bands on the hoofs were the main abnormalities.

Some biological specimens were collected from livestock on the affected property and analytical and field data are given in Table 6.

TABLE 6

SELENIUM CONTENT OF TISSUES FROM ANIMALS IN AREAS ADJACENT TO THE "POISON STRIP"

Specimen	Remarks	Selenium (p.p.m. Se on "as received" basis)
Tail hair	From introduced stock horse, scant mane and tail, scaly hoofs	9·6
Tail hair	From stock horse, scant mane and tail, scaly hoofs ..	11·0
Tail hair	From introduced thoroughbred, poor condition, previously lame, scant mane and tail, scaly hoofs ..	13·5
Faeces	From horses grazing on undulating downs	2·7
Feet trimmings ..	From ewe, partially shed fleece, overgrown hoofs ..	45·0
Wool	From same ewe, broken fleece	9·1
Wool	From same ewe, regrowth fleece, 1 cm staple length ..	14·8
Wool	From ewe showing tender wool, same flock	2·7
Wool	From normal ewe, same flock	6·0
Wool	From aged ewe, poor wool	2·7
Wool	From normal sheep, fine wool	5·9
Wool	From normal sheep, strong wool	4·7
Wool	From normal sheep, poor wool	2·0

(c) Observational Traverse Along the Landsborough Highway

(i) *Topography and Soil Type.*—The Landsborough Highway transects the Tambo Formation for a distance of 200 miles between the towns of Hughenden and Julia Creek. For a distance of 150 miles westward from Hughenden it lies just south of the Flinders River. It traverses open grasslands of brown clay soils with small intrusions of clay-pans about Hughenden. Undulations and sparsely timbered broad ridges occur towards Richmond. The underlying Tambo Formation was observed as an outcrop from a broad undulation about 30 miles east of Richmond. West of Richmond, open grasslands of brown or black clay soils occur and continue to within about 50 miles of Julia Creek. At this point the Flinders River sweeps north from the highway and the undulations become steeper and ridge-like, with some timber. An outcrop of Tambo limestone shales occurs on a ridge 6 miles east of Julia Creek. On this outcrop an extensive gravel pit is located.

Samples of soil were taken along the Flinders River at Hughenden, from the flat open grasslands, from the undulating brown-soil downs and from the exposed Tambo Formation near Richmond and near Julia Creek. Figure 10 shows the extent of the Tambo Formation and the location of towns and of portion of the Flinders River and Landsborough Highway. The selenium content and description of soil samples taken during this traverse are given in Table 7.

TABLE 7

SELENIUM CONTENT OF ROCKS AND AIR-DRIED SOILS COLLECTED DURING AN OBSERVATIONAL TRAVERSE OF THE NORTHERN PORTION OF THE TAMBO FORMATION ALONG THE LANDSBOROUGH HIGHWAY FROM HUGHENDEN TO JULIA CREEK

Location	Description	Remarks	Selenium (p.p.m. Se)
Hughenden	Brown heavy clay alluvium	0–6 in. near Flinders River . .	2·6
Hughenden – Richmond	Brown heavy clay . .	0–6 in. flat open downs . .	0·3
Hughenden – Richmond	Grey brown clay . .	0–6 in. high undulation . .	0·6
Hughenden – Richmond	Limestone shale	Exposed Tambo formation . .	14·5
Richmond–Julia Creek	Brown calcareous clay . .	Pit in exposed Tambo formation	3·9
Richmond–Julia Creek	Yellow clay	Wash from pit	2·5
Richmond–Julia Creek	Yellow-brown lime gravelly clay	Pit in exposed Tambo formation	4·8
Richmond–Julia Creek	Limestone shale	Pit in exposed Tambo formation	5·5
Richmond–Julia Creek	Limestone shale	Pit in exposed Tambo formation	12·7
Richmond–Julia Creek	Yellowish-brown heavy clay	Adjacent overlying soil . .	0·3

(ii) *Land Use and Vegetation.*—The route of the traverse was largely confined to open grasslands interspersed with some sparsely timbered and shaded elevated areas. This region contains most of the 3 million sheep that are extensively grazed in the shires of Flinders, Wyangarie and McKinlay. These shires, embracing about 25 million acres, also carry 250,000 cattle, largely north of the Flinders River. This most northerly portion of Queensland's sheep area provides a harsh environment for sheep. Summer temperatures are high and prolonged

