A

T H E S I S

entitled

VEGETATION STUDIES

in

THE EASTERN GOLDFIELDS OF WESTERN AUSTRALIA

with particular reference to

THEIR ROLE IN GEOLOGICAL RECONNAISSANCE AND MINERAL EXPLORATION

submitted for the

degree of

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ABSTRACT

Within the Eastern Goldfields vegetation studies have revealed that distinct associations characterise the different geologocial units. The relationship may be constant within a given field area but species differences may occur on similar rock types in different areas of the region. The physical and chemical environments are both influential in the establishment of geobotanical relationships; a vegetation association developed over an outcropping rock unit may vary from that growing on the similar unit when soil covered. Similarly, any marked changes occurring in the chemistry of the soil over differing rock types may be revealed by modifications in the plant assemblage. Thus, an increase in the soil metal content over the normal background content may affect the vegetation supported.

Soil geochemical anomalies over areas of mineralisation of nickel, copper and arsenic (gold) are not always characterised by recognisable geobotanical relations: where possible relationships are observable, as over part of the Jimberlana Dyke at Norseman, and over a limited

area at Kambalda, further work is necessary in similar localities of the region to substantiate them.

Biogeochemical analyses may usefully indicate areas where the concentration of metals in the soils becomes anomalous, thus indicating the location of potential mineralisation. The application of the biogeochemical method may be limited by the non-availability of elements for plant absorption.

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Abbreviations

As	Arsenic
Ca	Calcium
Cr	Chromium
Cu	Copper
Ft	Feet
Ins	Inches
K	Potassium
Mg	Magnesium
Na	Sodium
Ni	Nickel
Pb	Lead
ppm	Parts per million
Sp.	Species
T	Transect
Zn	Zinc

Botanical names

Amarantaceae

Amaranthus sp.

Gomphrena sp.

Ptilotus helichrysoides (F. Muell) F. Muell.

P. obovatus F. Muell.

Apiaceae

Trachymene ornata (Endl.) Druce

Apocynaceae

Alyxia buxifolia R. Br.

Caryophyllaceae

Polycarpaea glabra C.T. White et Francis

Casuarinaceae

Casuarina campestris Diels

C. cristata Mig.

C. helmsii Ewart et Gordon

Chenopodiaceae

Arthrocnemum halocnemoides Nees

Atriplex nummularia Lindl.

A. paludosa R. Br.

Bassia patenticuspis.R.H. Anderson

Kochia carnosa (Miq.) R.H. Anderson

K. georgei Diels

K. glomerifolia F. Muell.

K. pyramidata Benth.

K. radiata P.G. Wils.

Rhagodia gaudichaudiana Moq.

Combretaceae

Terminalia sp.

Compositae

Athrixia athrixioides (Sond et F. Muell) Druce

Brachycome perpusilla (Steetz) Benth var. *tenella* (Turcz) G. Davis

Calotis hispidula F. Muell.

Cephalipterum drummondii A. Gray

Cratystylis conocephala (F. Muell) S. Moore

C. subspinescens (F. Muell et Tate) S. Moore

Gnephosis ?*skirrophora* Benth.

Helichrysum davenportii F. Muell.

Helipterum adpressum W.V. Fitzg.

H. battii F. Muell.

H. chlorocephalum (Turcz) Benth.

H. demissum (A. Gray) Druce

H. humboldtianum (Gaud.) D.C.

H. polygalifolium D.C.

H. rubellum Benth.

H. tenellum Turcz.

H. variable (Sond.) Ostf.

Olearia muelleri Benth.

Podocoma sp.

Podolepis aristata Benth.

P. capillaris (Steetz) Diels

Schoenia cassinianum Gaud.

Senecio glossanthus (Sond.) Belcher

Trichocline sp.

Coniferae

Pinus contorta Boland

Podocarpus sp.

Pseudotsuga menziesii (Mirb.) Franco

Cruciferae

Stanleya pinnata Britton

Cupressaceae

Callitris verrucosa (A. Cunn et Endl.) F. Muell.

Cupuliferae

Nothofagus sp.

Quercus prinus Linn.

Cyperaceae

Bulbostylis barbata (Rottb.) C.B. Clarke

Fimbristylis sp.

Lepidosperma brunonianum Nees

Dilleniaceae

Hibbertia ?*pungens* Benth.

Ericaceae

Ledum palustre Linn.

Euphorbiaceae

Beyeria brevifolia (Muell-Arq.) Benth.

Ricinocarpus stylosus Diels

Ricinodendron africanus Muell.

Ficoidaceae

Disphyma australe Sol.

Frankeniaceae

Frankenia interioris Ostf.

Geraniaceae

Erodium cicutarium (L.) L'Her ex Ait.

E. cygnorum Nees

Goodeniaceae

Dampiera trigona De Vr. var. *latealata*

Scaevola spinescens R. Br.

Selliera sp.

Velleia rosea S. Moore

Goodenovieae

Brunonia sp.

Gramineae

Chrysopogon sp.

Danthonia bipartita F. Muell.

Eriachne mucronata R. Br.

Hordeum leporinum Link.

Plechtrachne sp.

Serrafalcus arenanius (Labill.) C.A. Gardner

Sorghum sp.

Stipa platychaeta Hughes

S. scabra Lindl.

Triodia irritans R. Br.

T. pungens R. Br.

T. scariosa Burbidge

Trisetum pumilum Kunth.

Labiatae

Becium homblei de Wild

Lamiaceae

<u>Prostanthera</u> <u>aspalathoides</u> A. Cunn.

<u>P</u>. <u>wilkieana</u> F. Muell.

<u>Westringia</u> <u>rigida</u> R. Br.

Laurinaceae

<u>Cinnamomum</u> sp.

<u>Laurus</u> sp.

Leguminosae

<u>Acacia</u> <u>acuminata</u> Benth.

<u>A</u>. <u>aneura</u> F. Muell.

<u>A</u>. <u>cochliocarpa</u> Meissn

<u>A</u>. <u>craspidocarpa</u> F. Muell.

<u>A</u>. <u>erinacea</u> Benth.

<u>A</u>. <u>graffianà</u> F. Muell.

<u>A</u>. <u>leptoneura</u> Benth.

<u>A</u>. <u>linophylla</u> W.V. Fitzg.

<u>A</u>. <u>merrallii</u> F. Muell var. <u>tamminensis</u>

<u>A</u>. <u>quadrimarginea</u> F. Muell.

<u>A</u>. <u>resinomarginea</u> Fitzg.

<u>A</u>. <u>salicina</u> Lindl.

<u>A</u>. <u>sowdenii</u> Maiden

<u>A</u>. <u>tetragonophylla</u> F. Muell.

Astragalus pattersoni A. Gray

A. preussi A. Gray var. *arctus*

Cassia artemisioides Gaud.

C. eremophila A. Cunn.

Cryptosepalum sp.

Daviesia ocanthoclona F. Muell.

Templetonia sulcata (Meissn) Benth.

Tephrosia sp. nov.

Malvaceae

Hibiscus sp.

Monimiaceae

Daphnandra sp.

Myoporaceae

Eremophila coerulea (S. Moore) Diels

E. decipiens Ostf.

E. dempsteri F. Muell.

E. drummondii F. Muell.

E. duttoni F. Muell.

E. gibsoni F. Muell.

E. glabra (R. Br.) Ostf.

E. granitica S. Moore

E. interstans (S. Moore) Diels

E. maculata F. Muell.

E. oppositifolia R. Br.

E. pachyphylla Diels

E. serrulata (A. Cunn.) Druce

E. weldii F. Muell.

Myoporineae

Myoporum platycarpum R. Br.

Myrtaceae

Calothamnus chrysantherus F. Muell.

Eucalyptus brevifolia F. Muell.

E. brockwayi C.A. Gardner

E. calycogona Turcz.

E. campaspe S. Moore

E. celastroidea Turcz.

E. clelandi Maiden

E. corrugata Lueh.

E. affin cylindrocarpa Blakely

E. diversicolor F. Muell.

E. diversifolia Boupl.

E. dundasii Maiden

E. flocktoniae Maiden

E. foecunda Schauer

E. gomphocephala D.C.

E. gongylocarpa Blakely

E. gracilis F. Muell.

E. kingsmilli Maiden et Blakely

E. leptophylla F. Muell.

E. lesouefii Maiden

E. marginata Sm.

E. melanoxylon Maiden

E. oleosa F. Muell.

E. oleosa F. Muell. var. *glauca* Maiden

E. oleosa F. Muell. var. *longicornis* F. Muell.

E. redunca Schau var. *elata*

E. salmonophloia F. Muell.

E. salubris F. Muell.

E. Stricklandi Maiden

E. torquata Lueh.

E. transcontinentalis Maiden

E. websteriana Maiden

Leptospermum roei Benth.

Melaleuca elliptica Labill.

M. lateriflora Benth.

M. sheathiana W.V. Fitzg.

M. uncinata R. Br.

Thryptomene sp.

Verticordia sp.

Wehlia sp.

Papilionaceae

Jacksonia hakeoides Meissn

Pittosporaceae

Pittosporum phillyraeoides D.C.

Plantaginaceae

Plantago varia R. Br.

Portulaceae

Calandrinia pusilla Lindl.

Proteaceae

Banksia sp.

Grevillea didymobotrya Meissn

G. nematophylla F. Muell.

G. petrophiloides Meissn

G. ?*pinifolia* Hook ex Meissn

G. sarissa S. Moore

Persoonia sp.

Rhamnaceae

Cryptandra ?*glabriflora* Benth.

Trymalium myrtillus S. Moore

Rutaceae

Eriostemon sp.

Santalaceae

Exocarpus aphylla R. Br.

Santalum acuminatum (R. Br.) D.C.

S. spicatum D.C.

Sapindaceae

Dodonaea boroniaefolia G. Don.

D. filifolia Hook.

D. lobulata F. Muell.

D. stenozyga F. Muell.

Solonaceae

Lycium australe F. Muell.

Sterculiaceae

Brachychiton gregorii F. Muell.

Urticaceae

Ficus sp.

Vacciniaceae

Vaccinium vitis-idaea Linn.

Violaceae

Hybanthus floribundus (Lindl) F. Muell.

Viola calaminaria Lej.

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INTRODUCTION

I. The location and mining activities of the Eastern Goldfields

The Eastern Goldfields are situated in the southern part of the State of Western Australia, east of Perth and west of the Nullarbor Plain. Kalgoorlie, 471 miles east of Perth, is the largest centre of the Goldfields and lies almost midway between Laverton (28.40S. 122.29E.) at the northern end of the region, and Norseman (32.10S. 121.48E.) at the southern. Coolgardie (30.55S. 121.8E.) and Menzies (29.43S. 121.0E.) are the main settlements on the western side. The sites of once-important gold mining townships, such as Bulong (30.42S. 121.50E.) and Kanowna (30.31S. 121.36E.) occur on the easterly limits of the Eastern Goldfields. Most of the centres shown on the location map (Figure 1) are no longer important settlements; they may still be marked by a few scattered dwellings or may consist only of a pattern of tracks on the ground where streets lined with houses once lay. Such is the case with Kanowna, where piles of rubble show where the town hall and other municipal buildings stood during its earlier prosperous days.

Besides the mining settlements of the past and present, the only other forms of settlement in the Eastern Goldfields are the sheep stations. The country is unsuitable for any other form of farming owing to the low rainfall.

Gold was first discovered in this region at Coolgardie by Bayley and Ford in 1892. Prospecting had previously been concentrated around Southern Cross, 120 miles to the west, but in the early 1890's prospectors and small parties began exploring and wandering eastwards more frequently. Bayley's Reward, the original discovery lease, heralded the beginning of the greatest gold rush in Western Australia's history. At Coolgardie gold was found in the alluvial form, as well as in rich reefs and shoots. The town was used as a base for parties exploring further north and east, and many discoveries were made during 1893 -- at Kunanalling, Goongarrie, Comet Vale and Ora Banda.

Gold was found at Kalgoorlie by Hannan during June, 1893, and this was ultimately to prove a more lasting and richer gold area, but for a time other finds appeared

LOCALITY MAP OF THE EASTERN GOLDFIELDS

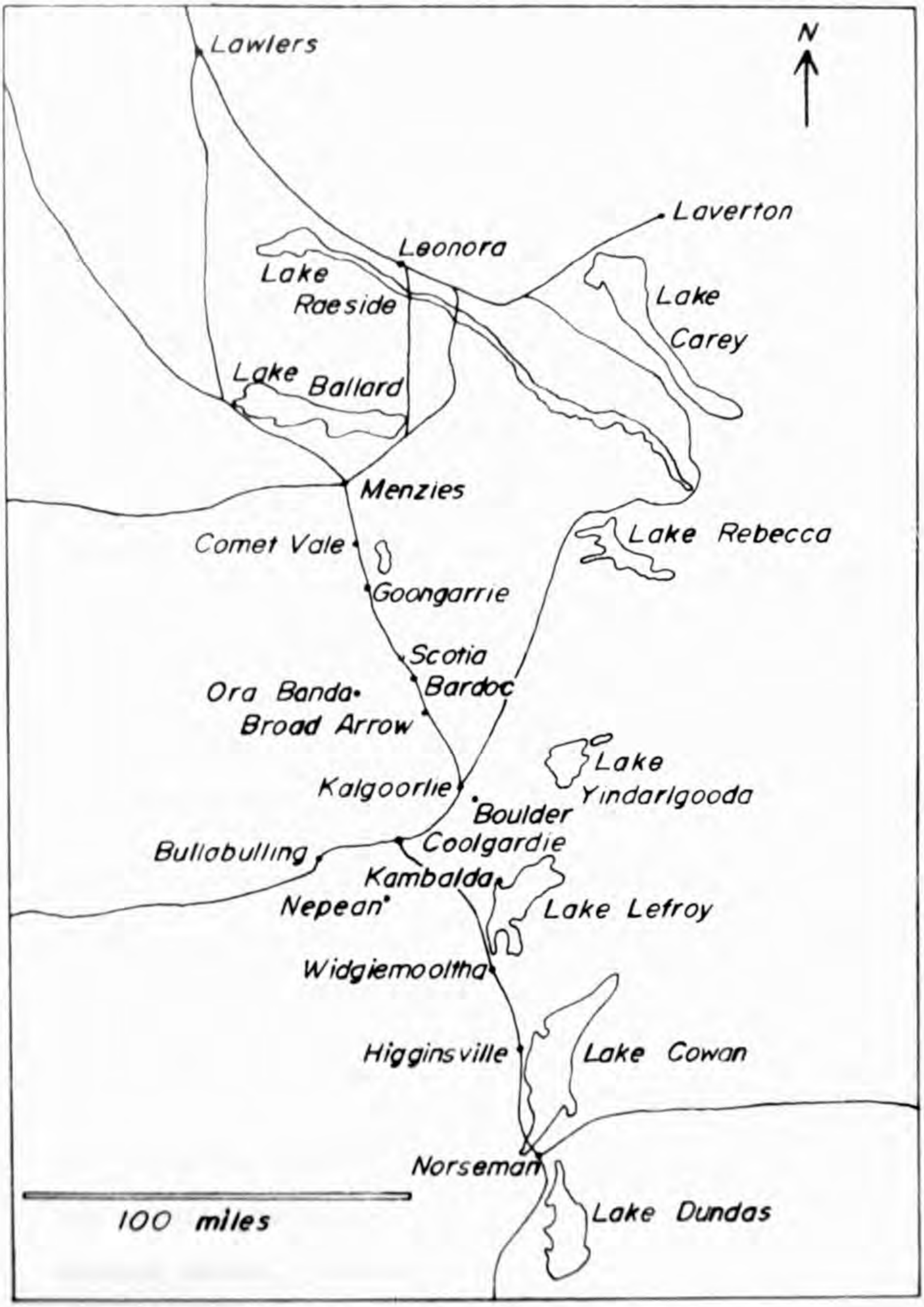


Figure 1

to be more exciting -- Londonderry, where 250 pounds of stone yielded 100 pounds of gold; Bulong, Kanowna, Broad Arrow and Bardoc. By 1898 Kalgoorlie began to overshadow Coolgardie, and as the big mining companies moved in and mines went deeper the days of the prospectors here were numbered; their interest was in discovery, not in development. They moved on to new territories or back to the Murchison and Ashburton Rivers, lying to the north-west of Kalgoorlie, where deep leads and alluvial gold had been found previous to the discoveries in the Coolgardie area.

The mines at Kalgoorlie developed with unparalleled speed during the first ten years of their existence. During this period, 1895 to 1905, with gold at £3 10 0 an ounce, the locality had produced gold to the value of £25,000,000; the ore treated averaged over an ounce to the ton. Then followed a gradual decline and period of consolidation. The demand for labour slackened as the easier and more accessible ores were exhausted. The oxidised ores cut out at fairly shallow depths and gave way to hard sulphide ores. A slow drift began away from the goldfields as men moved back to the coast and agricultural areas. Telluride ore was first discovered in the area in 1896 and in the early 1900's caused the opening up of a new era on the Golden Mile, which became the richest few acres of gold-bearing country in the world. Some of the assays carried out on the lode material yielded ninety ounces to the ton, and although minor finds of this ore were made in 1903 at Mulgabbie, ninety miles north-east of Kalgoorlie, and at Norseman in 1944 the Golden Mile contains the richest concentrations.

From 1914, at the beginning of the First World War, and up until 1931, many of the original townships in the goldfields were abandoned to become ghost towns, or slowly declined. As men left to enlist in the army and labour became short, production on the mines slowed down. Development costs increased as the shafts were sunk to greater depths and machinery became worn out. The grade of the ore fell as the richer, more accessible ores were worked out. Costs rose relative to the price of gold, which was fixed at £3 17 10½ an ounce.