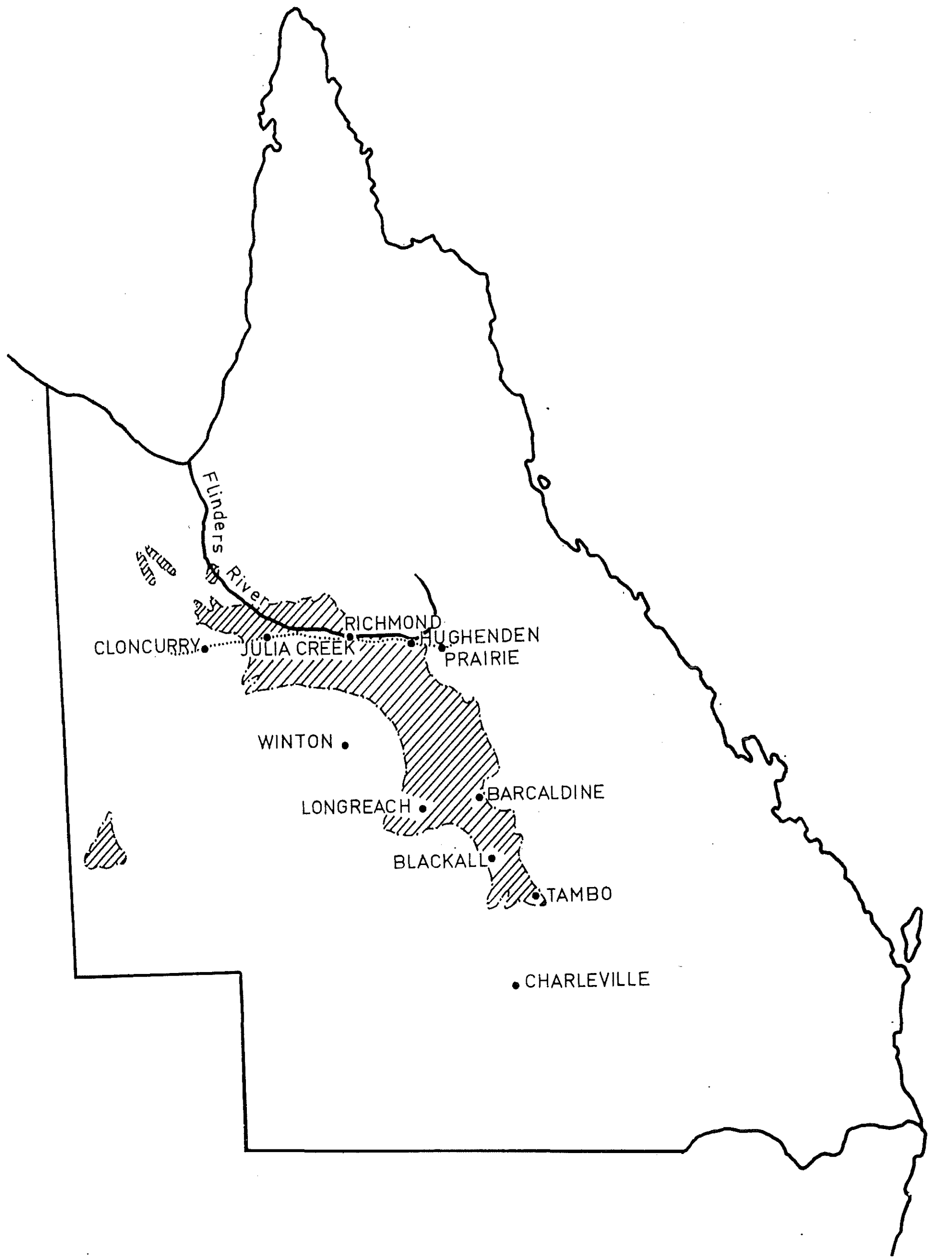

Fig. 10.—The extent of the Tambo Formation (hatched areas) in Queensland, showing portion of the Landsborough Highway (dotted line).

periods of hot weather occur. The region may experience six consecutive months with mean maximum temperatures exceeding 95°F. Summer rains are important but the region is semi-arid. Average rainfall is about 17 in. but the area receives effective rainfall in only two summer months in 75 per cent. of years. Long periods on pastures of low feed value and prolonged exposure to sun cause faults in the quality of wool.