Kalgoorlie itself could not escape from certain of the consequences following this decline in manpower in the mining industry, although it survived as the largest town serving the Eastern Goldfields. Gold mining continued there, although production was much lower than it had been in previous years. In 1929 only 337,000 ounces were produced on the Golden Mile.

The economic depression revived Kalgoorlie. Britain moved off the gold standard in 1931 and this doubled the price of gold. In the Eastern Goldfields mines re-opened and gold-mining centres which had been previously declining became thriving towns. Employment levels rose and ores previously uneconomic in grade now became workable. Production figures for the State of Western Australia in 1939 were 1,188,000 ounces. Later on, however, with the Second World War, the supply of manpower in the mines was again affected, and gold production was consequently lowered. In 1945 State production dropped to less than 500,000 ounces. The post-war period brought some increase in production but labour was difficult to attract and by 1949 the future of the industry was threatened by rising costs. These were partly offset for a short while when England depreciated her currency, the price of gold consequently rising from £10 15 0 to £15 10 0 an ounce. However, inflation followed; to counter fast-rising costs modernisation was carried out, and although some of the mines were able to increase tonnage, the smaller mines of the outback gradually closed down.

Today four big mining companies remain on the Golden Mile; Lake View and Star Ltd., Great Boulder Gold Mines Ltd., North Kalgurli (1912) Ltd., and Gold Mines of Kalgoorlie (Aust.) Ltd. Since 1955 the production of gold has been maintained at between five and six hundred thousand ounces each year; this constitutes over half the annual amount of gold recovered in Australia. Mining developments elsewhere in the State are having an adverse effect on gold mining, because the higher wages offered help to draw away labour. The gold mines are limited for, owing to the fixed price of gold, there is always pressure from rising costs. Production comes mainly from the small high grade ore bodies in which the mining costs are relatively high. Small low grade ore bodies have to be left from economic necessity. In 1964 Australian production fell below one million ounces, in spite of government efforts to help the industry. Gold mining is tax free, and there is a subsidy scheme on which even major mines in the goldfields, such as Gold Mines of Kalgoorlie and Lake View and Star, are assisted. However, developments continue to take place in the industry here; the Anglo-American Corporation of South Africa and America's Newmont Mining are seeking an extension of the Kalgoorlie field at depth in a current drilling programme. Should the price of gold increase in the future there are still large tonnages of low grade ore around Kalgoorlie, Coolgardie and other smaller settlements to be mined by modern methods.

The Kalgoorlie area has recently been given new confidence for the future, stimulated by the announcement in February 1966 by Western Mining Corporation Ltd. of a high grade nickel-sulphide ore body at Kambalda, thirty six miles south of Kalgoorlie. Testing has revealed that the percentage of nickel is as high as 12.46 in some cases. The area is being rapidly developed by this company and drilling and exploration continue. Other mining companies have moved into the area to carry out exploration programmes. Conzinc Riotinto of Australia Ltd. and Anaconda Australia Inc., in a combined venture, have found nickel mineralisation at Widgiemooltha; International Nickel Southern Exploration Ltd. has made another discovery on the same trend at Higginsville; Metals Exploration has located nickel mineralisation at

Nepean, and Great Boulder and North Kalgurli have a nickel ore body at Scotia, and will now jointly become Australia's second nickel producer.

2. The Eastern Goldfields as an area for geobotanical study

The State of Western Australia is undergoing rapid development in many fields. Geological reconnaissance and exploration are revealing new and more detailed knowledge of the country. Mapping by the Geological Survey of Western Australia, and by several mining companies is being carried out in various areas. The removal, in 1960, of the Australian Government's ban on the export of iron ore provided the stimulus for the search for new mineral fields, and an increase in activity has taken place in those areas where mineral wealth was known to exist. One of the most recent mineral discoveries is the nickel field at Kambalda, thirty six miles south of Kalgoorlie. This provided the stimulus for further exploration in the area of the Eastern Goldfields, and served to bring new life and hope into a region which had seen better days. Within the Kalgoorlie district nickel mineralisation has been discovered at Widgiemooltha, Nepean and Scotia. This region has been famous for mining in the past and the recent important discoveries are ensuring its future. There is obviously still much mineral wealth to be discovered, and there is clearly room for geobotanical techniques to be employed during any geological reconnaissance or mineral exploration in the region.

Geobotany has already provided a useful tool in mineral exploration and geological reconnaissance in the U.S.S.R., North America, Australia and Africa. In the United States, for example, the occurrence of carnotite ores has been indicated by selenium indicator plants, and another well-known indicator plant is the copper flower, Becium homblei, which grows in Zambia and Katanga (see section 3 of the Introduction). In the Eastern Goldfields geochemistry and other exploration methods are currently in use, but no detailed geobotanical studies had been undertaken prior to the present investigation. Reconnaissance work in the region by Professor M. Cole had indicated that geobotanical work could usefully be undertaken there.

The country of the Eastern Goldfields has suffered little permanent disturbance, and so provides a suitable environment for geobotanical studies. About seven million acres have been felled around the mining towns for firewood and mining timber since the discovery of gold (Brockway 1949). However, this fact should not seriously hinder any geobotanical observations as the secondary growth now seen presumably has essentially the same physiognomy and species and/or generic composition as had the virgin country. Particular rock types and the soil types to which they help to give rise exert the same influences on the vegetation composition, helping to delimit associations and the distribution of various species. The environmental conditions provided by different bedrocks and soils are favourable for the development of particular vegetation associations and plant distributions, which will develop accordingly. Agriculture presents no problems of land disturbance either, for the rainfall is too low (nine to twelve inches a year) to allow the country of the Eastern Goldfields to be used for anything except low density sheep grazing.

Further investigation into the region's mineral potential is valuable in view of the present agricultural situation here. The low rainfall prohibits the economical growing of crops. Mining activities are the means of opening up these drier, under-populated areas, allowing the development of a denser settlement pattern than would otherwise be expected in such a climatic environment.

Geobotanical and biogeochemical studies have not been carried out in a geographical environment which is comparable to that of the Eastern Goldfields, where the vegetation formation comprises open sclerophyllous woodland and whose history has been moulded by its own unique characteristics. The distribution and character of the vegetation in any area is partly determined by the past and present effects of many environmental variables, which will tend to differ in various aspects between different continents and countries. The geological and geomorphological history of any land will provide a unique background for any field work carried out, and the evolution of the flora will also have followed a particular course to give an area the floral characteristics of the present. In the Eastern Goldfields, for example, geomorphological factors to be considered include extensive peneplanation and lateritization. There has been very little tectonic disturbance to disrupt developing plant communities. Consequently, some of the plant genera growing there today are very old, many of them occurring only in Australia. There are a number of genera which have their greatest number of species in this continent, such as *Grevillea*, *Melaleuca* and *Eremophila*. Any ecological studies here are concerned with an interesting and unique flora.

The present climate of the Eastern Goldfields region is classified as semi-desert, its rainfall averaging about ten inches a year. In spite of such a low rainfall the vegetation supported is open woodland, although various adaptations to the drought factor have been developed, such as sclerophylly in the woody plants and reduced leaves. Such a formation presents an unusual background for geobotanical studies when placed in such climatic conditions. Australia is unique among the continents of the world in that factors of low rainfall and a woodland vegetation formation occur together in the environment.

The effects upon the vegetation of varying soil concentrations of metals can be studied against this background. Although gold itself may be taken up by plants, it is usually in infinitesimal amounts, and any geobotanical investigations concerning this metal are preferably carried out on arsenic. Arsenic is often associated with gold in this mining area and it is therefore known as a pathfinder element for this ore. Pathfinders are certain elements which are used to trace particular types of ore which may be more difficult to detect. The arsenic content of the soil exceeds 100 ppm in parts of the Goldfields area, although this does not necessarily indicate the presence of gold or, if present, its quality or abundance. High concentrations of arsenic normally cannot be tolerated by plants, and a corresponding physiognomic or teratological development may occur in the association as a whole or in particular species. Robinson and Edgington (1945) report that plants will usually die before they accumulate as much as 10 ppm arsenic, although Warren _et al_. (1964) found as much as 10,000 ppm arsenic in the ash of present year tips of the Douglas Fir (_Pseudotsuga menziesii_) over mineralised ground in British Columbia. Biogeochemical anomalies here were greater than the pedogeochemical. The Eastern Goldfields provide another area for examining the effects and behaviour of arsenic in the plant and the extent to which geobotanical relationships can be recognised between this element and the surrounding vegetation.

Other minerals exist in the region, increasing the scope for the use of geobotanical methods in mineral exploration. Nickel appears to be present in increasing abundance and copper has been worked on a small scale. As exploration continues, other minerals may be discovered, and the establishment of geobotanical relationships may assist in the exploration of new areas. The method may be of use not only in mineral exploration but also in geological reconnaissance and mapping in the region, as the field work has shown. The Eastern Goldfields provides both a suitable and interesting region for geobotanical studies.

3. Earlier geobotanical and biogeochemical studies

In the following account earlier work has been divided into two sections dealing with geobotanical and biogeochemical studies, although in the course of prospecting programmes these two methods may be linked with each other and used in conjunction with other methods. Some aspects of earlier work in these fields have been summarised by Provan (1965).

Earlier work in geobotany

It is only in the past twenty to thirty years that geobotany has been seriously recognised as a tool in geological reconnaissance and mineral exploration, and that the distribution of plant species and assemblages may be used as a guide to the underlying bedrock and to mineralisation.

Certain mustards and pinks are zinc indicators. The calamine violet, *Viola calaminaria*, thrives only in zinc rich soils in zinc districts of central and eastern Europe, and in early mining activities in these regions this plant was reported to have led to the discovery of a number of zinc deposits.

Copper indicators are perhaps better known than zinc indicators, and have proved useful in locating ore. Copper indicators belong mainly to the Caryophyll-aceae, Labiatae and Musci. Three copper deposits were found in Sweden by examining localities from which the herbarium specimens of the copper mosses had been collected. The copper flower from Zambia, Becium homblei, is another well-known example. This plant will not grow in soil containing less than 100 ppm copper, and contains an abnormally high amount of this element. The ash of its leaves may contain up to 2500 ppm copper, and up to 4500 ppm was found in root samples. It has been shown that the seeds will only germinate in solutions containing between 50 and 600 ppm copper. Cryptosepalum sp. is another copper indicator, growing in abundance in copper clearings and associated with B. homblei. In Katanga B. homblei is absent from clearings on some small hills where ore is located, while Cryptosepalum is abundant. It may be that here the soil is too rich for the copper flower, for fragments of malachite may be found in places on the surface.

Helen Cannon has carried out a considerable number of geobotanical studies in the United States. The method has been used in prospecting for uranium ores in the sandstone of the Colorado Plateau (1952). A uranium-tolerant flora has been recognised, characterised by selenium indicator plants and by sulphur-accumulating species of the Liliaceae and Cruciferae. Some elements are known as pathfinders for ore deposits, in that they are often associated with a particular metal and provide a guide to the location of the ore where the latter cannot be so easily traced. Such is the case with selenium, a pathfinder for uranium ore. In this connection the pathfinder element may show associations with geobotanical indicators or metal-accumulating species, which can therefore be of use in tracing mineral deposits. Where the selenium-bearing ores of the Colorado Plateau are not too deeply buried, the selenium indicator plants show by their distribution the occurrence of carnotite ores. By mapping their distribution a guide to exploration is given. Astragalus preussi var. arctus and A. Pattersoni are the most useful indicator species here. They absorb large amounts of selenium, up to 8512 ppm, although the amount taken up depends on a number of factors, including the time of the year, the availability of elements in the soil and the chemical composition of the country rock. Depth of root penetration is also important, as are water conditions and the nature of the rocks penetrated by the roots. These *Astragalus* species may indicate the presence of carnotite to a depth of fifty feet. *Stanleya pinnata* also appears to need a considerable amount of selenium, and grows in the indicator plant assemblage, its distribution varying with that of *Astragalus* as it requires sulphur and more water.

Earlier studies in Australia in the fields of geobotany, geochemistry and biogeochemistry include that carried out in the Mount Isa-Cloncurry mineral field of Queensland by Nicholls, Provan, Cole and Tooms (1965). At this point only the geobotanical studies will be mentioned. Deposits of copper, lead and zinc occur in the Dugald River area, where the bedrock geology includes shales and calc-silicates, each rock type being characterised by a particular vegetation association. It was found that particular plant species grow over the lodes. In such areas of high mineral concentration the characteristic background vegetation cuts out and is replaced by a plant assemblage of five species - *Eriachne mucronata*, *Bulbostylis barbata*, *Polycarpaea* glabra, Fimbristylis sp. (Dugald River 279), and Tephrosia sp. nov. (Dugald River 5). It appears that this distribution is due primarily to trace element anomalies in the soil, with other ecological factors of secondary importance. It is possible to follow the line of high copper, lead and zinc values of the Dugald River lode by noting the occurrence of these five species. Low metal concentrations of copper and lead are marked by their absence, while separate areas of anomalous values may be picked out by the patches of one or more plants from the assemblage.

Earlier work in biogeochemistry

It was Goldschmidt in the 1930's who first suggested that plant analysis could usefully be employed as a method of prospecting. Early work in this field was carried out in Sweden, England and the U.S.S.R., but it was not until after the Second World War that biogeochemical studies were begun in the United States.

Biogeochemical prospecting for uranium has been carried out by the United States Geological Survey in cooperation with the Atomic Energy Commission. 10,000 trees were sampled in advance of the drilling programmes and much basic information was acquired. Several ore bodies were found by this method.

Harbaugh (1950) carried out biogeochemical studies in the Tri-State district of the United States, covering parts of Kansas, Missouri and Oklahoma. Within the past twenty years geophysical and geochemical prospecting investigations have been carried out here with little success. However, biogeochemical methods were shown to offer more promise; anomalies were found to exist from analyses of plant material. The average zinc values of all grass species and herbs collected from mineralised ground were about 30% greater than the average zinc concentration for all samples from barren areas. It was possible to establish a direct relationship between the amount of zinc in these plants and their distribution with relation to the mineralisation. Where anomalous values did not appear to correlate very accurately it was thought possible that the entire extent of the mineralised zone may not have been revealed by drilling programmes, and that some of these plant anomalies may indeed be indicating undiscovered zones of mineralisation.

Biogeochemical investigations have been carried out in Finland by Marmo (1953). He used Vaccinium vitis-idaea and Ledum palustre as either one or the other species was of common occurrence in the areas under investigation. His findings revealed that the amounts of copper, zinc, nickel and molybdenum in the ash of these plants reflected the content of these metals in the underlying bedrock. He concedes that biogeochemistry could be used in conjunction with geophysical methods of prospecting, particularly in Finland where pyrrhotite and graphite often give strong geophysical anomalies which may be unrelated to economic mineralisation. In order to distinguish between such false anomalies and those recording actual metal occurrence, biogeochemistry could be used. Biogeochemical methods could also be helpful where an ore such as molybdenum is present but gives no geophysical anomaly.

A considerable amount of work in the field of biogeochemistry, particularly in British Columbia, has been carried out by Warren, Delavault and various co-workers. Extensive collecting and analytical programmes were carried out to determine which plants could best be used and what parts of the plant were most satisfactory as indicating variations in the metal content of soils and rocks.

Biogeochemical methods were used in prospecting for manganese ore in north-east Tennessee by Bloss and Steiner (1960). Exploration for this mineral by drilling and test pits had been limited to areas where float ore was present near or on the surface. Biogeochemical methods were therefore tested to ascertain their usefulness in areas masked by overburden. Quercus prinus was chosen for sampling and analysis owing to its being one of the few deeply rooting trees which was well distributed over the areas of manganese deposits. Results of the analyses of twigs and leaves reflected manganese mineralisation. Leaf ash was high in this element and nickel was shown to be a particularly good indicator of manganese ore. Analyses were also carried out for cobalt as this element was present in the ore in greater amounts than nickel, but no cobalt was detected in the plant material.

The value of the biogeochemical method of prospecting for nickel has not, as yet, been assessed by many workers. Limited studies have been carried out in the

United States and in Russia. During the geochemical investigations of Aleskovskii *et al.* (1959) on the Kola peninsula the distribution of nickel in plants over a known nickel deposit was studied. A number of species was analysed for nickel content and the metal was found to be particularly concentrated in leaf material of birch species growing in the area. It was shown that the greater the amount of nickel sulphides in the rocks the greater the nickel content in the plants growing over them. The method is recommended for use in the Kola peninsula for prospecting for nickel ore bodies.

Miller (1961) carried out similar work in the United States in a programme involving both geochemical and biogeochemical methods. Several different types of nickel occurrences were represented in the sampling programme, but only two localities out of the approximate total of ten are examined briefly in this report. A lateritic type nickel deposit, formed on a nickel-rich serpentinite peridotite complex, was examined in Oregon. The nickel occurred in the peridotite and overlying soil, the possible mineralisation being concentrated in the lateritic soils. The surrounding area of weathered peridotite had an intermediate nickel content. The soil nickel values in the area ranged from 50 to 6000 ppm and averaged about 3000 ppm. The second locality in Montana was a nickel prospect in norite, peridotite and related rocks, and the ore was found in sulphide pods. The norite was distinguishable from the overlying peridotite zone by the higher nickel soil content, 100 to 500 ppm nickel, the peridotite containing about 80 ppm nickel. Soil prospecting outlined possible ore zones within the norite itself. Coniferous and deciduous trees were sampled. In the Oregon locality the Lodgepole pine, Pinus contorta, gave the most satisfactory biogeochemical results. It delineated the general high nickel area and also suggested nickel-rich lateritic areas. The other species sampled were only able to reveal the general area of high nickel content. By contrast, the second locality in Montana which was studied biogeochemically gave negative results, the nickel content of the plants showing no reflection of the nickel content in the soils and bedrock. Although the nickel content in the soil was high over the norite zone the tree species sampled showed amounts which were of background value only. Out of the ten localities studied only the plants sampled in the Oregon area contained amounts of nickel which exceeded background concentrations. It is concluded that the degree and type of weathering is a determining factor, for without sufficient available nickel in the soil for absorption by plants plant sampling will be ineffective. Where an acetate buffer extraction method shows the nickel soil content to be 200 ppm or more it is suggested that sufficient nickel is available for plant absorption and biogeochemical prospecting may consequently be applicable.