On the open grasslands, species of *Astrebla* (Mitchell grasses) and *Iseilema* predominate. Other grasses are *Dactyloctenium radulans* (button grass), *Chloris virgata* (feathertop Rhodes grass) and *Eulalia fulva* (browntop). Herbage is less prevalent here than in the more southern latitudes, but various legumes including species of *Sesbania, Swainsona, Neptunia* and *Psoralea* occur together with species of *Amaranthus, Euphorbia* and *Sida.* Lightly timbered ridges carry mainly *Acacia cambagei, Ventilago viminalis, Atalaya hemiglauca* and *Ehretia saligna.*

During the traverse of this area plant collection was confined to readily available legumes as they might be expected to be more efficient accumulators of selenium than grasses. The location and selenium content of plants collected from this area are given in Table 8.

TABLE 8

SELENIUM CONTENT OF PLANTS COLLECTED DURING AN OBSERVATIONAL TRAVERSE OF THE NORTHERN PORTION OF THE TAMBO FORMATION ALONG THE LANDSBOROUGH HIGHWAY FROM HUGHENDEN TO JULIA CREEK

Location	Botanical Name	Common Name	Remarks	Selenium (p.p.m. Se D.M.)
Hughenden	*Crotalaria novae-hollandiae*	A rattlepod ..	From town environs	18·5
	Cassia occidentalis	Coffee senna ..		7·9
	Aeschynomene indica	Budda tea ..		13·1
Hughenden	*Neptunia amplexicaulis*	A native sensitive plant	On Flinders River bank	105·4
Hughenden	*N. amplexicaulis* ..	A native sensitive plant	Near Flinders River	49·3
Hughenden	*N. amplexicaulis* ..	A native sensitive plant	Near Flinders River	48·7
Hughenden–Richmond	*N. gracilis* ..	A native sensitive plant	From flat brown soil downs	<0·5
Hughenden–Richmond	*N. gracilis* ..	A native sensitive plant	From undulating brown soil downs	<0·5
Hughenden–Richmond	*N. amplexicaulis* ..	A native sensitive plant	On exposed Tambo formation	66·9
Hughenden–Richmond	*N. gracilis* ..	A native sensitive plant	On undulating downs	<0·5
Richmond–Julia Creek	*N. monosperma* ..	A native sensitive plant	On flat brown soil downs	<0·5
Richmond–Julia Creek	*N. amplexicaulis* ..	A native sensitive plant	On exposed Tambo formation	47·3
Richmond–Julia Creek	*N. amplexicaulis* ..	A native sensitive plant	On exposed Tambo formation	34·3

(iii) *Livestock History.*—The area traversed is devoted entirely to extensive grazing for wool production. Sheep numbers fluctuate because of frequent and protracted periods of drought. Wool cuts of about 7 lb per head are about 12 per cent. below the Queensland average. Nutritional and climatic stress and a high proportion of aged sheep in the area are major contributing factors to lowered wool production.

Reproduction rates are low. The lambing percentage at 38 per cent. is about 75 per cent. of the average for Queensland flocks. Many factors are responsible. High summer temperatures and shade inadequacies cause low ram fertility. Irregular rainfall causes pasture variations which make the timing of mating or lambing difficult. Aged sheep are retained as the remoteness from markets makes their disposal rarely practicable or profitable. Lamb raising is difficult due to heat, drought and the presence of predators.

Disease problems including parasitism are in general of lesser importance than in southern sheep areas. No known condition directly attributable to selenium excess is endemic in the area but apparent alkali disease of sheep manifest as serious stock losses accompanied by wool and hoof shedding has been reported. The three or four such occurrences reported during the last 30 years have been widely separated and remain as unique occurrences in the livestock history of the properties concerned.

IV. DISCUSSION

The selenium problem in the Hughenden–Richmond district is potentially similar to that occurring in Wyoming, Nebraska and the Dakotas in the U.S.A. In both continents the problems are based on similar geological formations of similar geological age and set in areas of semi-arid climate. A legume of major selenium-accumulating status is present in each area.

In its gross geology the exposed Tambo Formation, despite topographical and botanical differences, exhibits a similarity to the Niobrara Formation in eastern Wyoming as described by Trelease and Beath (1949). These authors describe the Niobrara Formation in eastern Wyoming as consisting of "grey to buff or cream-coloured calcareous shales with some sandstones and limestones".

The selenium content of rock and soil samples from various long-exposed strata and in eroded gullies and gravel pits confirms the similarity between the Niobrara and the Tambo Formations. In the Niobrara Formation the co-precipitation of selenium and iron in the form of limonitic concretions has been reported by Trelease and Beath (1949). Similar limonitic concretions and rouge bands of high selenium content were found in the Tambo Formation.