It can be seen from these examples of earlier work that the geobotanical and biogeochemical methods have often proved to be useful tools in geological reconnaissance and mineral exploration. With the additional knowledge and information that these methods provide it is possible to obtain a more complete and accurate picture of the field area.

4. The aims and purpose of the present study

Fieldwork was carried out in selected areas of the Eastern Goldfields in order to investigate the distribution of the vegetation associations, plant communities and individual species and to evaluate the relative importance of the environmental factors on these distributions, with particular reference to bedrock geology and mineralisation.

Considerable economic importance has been brought to this area through mining activities, for without the occurrence of gold mineralisation the region would have experienced very little development in the past, the low annual rainfall suiting it for little else besides extensive sheep grazing. The discovery of gold and the subsequent mining of this metal served to open up this region of the State. Continuing economic expansion in the Goldfields depends upon the goldmines not only maintaining but increasing their productivity, for with the fixed price of gold rising costs cannot be passed on. Although development here has been based upon the mining of gold, it seems likely that the mining of other minerals in the area will help to maintain economic growth, and considerable confidence has been generated in the region by the various discoveries of nickel mineralisation, particularly that at Kambalda. The potentials of the mining industry here have not yet been fully realised. It was hoped that geobotanical and biogeochemical studies could help in further elucidating this background.

It is the aim of geobotany firstly to investigate the extent to which plant distributions are influenced by and can reveal by their presence the underlying bedrock, and secondly to note whether any particular species, by their presence or morphological characteristics, are indicative of mineral occurrence. Investigations were therefore undertaken to establish how far the distributions of associations and species, in the areas of the Eastern Goldfields chosen for study, are influenced by bedrock geology and mineralisation. Certain species may be characteristic of an association growing over an area where the underlying rock type is known. The physical and chemical conditions resulting from a particular geological environment will be more favourable for some species than for others, and a particular distributional pattern will occur, provided other environmental factors, such as topography and drainage, remain sufficiently constant to have no important modifying effect. Near Coolgardie, for example, adjacent areas underlain by basic and ultrabasic rocks are characterised by particular associations. The association growing over basic rocks comprises Eucalyptus campaspe and Atriplex paludosa, and gives way abruptly where these rocks abut onto the area underlain by ultrabasic rocks. These ultrabasics are marked by a completely different vegetation association, dominated by Eucalyptus foecunda, Eremophila interstans, Cassia eremophila and Atriplex paludosa. Elsewhere in the Eastern Goldfields particular rock types are marked by particular associations. The recognition of such a relationship between rock type and vegetation association may be of use in geological reconnaissance in comparable environments elsewhere in the area, especially where the geology cannot be known from direct observation. Fieldwork was therefore directed to discover the extent to which such relationships could be recognised in those parts of the Eastern Goldfields chosen for study.

Geobotany is also concerned with the recognition of indicator species over areas of mineralised ground. Fieldwork was carried out in areas of known mineralisation with the purpose of discovering whether or not indicators existed in these localities. Although many factors, such as length of growing season, elevation and sunlight, have little or no relation to the geology and yet affect the health and distribution of plant species to varying degrees, many important factors in the natural development of plants arise from their geological environment. Local areas of high soil metal content may be marked by the occurrence of particular plant communities or individual species which replace the more widespread background vegetation. For example, in the Cloncurry district of Queensland the background association of Eucalyptus brevifolia and Triodia pungens cuts out over the Dugald River lode, composed of lead and zinc with associated copper, and is replaced by an assemblage of Polycarpaea glabra, Eriachne mucronata, Bulbostylis barbata, Fimbristylis sp. nov. and Tephrosia sp. nov. (Nicolls, Provan, Cole and Tooms 1965). High concentrations of particular elements in areas of mineralisation may produce toxicity symptoms in plants, which may show abnormal colouring and/or morphology. Some plants develop diagnostic symptoms that indicate probable excesses of particular elements in the soil. For example, excess uptake of nickel produces white dead patches on leaves and apetalous sterile forms (Cannon 1960). Particular species may act as indicators in that they are either able to tolerate or resist the uptake of large amounts of minerals, and therefore the recognition of such species in mineralised areas is of value. It was desirable to note whether such factors were operating in the areas studied. For example, any uncharacteristic changes or unusual distributional patterns in the vegetation of a nickel-rich locality, such as Kambalda, could provide ancillary information to that gained by other methods, such as geochemistry or geophysics, and act as a guide during an orientation survey in a similar environment. In this connection it may be noted that in the Eastern Goldfields the presence of gold in parts of the region is associated with arsenic (which is therefore known as a pathfinder for the ore). Values of arsenic in the soil are in excess of 100 ppm in certain localities. Part of the present study was concerned with botanical investigations in an area where arsenic soil values ranged from below the level of determination to over 100 ppm, and with noting any effects the varying concentrations had upon the plant species -- whether toxicity effects were produced when arsenic is present in certain concentrations, and the effect such concentrations have on the actual distribution of species within an association. It was thus hoped to be able to assess the role of arsenic as a pathfinder in geobotany.

Biogeochemical studies were linked with the geobotanical investigations. The aims of biogeochemistry are to establish the extent to which a relationship exists between plant metal content and soil metal content, and to discover the characteristics of species in connection with their uptake of metals. Some plants require large amounts of certain metals, and can only grow where high concentrations occur in the soil. For example, the seeds of the copper flower of central Africa, Becium homblei, require between 50 and 600 ppm copper in the soil before they will germinate. Species behaving in this way will usually accumulate large amounts of the metal in their tissues, so that the analysis of such plants, as well as their presence, may lead to the recognition of a biogeochemical anomaly, thus providing an indication of underlying mineralisation. Whereas B. homblei is an example of a plant requiring large amounts of a particular element before germination will occur, other species may absorb high concentrations of apparently useless elements. A chickweed, Holosteum umbellatum, will accumulate mercury when growing on soils containing mercury salts, although apparently having no need of this metal (Rankama and Sahama 1950, quoted by Fogg 1963). Other species, when growing over mineralised ground, will reject the uptake of excessive quantities of the metal in question so that analysis of material from such plants may not reveal anomalous quantities. Polycarpaea glabra, growing in soils containing up to 10,000 ppm copper in the Turkey Creek area of Queensland, takes up very small amounts of copper, less than 20 ppm being found in the leaves (Nicolls et al. 1965).

The purpose of the biogeochemical studies was to establish the extent to which these aims could be fulfilled in this type of work in the Eastern Goldfields, and to examine the behaviour of particular species with regard to their mineral uptake. Areas of nickel mineralisation at Kambalda and copper mineralisation near Widgiemooltha provided areas for the study of the uptake of these particular metals by plant species. Part of the field work at Moran's Copper Prospect, near Widgiemooltha, was concerned with the collection of samples of Eucalyptus torquata which grows over the anomalous copper area and also in a nearby locality where subsurface geochemical sampling had revealed no anomaly. Analysis of the samples of a tree, drawing its nutrients from a greater depth than that at which geochemical samples are normally collected, may indicate that a mineral may be present but at too great a depth to give satisfactorily positive results by soil sampling. This is particularly so where the metal in question is concentrated particularly in the twigs rather than the leaves, which would tend to enrich the surface soil through leaf fall and resulting humic matter.

Both the geobotanical and biogeochemical methods were used in conjunction with geochemistry during the course of the field work. It is part of the purpose of geochemistry to provide the basic quantitative information on the elements present in the soil, both the total and the available amounts. When considering the requirements or tolerances of the vegetation it is the available amounts of elements that are of immediate concern. Available elements are those which are dissolved in the soil moisture or are adsorbed on the clay minerals of the soil in readily exchangeable form. Elements in this form are therefore available for uptake, but they constitute only a small proportion of the total amount in the soil, for a high proportion is composed of ions tightly bonded within the clay-mineral lattices. The method of cold extraction provides information on available amounts of elements, and these results may differ considerably from the total amounts present within the soil, although providing a clearer indication of amounts available for plant uptake. The fact that plants exhibit specific reactions to the chemical environment complicates the evaluation of their analysis and the assessment of their reflection of the soil metal content. Without soil sampling it would not be possible to have any comparative data with the results obtained through biogeochemistry. Thus geochemical sampling was an integral part of the field work programme.

PART I

GENERAL ENVIRONMENTAL FEATURES OF THE EASTERN GOLDFIELDS

1. Climate

The climate of the Eastern Goldfields is largely controlled by continental airmasses which form in the interior and are consequently dry at all seasons and cool in winter and hot in summer. Other airmasses may be brought in -- maritime by the westerlies, equatorial or tropical by the tropical cyclones -- and these may cause a brief change with more humid conditions prevailing.

July is usually the coldest month, with an average temperature of 51°F. or 52°F. By September it may have risen to 60°F., and to 70°F. by October or November. January is usually the hottest month, with average maximum temperature of 92°F. in the south and 97°F. in the north. Minimum temperatures during this month are 62°F. in the south and 71°F. in the north. The differences between day and night temperatures may be fairly wide -- 20°F. in winter and 30°F. in summer in southern areas, although it may be higher than this as, for example, in Kalgoorlie on October 16, 1966, when the difference was 40°F. In the northern part of the Eastern Goldfields summer differences are smaller, about 25°F., for the nights are warmer here.

The wind systems of the region will be examined with reference to the station at Balladonia, east of Norseman. In winter (June, July and August) the prevailing winds blow from westerly points; most of the winds experienced are from the south-west, west or north-west, although during these winter months a northerly wind is also experienced. The south-westerlies and the westerlies have a greater proportion of winds exceeding 20 miles per hour. There are very few easterly winds.

In spring (September, October and November) winds are experienced from the west, east and south with almost equal frequencies, the south-westerlies predominating slightly; with the westerlies they again have a greater proportion of winds exceeding 20 miles per hour. There is a high frequency of northerly winds, these being particularly noticeable during the mornings, but becoming less frequent during the afternoons.

The summer wind systems, from December to February, blow mainly from a north, east and south-east direction. The morning north wind is again an important feature, and the afternoon winds blow more from the east and south-east. Although few of the winds experienced blow from the west, the westerlies are still the strongest winds experienced at this station.

In autumn (March, April and May) the situation is very similar to that of the spring months, but differs in that there are fewer winds exceeding 20 miles per hour, and there are more afternoon calms.

Rainfall is low, averaging about 12 inches per annum in the west of the region to 10 inches in the east. Winter rains begin in May, brought in by the westerlies, which have little moisture left by the time they reach the Eastern Goldfields, having travelled over 300 miles eastwards from the coast. During both May and June Kalgoorlie receives over one inch of rain, with places further north receiving less during June. Scattered falls are received irregularly throughout the winter months, but by August the total amount may be under half an inch. From September to November rainfall is negligible in the northern part of the area. During

February and March the amount of rainfall experienced increases slightly, the rain falling in sudden heavy thunderstorms, which can change the appearance of the country from a dry and dusty stretch of terrain to one of vast pools of red water, filling the creeks and salt lakes. The rainfall is characteristically erratic in nature, usually brought in by tropical cyclones during the summer months. Amounts fall off again after the summer until the first winter rains.

2. Geology

The Eastern Goldfields lie within the wide area of the great inland plateau of Western Australia, underlain by Precambrian rocks. The oldest rocks are the older greenstones, composed of basic lavas, pyroclastics, including tuffs and agglomerate, pillow lavas and minor interbedded metamorphosed sediments. The older greenstones are overlain by rocks belonging to the whitestone phase. These consist of metamorphosed sedimentary and interbedded igneous rocks, with metasediments predominating.

Both the older greenstones and whitestones have been intruded by the quartz-dolerite sills and dykes belonging to the younger greenstones phase. Orogenesis followed, associated with the emplacement of granite, granite-gneiss, granitised metamorphosed sedimentary and volcanic rocks.

The low grade regional metamorphism has produced a north-north-west to south-south-east foliation in places. The foliation is more marked in the older greenstone series and some of the older igneous rocks have been converted into chlorite, talc and chloritoid schists.

Local phases of metasomatic metamorphism have been superimposed upon the regional metamorphism, as in the Golden Mile, and these have produced calc-schists, bleached greenstones and bleached dykes.

Most of the gold mineralisation is related to the granitic intrusions, the deposits usually being found near intrusive granite contacts or else in close association with acid dykes. With one or two exceptions all the primary metalliferous deposits were formed in Precambrian times as the aftermath of igneous activity. The lower Precambrian greenstones form an especially important host rock for gold, particularly when characterised by shearing and schistocity, the fracturing having permitted free circulation of the auriferous solutions. The gold is often found in quartz reefs, characterised by very slight potash silica metasomatism of the country rocks. The reefs may be traced from the greenstone into intrusive granite, and in some localities, for example Bonnievale, Coolgardie, the reefs are found entirely within granite or granite-gneiss. Sulphide-bearing lode formations, such as those of the Golden Mile, Kalgoorlie, are associated with extensive silica-carbonate metasomatism of the country rocks. Gold may also be found in acid porphyries in the disseminated form or in stockworks, veins and lodes. Examples of such stockworks occur in Binduli, near Kalgoorlie, and at Bardoc. Veins and lodes in porphyry are found in the East Coolgardie and other goldfields. Although the greater part of the gold in the region occurs in veins and quartz reefs, tellurides, very rich complex ores, are also found. Small occurrences of these ores came in the past from Mulgabbie, Ora Banda and Norseman, but today Kalgoorlie remains the centre for the production of tellurides. On all the goldfields detrital gold has been found on or near the surface, having been weathered from veins and lodes. The eastern lode system at the Golden Mile is covered with detritus which is at least one hundred feet deep in places, and small traces of gold can be found. Gold is often won from alluvial deep leads, as was the case at Kanowna.

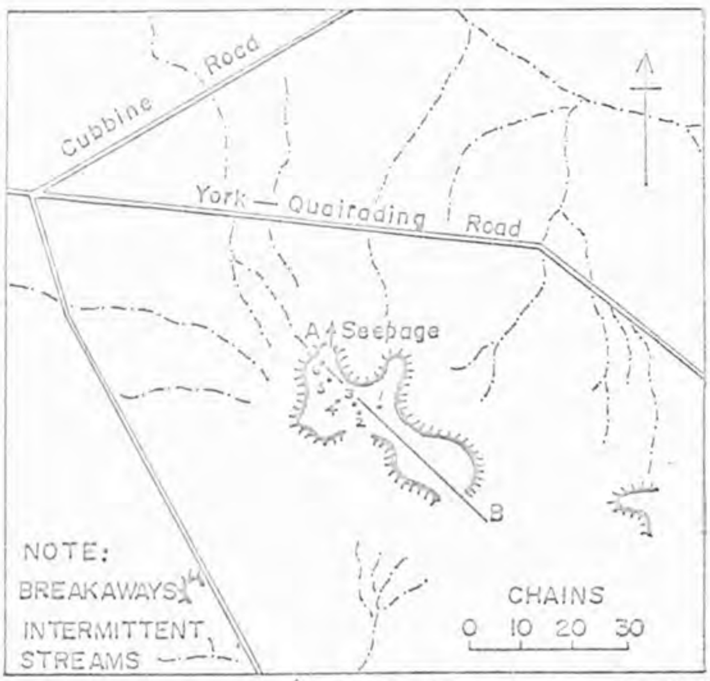
The mineral most commonly associated with gold in the quartz veins is pyrites. Pegmatite mineralisation is also seen in parts of the region as, for example, in the Coolgardie goldfield. The pegmatites may carry minerals of economic importance, such as lithium, beryllium, columbite and niobium-bearing minerals. At

Gibraltar, south-west of Coolgardie, beryl, topaz and tantalite have been recorded. The pegmatites are associated with the major granite intrusives. Other minerals found in the Eastern Goldfields are mispickel and pyrrhotite; copper pyrites, galena and zincblende are widespread in small quantities. Nickel has also been recently found: discoveries of this ore occur in the Archaean rocks of the Eastern Goldfields. The deposits at Kambalda, St. Ives and Scotia are in ultramafics. Other sporadic discoveries have been made at Mt. Martin and within a north-south belt running from Higginsville through Widgiemooltha to Coolgardie.

3. Geomorphology

The geomorphological evolution of the Eastern Goldfields will be appreciated if briefly set within the wider background of the State of Western Australia. The greater part of the State consists of a plateau rising to 1000 to 2000 feet above sea level and carved out of older and middle Precambrian metamorphic and igneous rocks. Within this general setting various surfaces can be distinguished. The most ancient consists of residuals of Pre-Miocene surfaces, while the uplifted Miocene peneplain forms the Old Plateau of Jutson (1934). It appears that before uplift occurred the Miocene peneplain was relatively uniform and continuous over large areas: laterite formed on its surface and still serves to characterise those parts of the Miocene remaining today. Much of the lateritised surface has been removed under the effects of erosion. Valleys were initiated and consequently broadened out, forming a newer, younger surface at its expense. This younger surface lies within and below the older Miocene, which remains today as lateritised mesas and buttes, and as isolated hills and ridges of various undecomposed rocks, the chief of which are granite and greenstones. The wide valleys formed within the Miocene level comprise the Pliocene level. In inland areas a fourth surface, the New Plateau of Jutson (1934) is forming as the Miocene surface is eroded. This New Plateau occurs chiefly where the rainfall is lower, and on its surface lie alluvial deposits and residual soils which are developing over the truncated lateritic profile. The surface originated either as flat-floored valleys or wide plains, and lies about thirty to one hundred feet below the Old Plateau, the two linked by cliffs known as breakaways. As the breakaways are subjected to erosion they retreat and the New Plateau is extended. The surface was probably initiated as a series of mature valleys produced by normal river erosion during the Pliocene and subsequently uplifted. Residuals of the Miocene may be found upon it. However, laterite capped residuals cannot always be accepted unquestionably as parts of a lateritised peneplain belonging to the Old Plateau; an examination of their nature and geomorphological relationships may indicate otherwise. A residual situated on a small hill about twenty miles east of York, approximately 290 miles west of Coolgardie, has been investigated (Mulcahy 1964).

It has been suggested that the residual here is not capped with laterite developed _in situ_ but with sand-plain materials. The sandplains of Western Australia are believed to be derived from weathered lateritic materials which have undergone colluvial transport [see (d) section 4, Part I]. They often contain layers of ironstone gravel and may overlie kaolinised pallid zones. The plan of the residual (Figure 2) shows it to consist of two parts connected by a narrow waist, the highest part lying on the south-east side and dipping towards the waist.

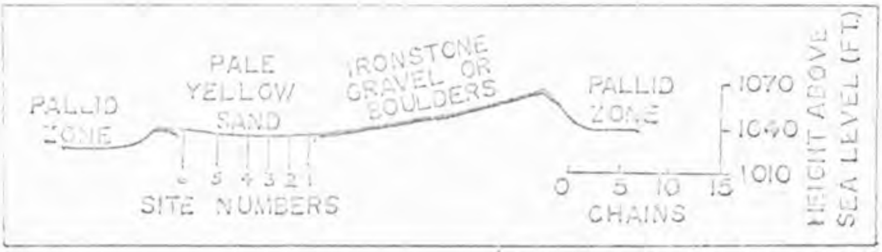


(After Mulcahy 1964)

The Residual in Plan

Figure 2

The northwest part of the residual is almost horizontal; it is rimmed with hard ironstone material and filled with yellow sandy material. Pallid zone is exposed on the flanking pediments (Figure 3).

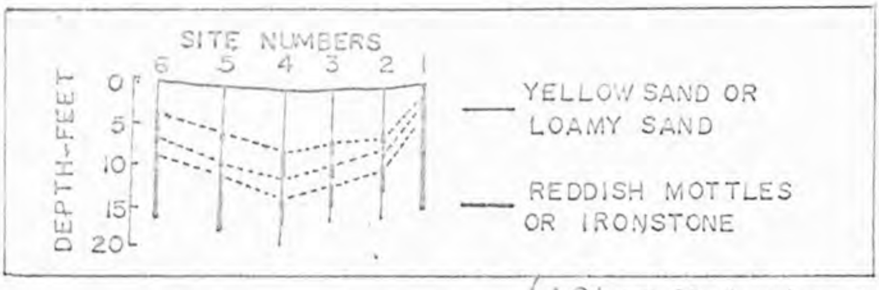


(After Mulcahy 1964)

Section along A-B

Figure 3

Profiles examined in the sands of the lower-lying part of the residual were those of a typical sandplain, with fifteen feet or more of yellow-brown sand to loamy sand with two or three bands of ironstone gravels or mottles (Figure 4).



(After Mulcahy 1964)

Profiles at sites 1-6

Figure 4

These bands were found to harden on exposure. They also pass into and become continuous with the ironstone on the edges of the breakaway. Thus the lower-sited part of this residual may not be capped with laterite developed *in situ* but with sandplain deposits, and the higher portion is a remnant of surrounding slopes from which such deposits came. Other similar features have been observed in Western Australia.

Within the Eastern Goldfields the surface is mainly that of the New Plateau, and is flat or gently undulating. Remnants of the Miocene form laterite-capped tablelands and mesas, often found where granite constitutes the underlying rocks, although each rock type occurring in the region may be capped by laterite. Rounded hills and ridges tend to lie where greenstones or quartz-haematite belts outcrop.

There are no adequately contoured maps for the greater part of the Eastern Goldfields and most of the precise levelling data are confined to the railway, running in an east-west direction through Kalgoorlie and Coolgardie, with a branch south from Coolgardie passing through Norseman and another branch from Kalgoorlie running northwards through Menzies to Leonora. The average height of the country in this region is about 1300 feet above sea level, and there is a general slope to the east and a fall southwards towards Norseman. From Kalgoorlie northwards to Malcolm (1225 feet) there is no continuous rise in the contour of the land, the country undulating between 1200 and 1400 feet above sea level, attaining its highest point at Niagara (1460 feet), lying 114 miles north of Kalgoorlie.

Granite outcrops occur in various parts of the Eastern Goldfields, forming either prominent knolls or flatter expanses of bare rock surface. McMath (1953) gives the average area of such outcrops as around twenty to thirty acres and states that they may reach to 200 feet above the general relief level. Examples of granite outcrops forming prominent knolls are those at Bullabulling, west of Coolgardie, and Depot Rock, north of Spargoville. The Mungari granite contrasts with these as forming a relatively flat expanse of rock surface. Such areas of granite are important as water catchments, and were of particular value in this respect during the early history of the Goldfields.

The Eastern Goldfields fall within Jutson's Salt Lake Division, characterised by the occurrence of numerous salt lakes, "the chief physiographic feature of the division and one of the most striking physical phenomena in Western Australia." Many of the lakes are of vast extent -- Lake Mackay along the eastern boundary of the State covers an area of 1200 square miles. 'Lake' is a misleading word in this part of the continent for only briefly after heavy rainstorms do the lakes hold any water, which usually covers only part of the lakes surfaces to a shallow depth. For the most part they remain dry with a veneer of salts and/or gypsum which is left behind after the water has evaporated. Thick deposits are not generally allowed to build up as the lakes are flushed after particularly heavy downpours. The lake floors are frequently damp, with saline ground water lying a few feet below the surface, and if rainfall permits water may remain at a shallow depth for several months. Some of the lakes are isolated, others more or less linked up together, and most of them are irregular in shape and often very elongated. Lake Raeside, north of Kalgoorlie, is thirty three miles long yet little over two miles wide at its greatest width. The lake floors have been planed by the wind and may be smoothed solid rock or else covered with sand and silt. It has been inferred from the depth of alluvium in some of the deep leads sloping towards lakes at Kalgoorlie that many of the lakes must contain great thicknesses of sediment. In Lake Cowan at Norseman a bore passed through 277 feet of silt. Similarly, Upper Eocene or Lower Oligocene sediments of lacustrine origin, deposited possibly in a coastal lake, have been found at a depth of 400 feet in a locality about one and a half miles east of Coolgardie railway station (Balme and Churchill 1959).

Under the prevailing westerly winds lake margin deposits are often built up on the east and south-east shores. Gypsum dunes are of recent origin and are still growing as material from the lakes is added to them. Lunettes are situated farther from the lakes and are composed of sand, silt or clay; bands of fossilised shells of Coxiella species have been noted in some of the coarse-textured lunettes. In view of Jutson's hypothesis of a westerly migration of the salt lakes these may well mark part of a former shore line (Bettenay 1962). Sheet deposits or lake parna may be present further away, varying from a few inches to several feet in thickness. The deposits gradually become discontinuous at a distance of several miles from the lakes.

The presence of these lakes is probably best explained by regarding them as the remnants of ancient river systems which were probably still flowing in Tertiary times. The elongated shape of many of them is reminiscent of this type of origin, and the deep leads of the Goldfields are witnesses from an older drainage system. With a decreasing rainfall, such as occurred in the Recent period, the systems would gradually decay and be filled in. Dismemberment would also follow the uplift which has occurred along the Darling Fault scarp (Jutson 1934). David (1950) gives an example of such a river system coming to life again after heavy rains in May 1921. Lake Austin overflowed round Mount Magnet to Yarra Yarra Lake and via the Arrowsmith River to the Indian Ocean. Bettenay (1962) has also noted connected flows following heavy rain and has been able to trace such a flow for over one hundred miles from Lake Brown (north of Merredin) to south of Quairading, the waters eventually passing into the drainage of the Avon River.

Drainage at the present day is entirely internal, the salt lakes and clay pans forming local base levels. Major drainage lines are dry, wide, shallow valleys, trending towards the depressions occupied by salt lakes. Tributary valleys join them, usually at right angles, and short creeks may debouch from hills and ridges. The drainage channels are dry for the greater part of the year, only coming to life for a brief period after rainstorms. Most of the channels are infilled with alluvium: renewed erosion of these deposits may be seen in a number of places and is attributed to the increased run-off caused by the heavy cutting of timber around the Goldfields over the past years.

4. Soils

The nature and distribution of soils in the shield area of Western Australia have been influenced to a great extent by the age and relatively stable geological history of the Great Plateau of Western Australia. In its geomorphological history there has been no glaciation which helps destroy weathered profiles, as in many other of the major shield areas of the world, and there are few permanent rivers to constitute effective agents of erosion. Here landforms of great age are found, where weathering has long been active and soils tend to be old and stagnating. Consequently, remnants of ancient soils, generally containing ferruginous concretions from laterites in various stages of preservation, may be found on the widespread late Tertiary and Pleistocene peneplained land-surfaces. Pronounced leaching within the soils occurred in the moist stages of the Pliocene and Pleistocene, while this factor was less important during the increasing aridity of the Recent. Thus it is not unusual to find very leached soils in areas where the drier climate of the present is more compatible with soils of a higher cation status (Stephens 1961). Many soils are therefore a reflection not only of present day conditions but also show features derived from a different climatic environment. For example, the widely spread lateritic soils were formed on the Tertiary peneplain when the climate was warmer and moister than it is today. Younger soils have formed and are still evolving over the underlying rocks and parent material exposed to weathering where newer geomorphological cycles are cutting back and eroding into the Old Plateau surface. Here the most important residual soils are the solonised brown soils.

Four main soil types occur within the Eastern Goldfields; laterites, solonised brown soils, skeletal soils and sandplain soils. Laterites have a limited distribution in the area owing to their destruction by erosion during geomorphological history, and they are restricted almost entirely to cappings on the isolated hills of the Old Plateau. Solonised brown soils are the most widely spread in the Eastern Goldfields. Skeletal soils are the youngest of these four types and are widely scattered wherever bedrock outcrops or lies very near the surface. Sandplain soils cover large but scattered expanses of country, although they do not occur within the areas studied.

Laterite:

Laterite is one of the most widespread soil types in the southwest of the State, but in the Eastern Goldfields its distribution is limited. Areas of lateritic soils occur in the vicinity of Coolgardie. For example, a small laterite capped residual, the Bluff, lies on the northern outskirts of the town, while in the northern part of the Three Mile Hill group, about three miles north-east of Coolgardie, is another occurrence, lying within an area of fine-grained basic lavas. The largest lateritic area in this locality lies seven miles north-east of the town, and is crossed by both the road and railway to Kalgoorlie. A line of breakaways marks its eastern side, the scarp faces standing above the New Plateau whose immediate surface here comprises rocks belonging to the metasedimentary series. An ultrabasic belt of rocks abuts onto the north-eastern end of the laterite, while soil masks the geology of the surrounding sides. Laterite also surmounts such flat-topped residuals as Mt. Burges, eight miles north of Coolgardie, situated in a belt of ultrabasic rocks.

No laterite occurs in the field area of Mt. Hunt, although small lateritic breakaways may be found in the surrounding area, such as to the south on the road to Kambalda.

At Norseman laterite also has a limited distribution, occurring only in one of the areas studied here, near the Iron King.

None was seen at either the Kambalda or Widgiemooltha study areas.

The main features and the origins of lateritic soils will now be considered. The profile of this soil type is characterised by the three horizons of eluviation, illuviation, and weathered bedrock. In a fully developed profile the A horizon may be divided into A_1, showing an accumulation of humic material, and A_2, where most of the organic matter has been decomposed. The zone of laterite corresponds to the B_1 horizon. The B_2 horizon is usually mottled grey, brown and red, and is composed of kaolinitic clay. It passes into the pallid zone of the C horizon, which may be more coarsely mottled in its upper parts but is composed predominantly of white kaolin. Beneath lies the parent material.

A fully developed profile is very restricted in occurrence, and usually the A horizon has been stripped to form the hard lateritic layer exposed at the surface. Most of the present day laterites are thought to date back to the Pliocene when the climate was warmer and more humid than that prevailing today. During Recent times rising temperatures have been coupled with an increasing aridity and under such conditions the A horizon was removed during the course of extensive erosion. The arid conditions were not favourable for the thick vegetation growth characterising the land surface of the former humid period, and the flora was profoundly affected, resulting in elimination and retraction. The A horizon was exposed more readily to erosional forces with the lowered vegetation density. The material from this upper horizon was stripped from the lateritic profile and today is found composing the sandplains which are a characteristic feature of this region. Locally deposited sands from the former A horizons occur in the south-west of the State (Stephens 1946). In the Margaret River district, for example, two suites of alluvial soils have been built up from sand and clay originating from a laterite.

Laterite is relatively soft when fresh, but as it is exposed to the air it dehydrates and becomes hard and compact. Such indurated material is resistant to erosion, in contrast to the unconsolidated A horizon. The laterites of Western Australia became indurated during the arid Recent. The laterite has acted as a protective capping and although forming a resistant material has been subjected to various degrees of weathering leading to a general lowering of relief. The resultant products of lateritic gravel and nodules may be found covering the surface. The crests of divides may be occupied by fresh rock outcrop surrounded by sandplain deposits which overlie deep pallid zones (Mulcahy 1967). Sometimes the lateritic ironstone has been completely removed, leaving only the underlying mottled and pallid kaolinitic zones.

Under conditions of heavy rainfall silica and metallic cations are leached from the profile, and iron oxide and resistant minerals remain as residual products, concentrated in the B_1 horizon. The mottled and pallid zones beneath are the result of a fluctuating water table under a climate of alternating wet and dry seasons during the Pliocene period. Iron and aluminium oxides are removed from the upper layers of the soil and redeposited at lower depths, either at the surface of the water table or within the zone of fluctuating saturation above the water table. Here conditions are most favourable for the deposition of the iron oxides leached downwards and those which have been carried upwards with a rising water table. The mottling beneath the lateritic horizon is explained by the occurrence of a fluctuating water table; the zone of water table fluctuation is a reflection of the periodic oxidation in this zone during the year. The underlying, permanently saturated horizon, having been depleted of iron, aluminium, silica and bases, which were carried upwards with a rising water table and redeposited at its surface, becomes the white kaolinitic zone. With iron oxides, clay minerals which are derived mainly from feldspars are some of the final products remaining under heavy leaching. Montmorillonite and illite clay minerals are not very stable under extreme leaching, and kaolinite is likely to be the most characteristic clay mineral found. Kaolin is closely associated with many examples of laterite and may therefore be said to be relatively stable. However, under conditions of very heavy leaching even this may break down to release alumina, as, for example, where hydrogen ions have become the dominant exchangeable cations; the environmental pH will fall to below 4.0, which is the lower pH limit for the stability of kaolinitic clays (James and Kanzucchelli 1966).

Thus in the evolution of lateritic soils climate had played an important role, but their formation has also been influenced by geomorphological conditions. Subdued relief is necessary for the formation of laterite and much of Western Australia had been reduced to a peneplain by the mid-Tertiary period. The laterite here formed under peneplain conditions when the original land surface was at a slight elevation above sea level (Woolnough, quoted by Prescott and Pendleton 1952). The laterite subsequently formed the surfaces of plateaux as the land was uplifted, although subsequent denudation and erosion has dissected these areas, often leaving only isolated and scattered relicts of the ancient peneplain surface. The laterite, however, is very resistant, and may therefore still be found on these remnants of the old peneplain.

Laterites may also be developed on valley sides and floors. Two such lateritic surfaces have been recognised in the York district of the State, the Belmunging and the Mortlock, cut in the Old Plateau (Mulcahy 1960). Weathering here has not proceeded so far as on the older adjacent lateritic surfaces, the Bolmunging having no pallid zone. Lateritic materials, therefore, may not necessarily indicate an ancient peneplain. Nevertheless, with low relief lateritic soils are enabled to develop as erosion will be relatively ineffective. Evidence of low relief during the Tertiary period is provided by the pronounced depth of weathering in the Eastern Goldfields region. Under conditions of tectonic stability weathering was able to continue and there was little removal of weathering products by erosion. Considerable thicknesses of laterite may be built up if the general water table level falls slowly over an appreciable time. Where rainfall is higher pallid zones may be sixty to eighty feet deep, decreasing to about ten feet by the thirteen inch isohyet (Mulcahy 1960). The total depth of weathering in lateritic profiles at Kalgoorlie and Coolgardie was investigated by Mazzucchelli (1965), who found it to be at least twenty feet and sometimes over fifty feet.

A modification in the normal lateritic profile occurs in the drier regions of the State, such as in the Eastern Goldfields, in that lime is present within the profile. The lime may occur as a veneer around the ironstone nodules, within cracks in the laterite horizon, or in loose powdery form. An example of a calcareous lateritic soil may be seen about seven miles north-east of Coolgardie. Part of the laterite here contains depositions of lime. Some of this material has possibly originated from surrounding or nearby calcium-bearing rocks, provided such are present, and was deposited in the laterite by calcareous ground water. Leaching in this region of low rainfall has limited importance; evaporation rates are high, and capillarity may lead to lime deposition at or near the soil surface. The origin of the calcareous material in these soils and in solonised brown soils is discussed in greater detail below.

Solonised brown soils:

Solonised brown soils are the commonest soil type developed in the areas which were studied. They are found around the Coolgardie district, particularly where the underlying bedrock is ultrabasic. They may also be developed over basic rocks, although in this locality it is the basic rocks which tend to form some of the more positive relief features, and bedrock is often too near the surface to allow much soil development to occur. At Mt. Hunt this soil type is encountered less frequently owing to a high proportion of outcrop in the area and the development of skeletal soils in such environments, but they may be found on the lower hillslopes and lower-lying areas where the underlying bedrock is basic and ultrabasic. At Kambalda solonised brown soils occur on the areas of lower ground where rock outcrops are poorly developed, and the underlying bedrock is serpentinite. This particular profile is not found to any great extent in the study areas at Norseman, most of the deeper soils here belonging to the type of solonised brown soil which contains less apparent lime, described below.