In Queensland the seleniferous area is devoted to extensive grazing—a situation pertaining in the U.S.A. during the last century—and the more spectacular effects of selenium excess have been revealed by an intensification of land use. A similar intensification both of land use and in the selenium problem occurred in the U.S.A. as farming replaced extensive grazing at the end of the last century.

Contrary to conditions then pertaining in the U.S.A., intensification of land use in Queensland is occurring when the cause of selenosis has been established. This has enabled a different approach to the problem. The present investigation of the acutely toxic area has been directed towards an examination of the factors involved in the intensification of land use. In particular, emphasis has been placed on measuring available selenium in a number of discrete areas within the "poison strip" and evaluating the influence of agricultural practices on the recent redistribution of this selenium.

The selenium content of rocks and soils indicate that the flat watercourse and the adjoining ridges both inside and outside the fenced area embracing the "poison strip" are highly seleniferous. It was evident from observations and from consideration of the topography of this area that the central flat watercourse had received both its soil and its selenium from past weathering of the adjacent ridges and that this process had largely ceased when the ridges had weathered to a hard-cap of limestone or gypsum. Recent disruption of this hard-cap and the exposure of friable calcareous clay shales had occurred on both ridges and at the head of the flat, allowing further transport of selenium-bearing material over the area.

At the head of the flat but outside the fenced area an extensive pit has been excavated. This pit is located in the line of main drainage from the high ridges to the north-east and provides for extensive wash of newly exposed friable clay shale onto the flat watercourse and directed down its whole length. The limestone shale in this pit has the particularly high selenium content of 24·6 p.p.m. Se, but the 2–6 p.p.m. Se contained in its more readily dispersed components is similar to concentrations found in the area generally.

Harrowing of the eastern ridge disrupted a wide area of hard-cap but the positioning of the old bore drain and the contours ensured that wash from this area affected only the southern portion of the flat, largely down and beyond the road intersecting the flat. The selenium content of 3·2 p.p.m. Se in the top-soil of the harrowed area is greater than that from adjacent unharrowed soil but is similar to that in other unharrowed soils.

On the homestead ridge, roadworks and a small gravel pit disrupted the hard-cap, but wash from these areas is directed to the lower slopes above the main bore drain and out into adjoining grazing paddocks. A swimming pool constructed near the homestead is situated outside the fenced area and run-off from the site would not affect the "poison strip".

The overall indication from rock and soil analyses is that the area is highly seleniferous. The area of highest selenium content is at map reference N and has 32·3 p.p.m. Se. It is located in the line of wash from both the gravel pit at the head of the flat and the harrowed eastern ridge. This latter wash is directed by the old bore drain down the road towards this location. Samples from J illustrate the uniform distribution in the first 3 ft of the ridge. Sites O and P in a localized area of "salt" incrustation yielded samples that indicate that selenium is present in a soluble form.

An indication of the selenium-supplying power of these soils, an understanding of the development, extent and intensity of the seleniferous "poison strip" and a knowledge of the availability of selenium to livestock are given by the selenium content of plant specimens taken from recorded locations on the "poison strip".

To assess the selenium-supplying status of discrete areas within the 70-ac enclosure, locations yielding *Neptunia amplexicaulis* containing less than 200 p.p.m. Se or other species containing less than 20 p.p.m. Se were designated areas of minor selenium-supplying power. Selenium content greater than these but less than 500 and 50 p.p.m. Se respectively indicated areas of moderate selenium-supplying power. Areas yielding *Neptunia amplexicaulis* containing more than 500 p.p.m. Se or other species containing more than 50 p.p.m. Se were designated areas of major selenium-supplying power.

On this basis the whole of the north-eastern portion of the enclosure above the old bore drain is of major selenium-supplying power. This extensive area embraces plant samples located both within and above the area harrowed in 1951. A second area of major selenium-supplying power occurs in the flat area above the junction of the road and the bore drain. A smaller area occurs below the old homestead and another in an area of local wash about map reference 37. The central and southern slopes of both the eastern and the western ridges are of moderate selenium-supplying power, as is the central flat area. This latter area merges with areas of minor selenium-supplying power at the head of this flat and about the extensive gravel pit. The southern end of the enclosure, including the lower slopes of both ridges and the flat watercourse, are of minor selenium-supplying power, as is their extension into the adjoining grazing paddock.