Over the area studied the typical profile of a solonised brown soil, developed over basic and ultrabasic rocks, shows three horizons (Figure 5). The A horizon, varying from zero to about six inches, consists generally of a sandy-silt to silty-clay loam, yellowish red to dark reddish brown in colour when wet (5YR 4/6 to 5 YR 3/4, Munsell Soil Colour Chart). The pH values vary from 7.0 to 8.1. The B horizon varies in depth from about six inches to thirty six inches. It is markedly more powdery in texture, with more clay present, and with numbers of travertine coated pebbles and nodules increasing down to the weathered bedrock and C horizon. The soil is much paler in colour owing to the presence of

Profile of a solonised brown soil

An example taken from the Coolgardie area, where the underlying rock is ultrabasic.

0-10"

Yellowish red loam (5YR 4/6); occasional travertine coated pebbles; pH 8.2; fine to medium plant roots present.

10"-35"

Paler coloured (5YR4/6) silty-clay loam of looser more powdery texture; travertine coated pebbles become more abundant; pH 7.5; roots present only in upper part of horizon.

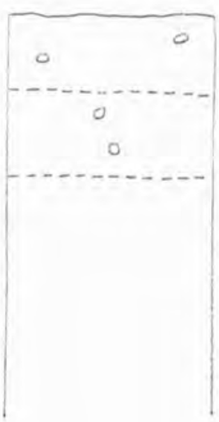
35"

Beginning of weathered bedrock; pH 8.4.

Profile of a solonised brown soil

containing less apparent lime

An example taken from South Norseman, where the underlying rock is greenstones.



0-6"

Dark brown (7.5YR 4/4) silty-clay loam; occasional travertine coated pebbles; pH 8.8; fine to medium roots present.

6"-12"

Dark brown; higher proportion of clay; pH 9.1; roots absent.

12"-18" and continuing

Strong brown (7.5YR 5/6) clay; crumbs of white and reddish clay present; pH 9.3.

Figure 5

fine calcium carbonate (dry soil 7.5YR 7/2, wet soil 5YR 5/6), the most marked colour contrast being seen when the soil is dry; wet soil assumes the same yellowish red colour as the above horizon. The pH does not differ very greatly from the A horizon, and readings of 7.0 to 8.2 were recorded.

A solonised brown soil, containing less apparent lime, occurs in certain parts of the area studied where conditions had allowed a mature profile to develop. Such a soil is encountered at South Norseman, developing in the lower-lying flatter areas where the underlying bedrock is composed of greenstones, and also occurs in a costean overlying metadolerite south of Mt. Hunt. The A horizon is similar to the profile described above. From the surface to approximately six inches depth is a dark brown (7.5YR 4/4) silty loam. A few travertine coated pebbles may occasionally be present. The pH varies from 7.2 to 8.8. The B horizon differs from the typical solonised brown soil in that below the A horizon to a depth of eighteen inches and continuing is a strong brown (7.5YR 5/6) horizon. Some of the soil crumbs in this locality have a mottled appearance with white and red-brown colours. There is a higher proportion of clay which often becomes very sticky when wet. Travertine coated and weathered pebbles are present in varying numbers. pH readings are usually fairly high in this horizon, and values up to 9.6 were recorded.

The origin of the calcareous material in solonised brown soils and in calcareous laterites is the subject of a number of hypotheses, and it is probable that in different areas different origins are involved. For a number of reasons Stephens (1961) dismisses the theory put forward in 1946 by Crocker that the parent material was a calcareous loess derived from calcareous coastal dunes which were associated with a lower sea level during the Pleistocene: a southerly wind direction, necessary for such a distribution of calcareous material, is unrealistic, and no evidence has been gained from certain dunes studied in South Australia that calcareous material is lost by deflationary suspension. Moreover, Stephens finds it difficult to reconcile Crocker's hypothesis with the humidity and close vegetation cover which would have been present during the period of lowered sea level. He considers that calcareous loessial material is far more likely to have been blown from the region of the Nullarbor Plain, an extensive area of limestone. Investigations in the Merredin area have shown that calcareous material here is derived from salinas, the prevailing westerly winds transporting it from these salt lakes and depositing it over the landscape.

The solonised brown soils may be compared with other semi-arid soils found outside Australia in that accumulations of lime are present. The Australian soils occur almost exclusively over a deep mantle of aeolian calcareous material which overlies a variety of rock formations, and therefore have a greater degree of solonisation than solonised soils in other continents, judging from their alkaline reactions and proportion of sodium and magnesium. However, any visible expression of solonisation may be masked by the lime (Stephens 1961).

In all rainfall there is a small amount of cyclic calcium and somewhat more sodium. In arid regions where rainfall does not percolate deeply at the point of impact, but only after run-off, removal of soil moisture by evapo-transpiration must lead to the precipitation of any dissolved salts. The depth of precipitation of alkaline-earth carbonates is also affected by the phase relationships of unionized carbonic acid, the hydrogen carbonate ion and the carbonate ion in the soil moisture, and the depth to which that moisture has penetrated.

The excess of sodium in rainfall over very long periods leads to the leaching and replacement of calcium adsorbed to clay particles. Further, since sodium forms more relatively soluble compounds than the alkaline earths, successive wetting at high pH will lead to the concentration of calcium in carbonates and leave sodium free for adsorption to clay particles.

Skeletal soils

These soils occur in each area studied, wherever the underlying rock outcropped or had weathered to produce scree and coarse rock fragments, which often help to mask any outcrop present. Soils developed in such areas are usually very shallow, only a few inches deep, and do not show any profile development. Skeletal soils occur wherever the relief is sufficiently rugged, for in such areas erosion will tend to remove most weathering products before they can build up into a soil; it may be only in pockets that a shallow soil can develop. Skeletal soils may occur in lower-lying areas where bedrock outcrops, and here may be due to the recent exposure of the parent material.

At Coolgardie these soils occur particularly on the basic lavas, which are more resistant to degradational processes than are the ultrabasic rocks, and constitute the most prominent hill features. Here they are yellowish red in colour (5YR 4/6) with a sandy-silt texture. They have a high proportion of free lime and a high pH, the highest recorded being 9.7.

These soils also occur at Mt. Hunt, particularly on its topmost slopes where metabasalt and metadolerite outcrop. In this locality the soil is dark reddish brown (2.5YR 3/4) to yellowish red (5YR 4/8) in colour and with a sandy loam texture. pH values recorded here are lower than at Coolgardie, ranging from about 5.0 to 6.2. Skeletal soils also occur on the other rock types which outcrop in the vicinity of Mt. Hunt, for example, on parts of the metajaspilite bands and on the areas of serpentinite, where they are characterised by similar features to those in soils over the metabasalts and metadolerites.

In the Norseman area skeletal soils are also fairly common, occurring over the Jimberlana Dyke, and on the greenstones where such outcrop. In the Norseman Reef area they are frequently found where the Mararoa pillow lavas lie at or near the surface.

At Kambalda the upstanding metabasaltic areas are characterised by these soils, although they also occur over the more limited areas of serpentinite outcrop.

Sandplains:

Sandplains occur within the Eastern Goldfields but were not included in any of the field study areas; a detailed account of their profile and occurrence cannot therefore be given for any specific locality. They occur in various parts of the region and vast areas may be mantled by considerable depths of these materials. For example, the Great Eastern Highway midway between Bullabulling and Woolgangie passes over a sandplain which stretches southwards for many miles, expanding to the east and west before abutting onto the Coolgardie and Kalgoorlie metamorphics in the east by Spargoville and Larkinville, and passing into the Dundas goldfield to the south.

Sandplains are characterised by sandy grey and pale yellow surface soils. Layers of nodular and pisolitic gravel occur within the profile and may overlie mottled and pallid kaolinitic zones. Texture gradually increases with depth and pH values are slightly acid to neutral.

Sandplains were originally thought to be residual fossil soils (Prescott 1931). However, studies in the York district of Western Australia have led to the proposal that the sandplain soils in the south-west of the State are locally derived from weathered lateritic material which has undergone colluvial transport (Mulcahy 1960). The grey sandy A horizon of the lateritic profile has been stripped, particularly during the arid period of the Recent, to expose the underlying ironstone of the B horizon, which has undergone weathering and provided a source of extensive sandy material. Provided such processes continue over a long period of time and the material suffers no further removal, then it is possible for resistant quartz sands to be separated and retained, while less resistant, more easily weathered primary and secondary minerals are destroyed. It is these deposits which are proposed to form the sandplains of the present. They may be found overlying a range of materials, such as fresh rock or young soils, although they are most usually underlain by the pallid zones of lateritic soils. Boring has shown that layers of ironstone gravels or soft reddish mottles occur in these deposits, possibly indicating deposition under varying conditions with alternating periods of stability. These layers harden when exposed, and it is probable that many ironstone crusts now found at the surface formed in this way. Such ferruginous material therefore, even when overlying a kaolinitic horizon, cannot always be assumed to represent evidence for an ancient landsurface, for it may well be relatively recent rather than the remnants of a Tertiary fossil soil in situ.

5. Vegetation

A brief introduction will be given to the vegetation types which occur in the Eastern Goldfields and adjacent regions of Western Australia. A more detailed discussion of the floral elements of the State follows, with particular reference to the region in which the field work was undertaken.

The vegetation of the Eastern Goldfields consists of open sclerophyllous woodland in which a wide range of Eucalyptus species occur, associated with low woody perennial shrubs and a few harsh perennial grasses, with weaker growth of annuals during the cool wet season. These woodland belts are surrounded and separated by vast stretches of heathland and scrub, commonly known as sandplain. While the trees of the woodlands may attain heights of up to eighty feet, zones intermediate between the woodland and sandplain carry associations of mallee. The term mallee is used to describe a vegetative form found in a number of Eucalyptus species in which, instead of one main trunk, there are several stems arising from a large woody lignotuber, which is mainly below the ground surface. The mallee habit is thought to be an advantage over that of a single trunk in areas subject to fires because of the ability to produce new shoots from the lignotuber. To the north of the region, in the vicinity of Menzies, the Eucalyptus zone gives place to the low scrub known as mulga, an Acacia association in which the main species is Acacia aneura. Eucalypts have far less importance in this zone, and are represented by such drought-resistant species as the desert gum (Eucalyptus gongylocarpa) and several mallees, including E. pyriformis and E. Kingsmilli. The mulga extends for several hundred miles before giving way to the sparse vegetation of the central desert.

Forest formations grow in the south-west of the State. The karri (E. diversicolor) occurs where the rainfall exceeds forty inches a year, while elsewhere other species become dominant. The jarrah (E. marginata) is particularly well developed on the deep well-drained gravel on the slopes of the laterite-capped ridges of the Darling Range. The tuart (E. gomphocephala) replaces it on the limestone areas near the coast, and the wandoo (E. redunca var. elata) is dominant on the clays and granites east of the twenty five inch isohyet.

Studies of the genera of the flora of Western Australia suggest that it is possible to recognise three floral elements occurring in the State. Although showing no affinities with neighbouring regions, such as New Zealand and New Guinea, certain relationships are shown with floral elements in South Africa, South America and Antarctica. Such a division was first made by Diels, who listed an old Antarctic element, a Palaeotropic element and an Australian element. C.A. Gardner (1944) recognises three main climatic provinces which have influenced the development of three types of vegetation, resulting in three phytogeographical provinces. The Northern Province, with its wet summer and dry winter, is largely made up of palaeotropic plants which entered Australia from Indo-Malaya and Melanesia. Several groups of palaeotropic origin have undergone evolutionary changes so that they are now no longer seen as typical examples of this element; some authors regard such as typifying the Australian element of the flora. The area includes many families and species, having a particularly rich development in the Kimberleys, with residual areas in the De Grey River district and the Hamersley Ranges. A type of monsoon woodland grows where the rainfall is adequate, and a number of deciduous trees may occur, such as Terminalia and Brachychiton. Large areas of the country support savanna woodland where the underlying bedrock is sandstone, quartzite and basalt, while where the soil has been derived from limestone open grass country is frequently found. Mangroves fringe the coast and in the drier areas, especially in the south of this province, a shrub and grass formation grows where Acacia species are usually dominant with the grasses Chrysopogon and Sorghum.

The Antarctic element is found in the South-West Province which has a wet winter and a dry summer. Families present indicate connections with other continents; for example, the Proteaceae are also found in South Africa, the Persoonioideae in South Africa and Madagascar, and the Grevilleoideae in South America. The presence of conjunctive genera is of even greater interest. Podocoma and Trichocline (Compositae) and Selliera (Goodeniaceae) grow in both south-west Australia and South America, making the links between these two continents stronger than those between Australia and South Africa. The province is characterised by forest and woodland formations, such as that dominated by Eucalyptus diversicolor in the extreme south west corner where there is a high seasonal rainfall. Areas of shrub heath form a distributional mosaic with the woodland, according to the prevailing soil. The Australian element is best expressed in these heaths, for this province is the richest in endemic species; Gardner accounts seventy five per cent of the species present as endemic.

These two provinces are separated by a third, the Eremean Province, which receives less than 175 millimetres of rainfall a year, its central and eastern areas being very arid. In the northern part summer rainfall occurs in contrast to the south where winter rainfall is experienced. The centre of the province has no particular rainfall regime, receiving its falls from extensions of the north and south rainfall systems. The Eastern Goldfields fall into Eremaea, and this province will therefore be treated in greater detail. Its flora tends to be rather impoverished, consisting of the Australian element which is composed of families and genera occurring only in Australia, having no relations outside the continent, or simply a few scattered representatives connected with the Australian stock. Its permanent elements are plants of a sclerophyllous nature, and various adaptations to arid conditions are found, such as leaf reduction to the ericoid form, characteristic of many shrubs such as Melaleuca sheathiana, and complete leaflessness in a number of plants, such as Templetonia sulcata, whose stems have become flattened and photosynthetic. Other features of floristic distinction are the high development of phyllodineous species of Acacia, and the large number of Eremophila species, largely restricted to this province. Its herbaceous species are ephemeral. Owing to the evolution of the Australian element from Palaeotropic and Antarctic elements its claim to being a true element has been questioned. The following information on Eremaea is taken largely from the observations of Gardner (1944).

The province can be divided into three zones. The northern zone is largely composed of low tree and shrub savanna and large open tracts of grassland dominated by Triodia and Plechtrachne species where the ground is sandy, but other genera such as Eriachne and Sorghum species on loamier soils. The trees present tend to be stunted, Eucalyptus, Acacia and Hakea being the most important genera. Hibiscus and Cassia species are common in the shrub layer, while in the ground layer Ptilotus, Gomphrena and Amaranthus species assume importance with a number of herbaceous species.

Acacia aneura, commonly called mulga, dominates the central part of the Eremaean province. Eucalyptus species occupy only a minor part of the area and the vegetation comprises almost pure stands of *Acacia* species, the trees rarely exceeding twenty feet in height and often imparting a rather dull appearance to the country by their uniformity. The most outstanding species, besides *A. aneura*, are *A. craspidocarpa*, *A. linophylla*, *A. sowdenii* and *A. resinomarginea*. *Eremophila* is an important shrub here having most of its species in the mulga country. *Cassia* species are also common, and other genera frequently encountered include *Callitris*, *Grevillea*, *Dodonaea* and *Solanum*. The ground cover tends to be sparse, consisting of small perennial plants and hardy tussock grasses, such as *Danthonia bipartita*. In September, however, the region is transformed. The rainfall of late winter and spring draws the vegetation into new life and colour; white everlasting daisies, such as *Cephalipterum drummondii*, other Composites, and pink and yellow *Velleia* form patches of continuous colour beneath the Acacias.

The southern boundary of the mulga scrub tends to be fairly sharply defined. *Acacia* species give way to open *Eucalyptus* woodland, and *Eucalyptus* species dominate the vegetation over most of the southern part of Eremaea. *Acacia* species still grow, but are much more restricted in their occurrence. The variety of species found in the shrub layer increases. _Eremophila_ species are still important, as are shrubby Composites such as _Olearia_ and _Cratystylis._ Other dominant shrubs include _Cassia_, _Atriplex_ and _Kochia_; _Bassia_ is widely spread as a perennial in the ground layer. The study areas of the Eastern Goldfields are located in this southern zone of Eremaea.

The dominant _Eucalyptus_ and shrub species change throughout this area of open woodland as differences in the physical and chemical environment are encountered, and as species migration and dispersion influence the range of area over which a species may be found. A slight change in the microhabitat may result in a change in the dominant _Eucalyptus_ species present, and a mosaic of species will result as conditions change and recur . The Forests Department of Western Australia has listed the following sub-types found within this _Eucalyptus_ zone:

(1) _Eucalyptus salmonophloia-E. salubris-E. oleosa_ var. _longicornis_

This woodland may reach to a height of eighty five feet in favourable conditions and has suffered from disturbance by felling for mining timber and firewood. Subdominant trees which may be present include

E. flocktoniae, E. dundasi, E. melanoxylon and E. oleosa var. glauca. This type of woodland grows around Norseman, as for example south-east of the township towards the Iron King mine.

(2) E. lesouefii-E. oleosa woodland

E. oleosa tends to dominate in the western part of this woodland area, but further east is superseded by E. lesouefii which forms a lower woodland up to sixty feet high.

(3) Further north and east of Kalgoorlie as rainfall totals decrease, the Eucalypts become smaller, attaining heights of up to approximately thirty feet, with mallee forms predominating. E. oleosa and varieties of this species occur with other Eucalyptus species. Patches of mallee intrude into other woodland types and into the sandplains. It is possible for various species which grow as trees with single trunks in some areas to show the mallee habit under less favourable conditions.

Throughout the greater part of the year the surface of the ground remains devoid of herbaceous plants owing to lack of moisture in the upper soil layers. Small perennial plants, such as Kochia species and the ubiquitous Bassia, may relieve the wide areas of soil and weathered rock material beneath the trees. With the first rains of winter, and as the temperature becomes lower the green of young grass begins to show along the road verges and within the woodlands. During the spring the ephemerals (such as Erodium species and numerous Helipterum species) are at their best, but their time is short and as the season advances and the temperatures rise they quickly seed and die.

Around the salt lakes and pans most tree species cut out with the increasing salinity of the soil. Associations of salt-tolerant species grow, for example Arthrocnemum halocnemoides, Frankenia species and Disphyma australe, the latter of a particularly succulent nature. Halophytic associations may also occur in old watercourses.

On the sandplains, Eucalypts do not predominate and a wealth of shrubs may be found -- Melaleuca, Eremophila, Thryptomene, Wehlia and many others, as well as Triodia, the spinifex grass.

Eucalypts also have less importance in the association where outcrops of granite and gneiss occur and the soils tend to be sandier. Eucalyptus Websteriana may grow, but in low frequency. Acacia predominates in such localities, especially A. acuminata, which is often associated with Eremophila species (for example, E. granitica). The herbaceous flora is often better developed in the vicinity of these outcrops as the latter form water catchments; a dense growth of grasses and ephemerals may be found during winter and spring.

Origins of the floral elements

The fossil record indicates that during the early Tertiary period the Australian vegetation tended to be rather uniform, with Eucalyptus, Laurus, Daphnandra, Ficus, Casuarina, Nothofagus and Cinnamomum, and Proteaceous genera allied to Banksia, Persoonia, Grevillea and Hakea. This uniformity corresponded with the uniform edaphic and climatic conditions then prevailing. The climate was more humid and generally warmer, for mesophytic plants are known to have grown in what are today arid areas. Many of them had a more southerly and westerly occurrence, for example, Podocarpus grew widely over southern Australia in the early Tertiary, yet is now confined to the subtropics and tropics of Northern Australia and New Guinea (Cookson and Pike 1953, quoted by Crocker 1959). The Tertiary flora as a whole was mesic, in contrast to that of today which is mainly xeric and sclerophyllous. Although the flora of this period is known in a general fashion, practically nothing is known of the details of succession.

Australia had largely been reduced to a peneplain by the mid-Tertiary, covered by deep lateritic soils. The early Tertiary flora persisted with only gradual change into the upper Tertiary, and it was during the latter period that block faulting occurred, this being responsible for the elevation of the Mount Lofty-Flinders Range in South Australia. The Miocene marked the end of the period of great stability; epeirogenesis broke up the peneplain and marine inundation was responsible for the large limestone deposits of the Nullarbor Plain. New erosive cycles were initiated and new parent materials exposed and deposited, creating many new habitats. Adjustments were necessary in the flora because of changing climatic conditions. Eucalypts became more widespread, especially in southern and eastern Australia, Acacia and various Composites became prominent, and new species appeared, many having affinities with the Palaeotropic flora of Africa.

However, these edaphic and orographic climatic effects did not influence the flora of the continent as a whole, and the contrast between the distribution of the Tertiary flora and that of the present must result from climatic changes on a continental level. Since the time of the Pleistocene, which was generally wetter than the present, and up to the Recent the climate became more arid, judging from the distribution of truncated soils and aeolian sand systems. Many workers have put forward evidence for a mid-Recent period of aridity. The onset of the aridity was sudden, for the soils became freely exposed to erosion; much of the pre-arid flora was destroyed and only managed to survive in such areas as mountains and near rivers. The existing xeric species were unable to colonise the soils rapidly enough to prevent the widespread erosion. The extent of the wind erosion was only possible provided that there was a great reduction in the vegetative cover.

As the climate became wetter once more, recolonisation and migration occurred, resulting in present day communities. Australian plant communities are young; within a climatic zone their distribution has been determined by edaphic factors to a large extent, although other factors, such as location of surviving centres and dispersal capacity, have also exercised influence.

The vegetation today therefore consists of remnants of the Tertiary flora with southern and northern elements, and a post-Tertiary flora with new and specialised species which have evolved from them to withstand the hot and arid conditions; this is the Australian element.

The histories of the two most abundant and species-diverse genera in Australia, Eucalyptus and Acacia, will be considered briefly.

While Eucalyptus is absent from rain forest formations and species are not found in the most arid parts of the continent, it is otherwise very widely spread, covering a wide range of climatic and edaphic habitats. The Tertiary fossil record of this genus is not well recorded; twenty seven species have been listed by Duigan (1950, quoted by Wood 1959) in Eocene and Miocene beds. During the early Tertiary some differentiation of Eucalyptus is thought to have occurred while the continent was characterised by uniformity of topography and climate. While southern Australia suffered from earth movements and habitat disturbances during the Miocene the northern part of the continent has had a relatively undisturbed history since the Cretaceous. This has allowed species to become established over large areas.

There is a widely held view that the genus arose and developed in the northern part of Australia, based on supposedly primitive characters and distributional aspects, but much of this is conjectural (Wood 1959). Today the number of species and varieties of this genus is approaching 700 (Blakely 1955).

The fossil record of *Acacia* in Australia is poorly recorded. From palynological evidence the common association of this genus with that of *Eucalyptus* may be seen dating back to the late Miocene. It is probable that it developed from the fringe of species remaining after the disruption of the Tertiary pan-Australian flora by the increasing aridity of the Recent period. Certain morphological developments can be traced in the evolutionary history of *Acacia* through information gathered from the past and present distribution of this genus. For example, the pinnate leaf form, which is still present today in a number of species, has been shown to have undergone a reduction during evolution. Reduced leaves characterise many *Acacia* species, this being an adaptation to an arid environment by reducing the transpiration surface; it may well have been a development which was selected consequent upon the past climatic aridities.

This reduction in leaf form is believed to have led to evolution favouring the increased development of the phyllode as an organ of photosynthesis. Phyllodes have replaced leaves in many species of Acacia, the phyllodes varying in the degree to which they have expanded into leaf form. In drier parts they are relatively small organs, often under one centimetre in length, but where rainfall totals become higher they may grow to a length of several centimetres.

This genus has radiated to give about 700 species, about 600 occurring in Australia. Some of its species are more tolerant of arid conditions than are Eucalypts, and today Acacia forms the dominant genus over vast inland areas.

The present distribution of Eucalyptus and Acacia and other sclerophyllous genera, and the associations they form is the result of past history, coupled with factors relating to microhabitat conditions, sensitivity to which may be very great.

The recent history of the vegetation in the Eastern Goldfields

The history of the sclerophyllous woodlands in the Eastern Goldfields during the past seventy years has been one of exploitation. Since the discovery of gold some twenty seven million tons of timber have been cut from inland forests, especially around the mining towns, for use in the mines and as firewood (Brockway 1949). Cutting became heavier with the increasing activity during the early years of the goldfields, and was of necessity carried out over an ever-widening area from the settlements. Altogether, about seven million acres of forest were felled. Eucalyptus salmonophloia, the two gimlets E. salubris and E. campaspe, E. oleosa var. longicornis and E. Brockwayi, were all prized for their hard timber. Mature forms of Melaleuca sheathiana were found to be useful owing to their resistance to the attacks of termites, and were felled for building purposes.

Felling has been followed by natural regeneration, and the woodlands which grow today around the mining towns are secondary growth. In some parts, the regeneration has been prolific, in others only sparse, depending on such factors as the species, the site, and the occurrence or absence of fires. All trees in the interior are very fire tender and only the mallees coppice after a fire. Even a small low fire can cause the death of thin-barked species, such as E. salubris. Felling for firewood is no longer allowed. All the woodlands today are carefully surveyed and under the protection of the Forests Department at Kalgoorlie.

PART 2

FIELD AND LABORATORY TECHNIQUES

1. Vegetation studies

The distribution of the vegetation was recorded quantitatively in the field by the use of quadrats and transects. The transects were laid out with a hundred foot linen tape and oriented to cross the vegetation associations and communities encountered and the strike of the rock types within the limits of each field area. An aneroid barometer and abney level were used for the respective purposes of levelling and slope measurement along the transects. The distance between quadrats was varied according to the character of the vegetation: for example, where there were successive changes in the vegetation over a small area the quadrats were made continuous, i.e. a belt transect was run. The quadrat interval was increased to a hundred feet or more where an association remained uniform. The size of the quadrats used was varied for the purposes of recording each vegetation stratum. Quadrats 100 x 100 feet were laid out to gain quantitative information on the tree species present, while smaller quadrats of 20 x 20 feet were used to count the shrubs. The ephemeral nature of the ground layer precluded the recording of comparable information on percentage cover by various species in this stratum; data is lacking on such species in most of the areas studied.

Shrubs and trees were sampled along each transect, the sampling distance varying with the area under examination and the occurrence of the species chosen for sampling. Wherever Eucalypts were sampled leaves, older and younger twigs were collected, and also fruit and buds if present. Samples were also taken of the aerial parts of selected shrubs. Root samples of trees and shrubs were collected from selected localities. The same species of trees and shrubs were sampled over the different field areas so that information could be provided on their trace element content from different localities and from differing rock types. For example, Eucalyptus foecunda was collected from Coolgardie, Mt. Hunt, Kambalda and Norseman. Although this species characterises areas underlain by ultrabasic rocks, the particular type of ultrabasic differs to varying degrees between these localities. The plant samples were dried between sheets of drying paper before being stored in kraft paper bags.

Herbarium specimens were collected of each species for purposes of identification.

The distribution of the vegetation associations and of certain individual species were mapped over parts of the areas studied with the aid of aerial photographs.

2. Soil studies

Information on the soil types encountered over various geological units and on the catenary sequence associated with topographic features was gained by examining the profiles in the field and collecting samples for geochemical analysis. A posthole auger was used to obtain information on the character of the soil profile, where soils were not too stony to prohibit its use. It was often impossible to auger beyond a depth of about eighteen inches owing to the soil being dry and loose, and it was therefore not brought up in the auger but had to be scooped out by hand. In the Coolgardie district costeans adjacent to the transects were used in profile studies after their faces had been cut back.

Colour determinations were made in the field with a Munsell Soil Colour Chart, and soil texture was estimated. pH readings were taken with a portable pH metre and the amount of free lime was estimated using dilute hydrochloric acid.

Soil samples for trace element analysis were collected at 50 foot, 100 foot or 500 foot intervals along the transects, the sampling interval being determined by the locality; where the bedrock or vegetation differed over a short distance sampling was more frequent. The soils were collected from a depth of four to six inches, excepting where soils were skeletal and sampling was of necessity from shallower depths. Samples were also taken from each horizon in the profiles examined. The soil was sieved in the field to obtain the -80 mesh fraction for trace element analysis and stored in kraft paper bags. Unsieved bulk soil samples were collected from each vegetation association and from each rock type for major element analysis.

3. Geochemical and biochemical studies

The -80 mesh sieve fraction from the soil samples was analysed for trace elements using the colourimetric methods of the Geochemical Prospecting Research Centre, London (1962). In all cases the total metal content was determined. An acid extract of a bisulphate fusion was used for copper, zinc, lead and nickel. Copper was estimated using 2,2'-diquinolyl; zinc and lead using diphenylthiocarbazone (dithizone); and nickel using α-furildioxime. A sodium hydroxide and sodium peroxide fusion was used for chromium, and a potassium hydroxide fusion used for arsenic. The Kambalda soil samples were analysed by atomic absorption spectrophotometer by courtesy of Western Mining Corporation Ltd.; nickel, chromium and copper were determined using a nitric perchloric digestion.

The -80 mesh sieve fraction was also used from the bulk soil samples for the analysis of major elements. Analysis was carried out by atomic absorption spectrophotometer at the C.S.I.R.O. laboratory in Wembley, Perth. A ~~hydrochloric~~ hydrofluoric acid digestion was used.

Plant samples were analysed for trace elements using the colourimetric methods referred to above. The various organs of the Eucalypts were analysed separately, although the shrub species collected were analysed as composite samples as their morphology made the separation of leaves and twigs generally impracticable. In preparation for analysis the plants were ashed in a muffle furnace at 410°F. for approximately twelve to twenty four hours. A few of the samples were milled prior to ashing, but this was discontinued as being an unnecessary procedure; breaking the material by hand is quicker and the subsequent ashing is completed sooner as combustion is more efficient with material which is less densely packed.

Tests were carried out to assess the amount of possible contamination from dust in the bush. Samples from various _Eucalyptus_ species and from _Olearia muelleri_ were divided into three parts; a third was brushed to remove possible dust; a third was rapidly but thoroughly washed and dried; and a third was ashed without any cleaning preparation. All three parts were ashed and analysed. Results from the analysis of these samples indicated that contamination from wind-blown dust is not a problem.

PART 3

THE NORSEMAN AREA

1. Climate

The maximum and minimum mean monthly temperatures for Norseman fall slightly below those for Kalgoorlie, owing to its more southerly latitude in the region. During the hottest months of the year the heat of the afternoons and evenings may be tempered by the "Esperance doctor", a cool breeze which blows northwards from the Southern Ocean.

The average annual rainfall for Norseman is $10\frac{1}{2}$ inches, the 10 inch isohyet passing to the north-east of the township. Temperature and rainfall observations are given in Table I.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean maximum temperature °F	92.0	89.2	86.3	74.3	67.3	61.6	61.3	64.1	70.3	74.5	82.1	87.0	75.8
Mean minimum temperature °F	60.1	59.8	57.9	50.8	45.4	41.8	40.1	40.8	44.1	47.6	51.9	55.5	49.7
Rainfall (points)	57	91	86	93	116	114	105	104	74	83	72	74	1069

Data supplied by the Deputy Director, Commonwealth Weather Bureau, Perth, W.A.

TABLE I CLIMATIC DATA FOR NORSEMAN

2. Geology

The Norseman area falls within a series of Pre-cambrian basic meta-igneous and metasedimentary rocks which form an extensive inlier stretching northwards through Kalgoorlie (Figure 6). Granite surrounds this belt of rocks on three sides. The dip of the rocks is fairly uniformly to the west at 50° to 60° on the westerly limb of a large anticline which dips gently to the north.

The greenstones here consist mainly of metabasalts and pillow lavas. Dolerite and gabbro dykes have invaded the lavas, the dykes transgressing at 45° and having a northerly strike. They vary in thickness from a few to several hundred feet, the oldest being those of meta-quartz-gabbro. The area has also been intruded by a swarm of quartz- and feldspar-porphyry dykes with a north-east strike and which transgress westwards at 50° or more.

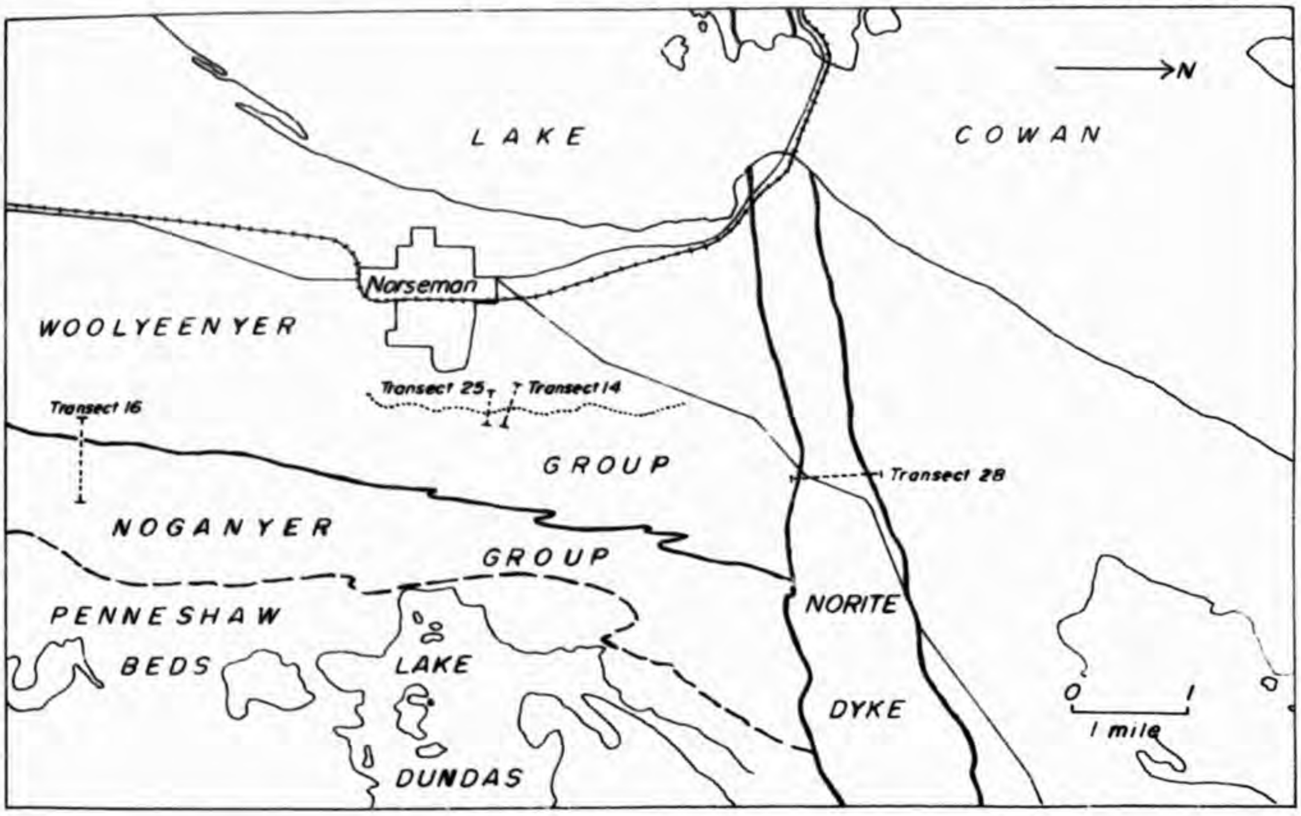
Several east-west trending dolerite dykes and a norite dyke belong to a later age. The noritic Jimberlana Dyke is the largest of these, averaging a mile in width, and traceable for over one hundred miles.