From an examination of the selenium levels in plants it is evident that the selenium problem in the "poison strip" has not been markedly intensified by the provision of readily dispersible material of high selenium-supplying power following recent disruption of the hard-cap. In the first place, the highly seleniferous area in the north-east includes the upper slopes of the ridge. These slopes were above the line of harrowing and are well beyond the influence of changes in agricultural practice introduced since 1951. In the second place, the similar selenium-supplying powers of the harrowed and unharrowed portions of the central slopes of this ridge suggest little redistribution of selenium. Thirdly, the selenium content of plants, particularly at the gravel pit at the head of the flat watercourse and generally over most of the flat area, does not indicate that wash is a major contributor to the recent intensification of selenosis in the area. The low selenium-supplying status of the southern end of the flat watercourse both inside and outside the enclosed area supports this conclusion.

On the other hand, the relatively small areas of major selenium-supplying power on the flat about the road and below the old homestead may have been influenced by soil dispersal factors new since 1951. Wash from the harrowed area directed by the old bore drain may have contributed selenium to both these areas, while the highly seleniferous area on the flat could also have been influenced by wash down the flat watercourse.

As the incidence of clinical selenosis undoubtedly followed disruption of the hard-cap in 1951, some consideration of factors other than dispersion is necessary. Change in plant distribution was an important end result of disruption of the hard-cap. Brush clearing and harrowing for the introduction of new pasture species also encouraged the spread of native plants not previously available over much of the enclosure.

Outbreaks of selenosis have been due to the intensification of an existing but dormant soil problem, the major contributing factor being the introduction of agricultural practices which have encouraged the germination and spread of *Neptunia amplexicaulis,* the main selenium-accumulating plant of the region, as well as encouraging the spread of introduced and native pasture species to formerly barren but highly seleniferous localities. Management by confining unacclimatized stock to a restricted highly selenized area has also contributed.

Plant analyses, as well as contributing to a knowledge of the varying selenium-supplying potential within the "poison strip," indicate that the area is a "poison strip" of major intensity. Trelease and Beath (1949) tabulate the maximum selenium content of plants from 105 geological Formations in 15 western States in the U.S.A. Compared with these data the maximum level of 4334 p.p.m. Se found in *Neptunia amplexicaulis* marks the Tambo Formation as a major supplier of selenium. The selenium content of the grasses *Cynodon dactylon* (263·3, 163·0, 125·8 p.p.m. Se), *Chloris barbata* (104·8 p.p.m. Se), *Cenchrus ciliaris* (77·6, 55·2, 53·9 p.p.m. Se) and *Cenchrus australis* (71·1 p.p.m. Se) indicates a "poison strip" of major intensity. *Acacia cana* demonstrates selenium availability in the area by accumulating the element in excess of 1000 p.p.m. Se in the leaves of a mature tree about 25 ft in height.

A most significant finding based on consideration of a single species is that *Sorghum almum,* introduced to the flat watercourse in 1959 as a cultivated perennial plant, is a relatively inefficient accumulator of selenium and its presence as a dominant species has reduced the hazard in portion of the "poison strip".

Of necessity, areas adjacent to the "poison strip" were not sampled in detail. Nevertheless, rock and soil samples from Tambo outcrops in grazing paddocks have a selenium content similar to comparable samples from the "poison strip". On this property alone exposed outcrops of the seleniferous Tambo Formation total 18,000 ac. Significant levels of selenium were found in samples of plants and soils from the undulating brown-soil downs and measurable levels of the element occur in the brown earths near the watercourses.

Apart from the "poison strip" area, disorders in livestock on the property due to an excess of selenium have been of a most moderate nature. Yet almost every specimen, whether of rock, soil, plant or animal origin, has contained significant levels of selenium. This suggests that under extensive grazing conditions of 1 sheep to 3 or 4 acres in this area the adverse effects of selenium excess are not apparent in terms of livestock health or livestock productivity.

Findings for the observational traverse of the northern portion of the Tambo Formation are generally similar to those on the affected property. Widely separated outcrops of the underlying formation were seleniferous and soils characteristic of vast areas of open grasslands contained measurable levels of selenium. The apparent absence of selenium-induced endemic disorders in sheep grazed extensively is contrary to the hypothesis of Brown and de Wet (1962), who suggest a possible role for selenium in the aetiology of several diseases of sheep in South Africa.

On the other hand, experience on the "poison strip" demonstrates clearly the toxic hazard associated with the intensive use of grazing areas which include outcrops of the Tambo Formation.

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