Marine, Tertiary and younger sediments occur, especially in the vicinity of the salt lakes, lying on the lower areas of the Precambrian.

There are two types of gold mineralisation at Norseman -- minor bedded quartz-sulphide lodes in the metajaspilites, and the economically important auriferous gold reefs in the meta-igneous greenstones. Production has come mainly from shoots along the Mararoa shear. The Norseman, Mt. Barker and other reefs were worked out during the early mining developments on the field. The Crown reef is now the most important producer of gold and mining continues in the Princess Royal area.

GEOLOGICAL SKETCH MAP OF THE NORSEMAN AREA

(After Central Norseman Gold Corporation)



LEGEND

Woolyeenyer Group:

- Desirable Pillow
- Crown Basalt
- Nulsen Slate
- Royal Amphibolite
- Bluebird Gabbro
- Gee Cee Slate
- Mararoa Pillow Lava
- Venture Slate
- Kingswood Basalt

Noganyer Group:

- Holstein Jaspilite
- Iron King Formation
- Hopetoun Jaspilite
- Lady Mary Formation
- Lady Miller Jaspilite
- Morell Schist
- Attlee Jaspilite
- Raggedy Formation
- Bon Accord Jaspilite
- Sawpit Formation

...... Norseman Reef

—— Geological boundary

– – Approximate geological boundary

—— Road

+++ Railway

Figure 6

3. Physiography

The immediate area of Norseman does not possess the monotonously flat to slightly undulating surface by which so much of the physiography of the Eastern Goldfields is characterised, but has some degree of topographic variety. The main relief feature in the northern half of the area is the Jimberlana Dyke. At its highest point it is 1308 feet above sea level, but in places forms a much less prominent feature so that it is equalled or surpassed in height by ridges formed from the surrounding greenstones.

Within the general area of the Mararoa pillow lavas to the south of the dyke stands Wireless Hill, a fine view point overlooking the township of Norseman, and reaching a height of 1295 feet above sea level. Woolyeenyer Hill, also within the lavas and lying to the south of the town, is the highest point in the Norseman locality. Its steeply sloping sides reach to 1580 feet above sea level. To the east the bands of outcropping metajaspilites provide features of relief on a smaller scale; resistant to weathering they form upstanding ridges, while narrow valleys may sometimes lie between them.

The general area of the township itself is situated on flatter ground, which slopes down gently from 920 feet in the east to 880 feet above sea level in the west to the eastern shore of Lake Cowan, whose flat surface at this point lies 866 feet above sea level. The lake, studded occasionally with small islands, has its southern extremity in the Norseman area, and stretches northwards for a number of miles, almost to the latitude of Widgiemooltha, just over fifty miles away. Lake Dundas, somewhat smaller in size than Lake Cowan, stretches south from Norseman almost to the vicinity of Kumari, forty miles to the south.

4. Soils

Skeletal soils are found in various localities around Norseman where bedrock is near the surface or is actually outcropping as, for example, on the Jimberlana Dyke and the metajaspilite bands. Such soils are very shallow and scree covered, either because erosion removes most of the weathering products before they have time to build up, or because the parent bedrock has not been exposed for a sufficient length of time to allow the forces of weathering to produce a deeper soil.

Solonised brown soils have developed on flatter areas and on some of the lower hillslopes, although on the latter terrain they do not appear to attain such a depth as in areas of more subdued relief. A description of this soil type has been given in Part 1, section 4.

A lateritic soil is present in the Iron King area. The A horizon has been removed, leaving the surface covered with weathered ironstone nodules and haematite gravel which overlie the indurated lateritic layer.

More details of the various soil types occurring in the Norseman area are given in later sections concerning the areas of detailed field study.

5. Vegetation

The vegetation formation developed over the greater part of the Norseman area is one of open *Eucalyptus* woodland. The dominant tree species vary from one area to another according to the local environmental factors, and the Eucalypts most frequently encountered are *Eucalyptus lesouefii*, *E. flocktoniae*, *E. celastroides*, *E. torquata* and *E. oleosa*. Other less frequent species, such as *E. calycogona* and *E. diversifolia* enter the associations as conditions become more suitable for them and as factors of competition alter. The Eucalypts are associated with a variety of shrub species growing in their understories. Various *Eremophila* species are common; for example, *Eremophila dempsteri* may occur in an association dominated by *Eucalyptus leptophylla* or *E. torquata*, and *Eremophila coerulea* in an association dominated by *Eucalyptus flocktoniae* and *E. celastroides*. *Atriplex* species and *Dodonaea* species are also widely spread. *Dodonaea lobulata* and *D. boroniaefolia* appear to favour scree covered ground and rocky terrain, while *D. stenozyga* tends to grow where the soil is somewhat better developed. *Melaleuca sheathiana*, the ti tree, becomes very common in some localities. Many of the tree and shrub species found at Norseman are not present further north, disappearing from the vegetation associations between Norseman and Kalgoorlie. Examples of such species are Eucalyptus Brockwayi and Eremophila pachyphylla.

In certain areas, for example, the Jimberlana Dyke, Eucalypts are rare and shrubs form the dominant stratum of the association. This is also the case in scattered localities around Norseman where soils are skeletal and weathering has not apparently proceeded to any great extent. Rich shrub associations may grow in such areas, the number of different species being high in comparison with the surrounding associations; their density is considerably greater than is usual in the understorey of woodland areas. Rocky areas in the Norseman Reef locality provide examples of such rich and dense shrub associations. Species present here include Grevillea nematophylla, Casuarina campestris, Acacia cochliocarpa, Eremophila maculata, Prostanthera aspalathoides, Dodonaea boroniaefolia, Crytandra ?glabriflora, a myrtaceous shrub sp. J.B./W.A.266, Dampiera trigona var. latealata, and Lepidosperma brunonianum.

Further details of associations and species growing in the Norseman area are given in following sections.

6. Areas of detailed field study

(A) JIMBERLANA DYKE

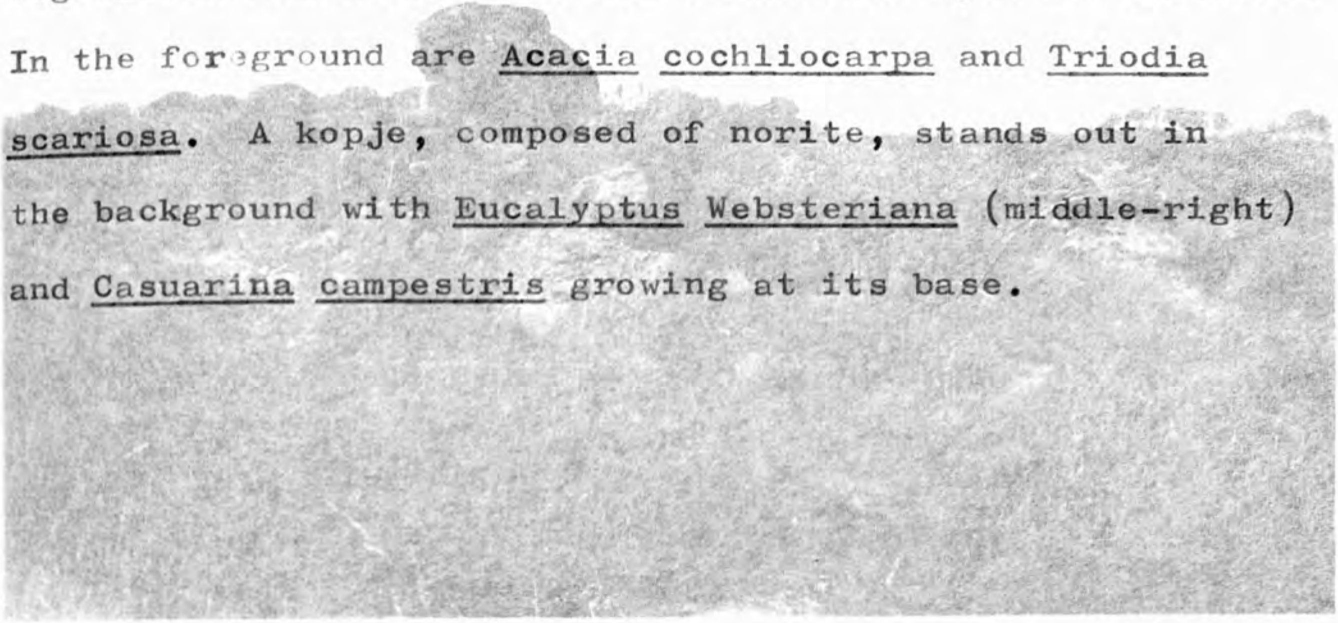
1. Distribution of vegetation associations and plant communities

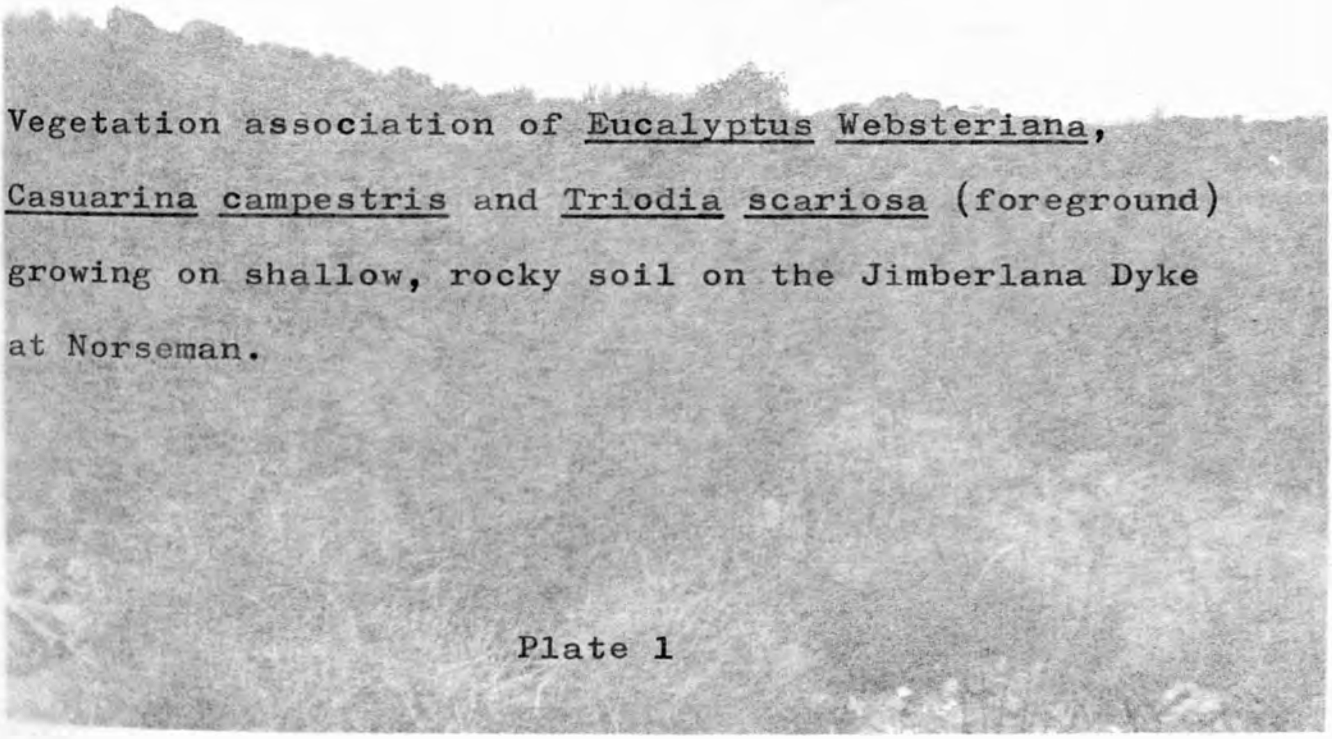
The association characterising the norite is one composed predominantly of shrub species. _Acacia cochliocarpa_, _Casuarina campestris_, _Melaleuca uncinata_ and the grass _Triodia scariosa_ form the dominant plants in a dense shrub cover which is interspersed with other shrub species of lower frequency -- _Eremophila serrulata_, _Melaleuca elliptica_, _Grevillea ?pinifolia_, _G. Wilsoni_ and _Cryptandra ?glabriflora_ (Plate 1). Trees are sparse; _Eucalyptus Websteriana_ and _E. oleosa_ occur occasionally, but do not form important members of the association (Figure 7). None of the trees or shrubs attains large proportions; _E. Websteriana_ may reach a height of ten feet, while _C. campestris_, a shrub-like species of this genus, grows to a maximum of seven or eight feet. _A. cochliocarpa_ grows to about four feet and _M. uncinata_ to about eight feet.

Parts of the periphery of the dyke have a different association, marked by the development of low open woodland. This is dominated by Eucalyptus foecunda, with E. oleosa occurring sporadically. Both tree species appear very stunted morphologically, reaching an average height of ten to twelve feet. Eremophila drummondii, Ricinocarpus stylosus, Westringia rigida and Triodia scariosa grow in the understorey beneath the Eucalypts.

Over a limited part of the dyke, five miles north-west of Norseman, the peripheral association passes abruptly into a different association -- a belt of denser woodland about 600 feet wide, forming a contrast with the adjacent vegetation both in species and physiognomy. Eucalyptus affin. cylindrocarpa dominates the woodland and is the only arborescent species present, but the density it maintains is much greater than that shown by the tree stratum in the associations on the outcrop of the norite and the peripheral areas of the dyke (Plate 2). Associated dominant shrubs are Eremophila interstans and E. drummondii, and other less frequent shrubs present are E. dempsteri, Acacia merrallii var. tamminensis, Daviesia ocanthoclona and Atriplex paludosa. This belt of woodland passes sharply into the noritic shrub association on its southern side.

Vegetation association on the Jimberlana Dyke at Norseman. In the foreground are Acacia cochliocarpa and Triodia scariosa. A kopje, composed of norite, stands out in the background with Eucalyptus Websteriana (middle-right) and Casuarina campestris growing at its base.





Vegetation association of Eucalyptus Websteriana, Casuarina campestris and Triodia scariosa (foreground) growing on shallow, rocky soil on the Jimberlana Dyke at Norseman.

Plate 1

MAP TO SHOW THE DISTRIBUTION OF THE VEGETATION ASSOCIATIONS OVER PART OF THE JIMBERLANA DYKE, NORSEMAN

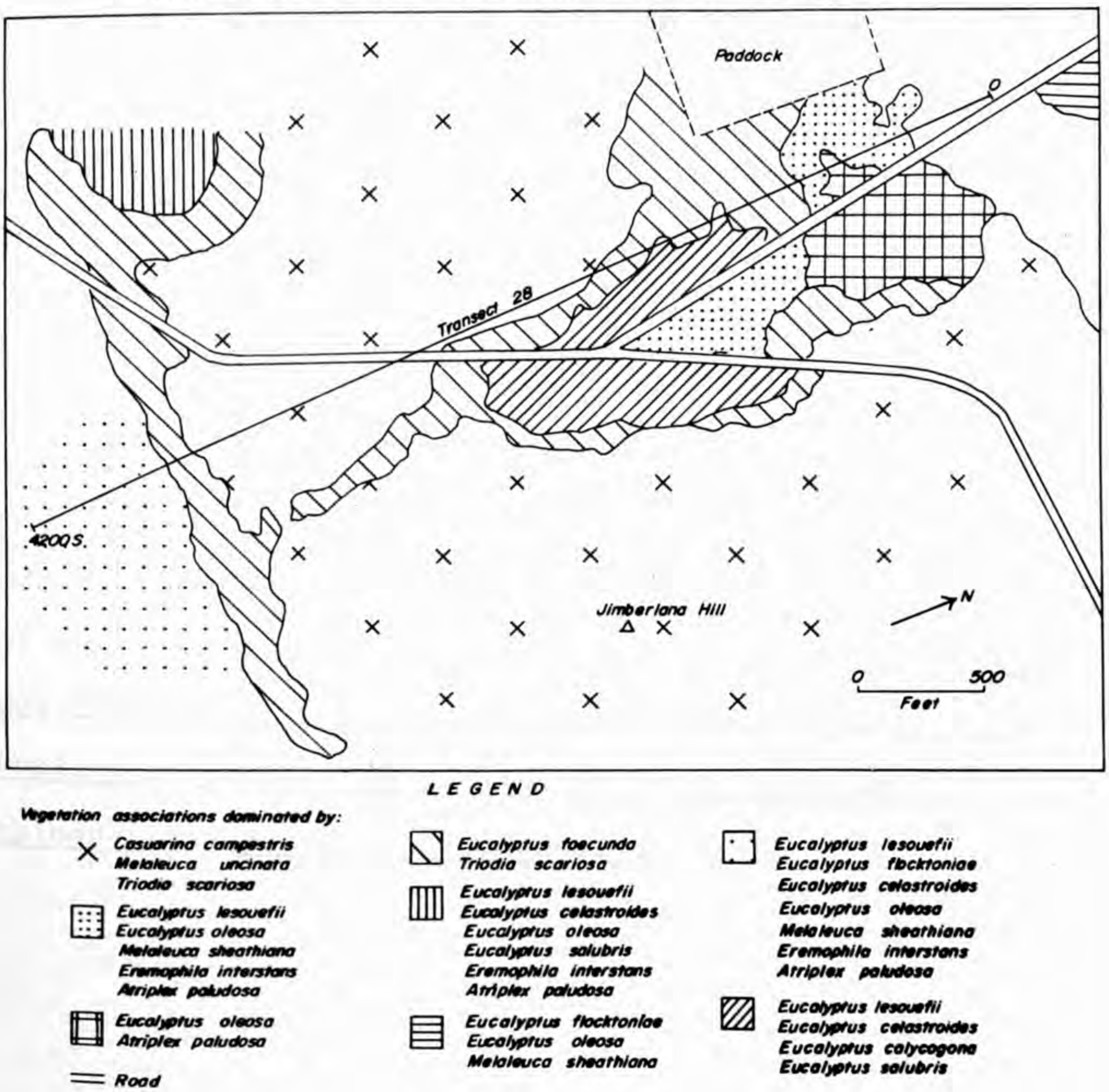
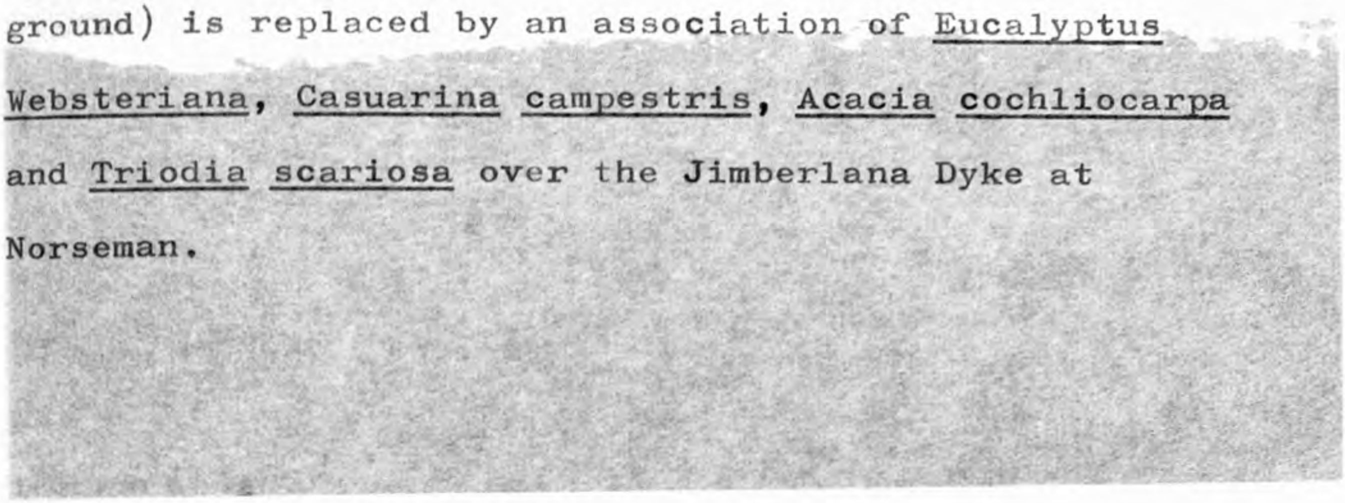


Figure 7

Open woodland occurs on the greenstones adjacent to the dyke, the appearance of the tall and evenly spaced Eucalypts presenting a marked contrast with the association on the dyke (Plate 2). *Eucalyptus torquata*, *E. lesouefii*, *E. flocktoniae* and *E. celastroides* dominate the tree stratum, while in the shrub layer *Melaleuca sheathiana*, *Eremophila interstans*, *Beyeria brevifolia*, *Olearia muelleri* and *Atriplex paludosa* are the most abundant species.

Open woodland also occupies the area of alluvial soils encountered on the northern periphery of the dyke to the west of Jimberlana Hill. *Eucalyptus oleosa*, *E. celastroides*, *E. flocktoniae*, *E. salubris* and *E. calycogona* grow in the tree stratum associated with *Santalum acuminatum*, *Eremophila interstans*, *Cassia eremophila*, *Atriplex nummularia*, *Beyeria brevifolia*, *Scaevola spinescens*, *A. paludosa* and *Bassia patenticuspis*.

Open woodland of <u>Eucalyptus</u> <u>lesouefii</u>, <u>E</u>. <u>torquata</u>, and <u>E</u>. <u>celastroides</u>, growing on greenstones (background) is replaced by an association of <u>Eucalyptus</u> <u>Websteriana</u>, <u>Casuarina</u> <u>campestris</u>, <u>Acacia</u> <u>cochliocarpa</u> and <u>Triodia</u> <u>scariosa</u> over the Jimberlana Dyke at Norseman.



The vegetation association in the foreground includes <u>Casuarina</u> <u>campestris</u>, <u>Westringia</u> <u>rigida</u> and <u>Triodia</u> <u>scariosa</u>. In the background is a dense belt of vegetation dominated by <u>Eucalyptus</u> affin. <u>cylindrocarpa</u>, growing over a restricted part of the Jimberlana Dyke at Norseman.

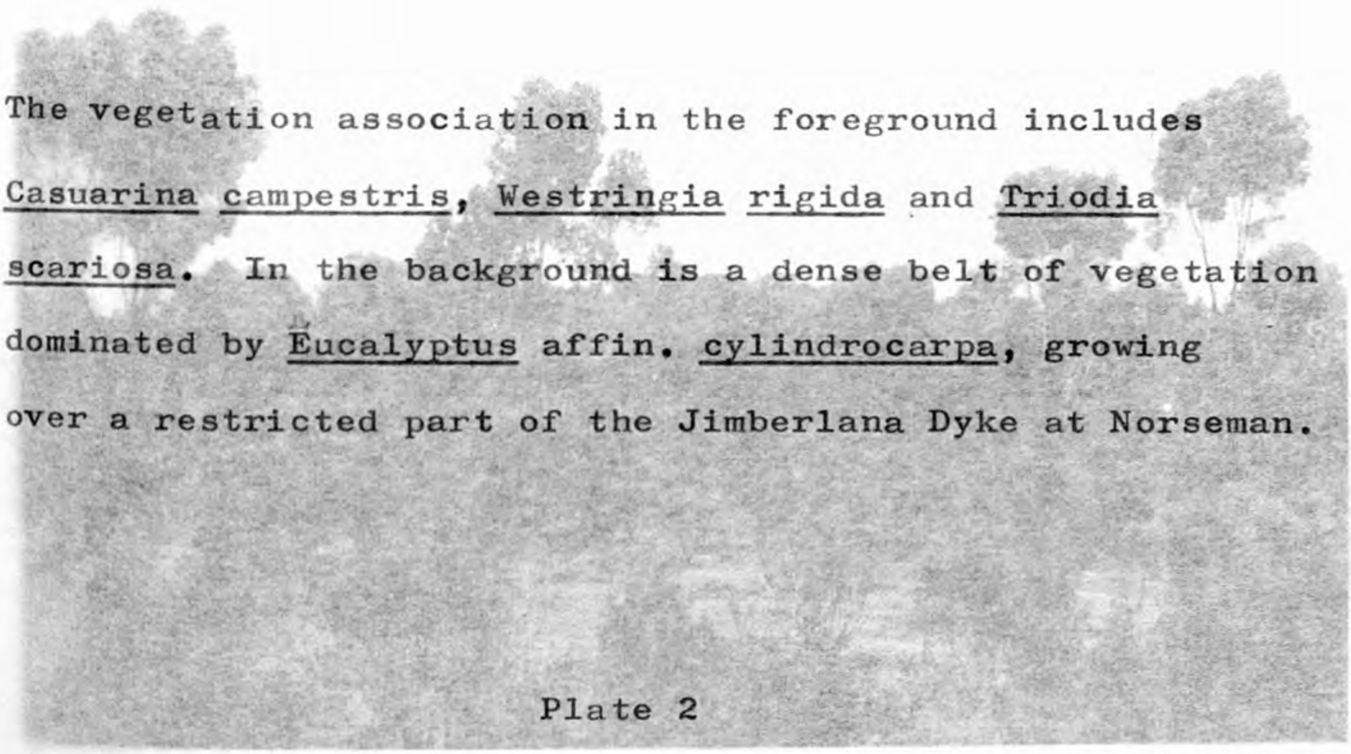


Plate 2

2. Factors governing the distribution of the vegetation associations and plant communities

(a) Geology

The Jimberlana Dyke, belonging to the last phase of igneous activity in the area, is composed predominantly of norite and feldspathic bronzitite. Parts of the geology of the dyke are shown in the two accompanying maps (Figures 8 and 9), which cover the areas of field study. These show that the major part of the dyke consists of norite-gabbro, with feldspathic bronzitite occupying parts of the periphery. Small areas of noritic dolerite and olivine norite occur on Bekker Hill and in other localities, but these rock types are of limited occurrence. The dyke averages a mile in width and has been traced from its outcrop and from magnetic data for twenty five miles east and ninety miles west of Norseman. It strikes east-west at 80° in accordance with the other dykes belonging to the younger greenstones period.

From field observations it appears that the distribution of vegetation associations is closely controlled by the underlying rock type. The outcrop of the norite can be traced by its characteristic shrub vegetation, dominated by *Melaleuca uncinata*, *Acacia cochliocarpa*, *Casuarina campestris* and the grass *Triodia scariosa*, and the associated feldspathic bronzitite by its growth of stunted *Eucalyptus foecunda*. Both associations are confined in their distributions to the dyke and occur on no other rock type in this area. The geological influence on the development of the vegetation at the association level, expressed through the chemical and physical properties of the soils, must therefore be of primary importance.

(b) Relief, soils and drainage

Parts of the dyke form features of striking relief in the landscape, the outcropping norite often forming prominent hills and ridges (Figure 10). Jimberlana Hill is 1304 feet above sea level, and is the highest point along the dyke in the Norseman area. Elsewhere along the dyke relief may be subdued and the more positive relief features occur over adjacent rock types, which, in this locality, are mainly greenstones. The microtopography of the dyke in the areas studied comprises kopjes and interjoining lower-lying areas. The larger kopjes stand about twenty feet or more above the general surrounding level. The norite outcrops forming them are

GEOLOGICAL MAP OF PART OF THE JIMBERLANA DYKE, NORSEMAN

(After I. Campbell)

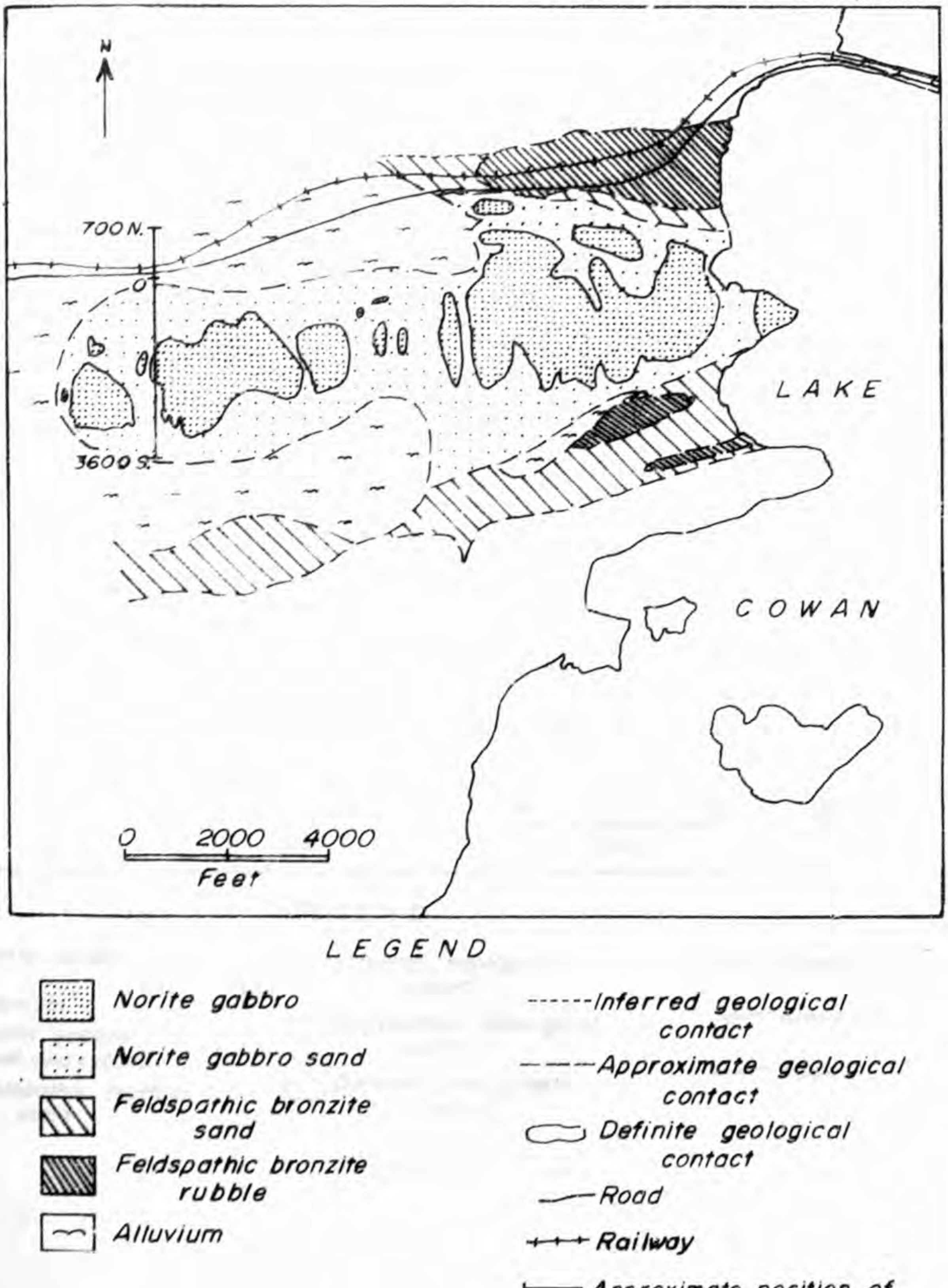


Figure 8

GEOLOGICAL MAP OF PART OF THE JIMBERLANA DYKE, NORSEMAN
(After I. Campbell).

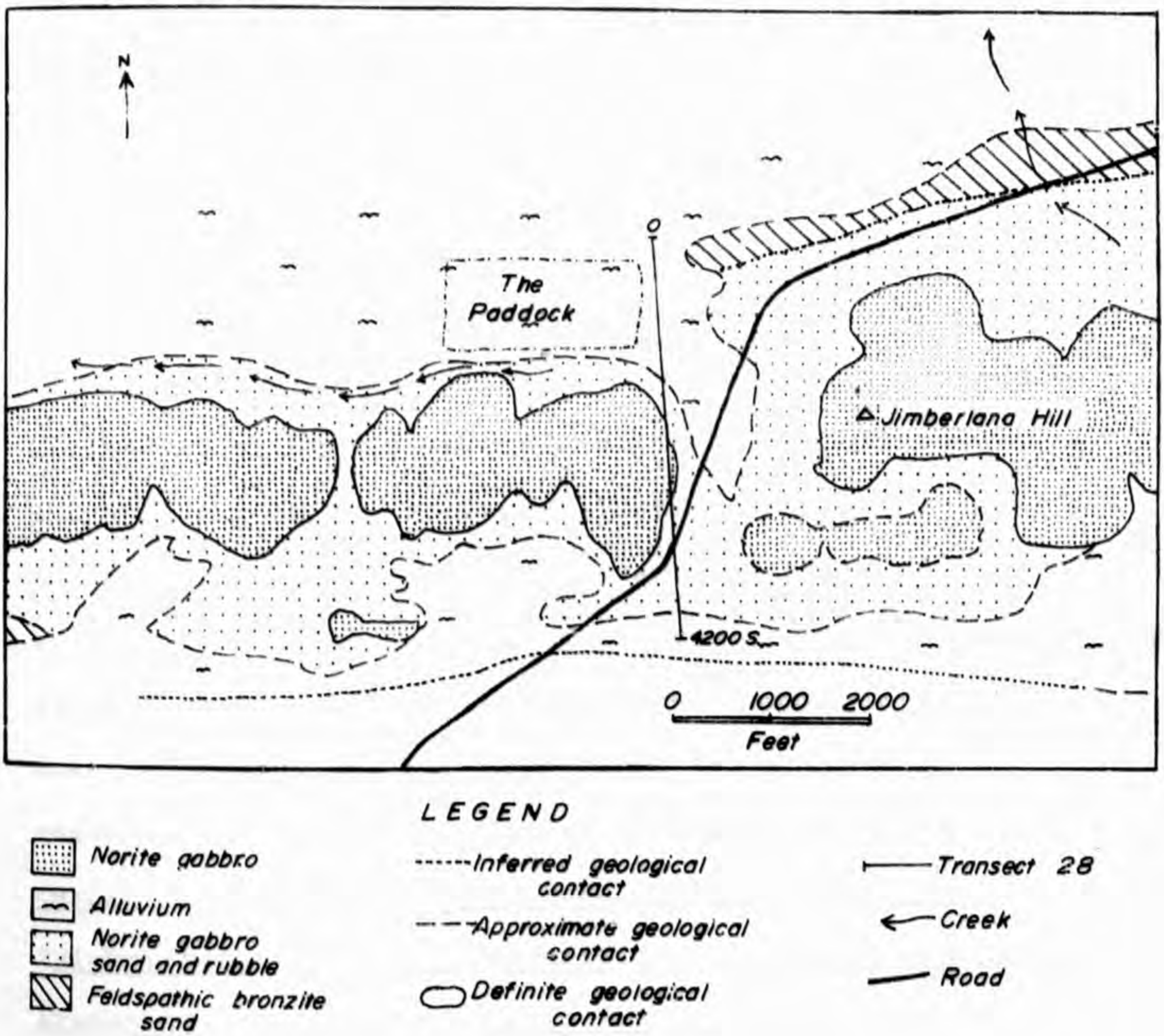
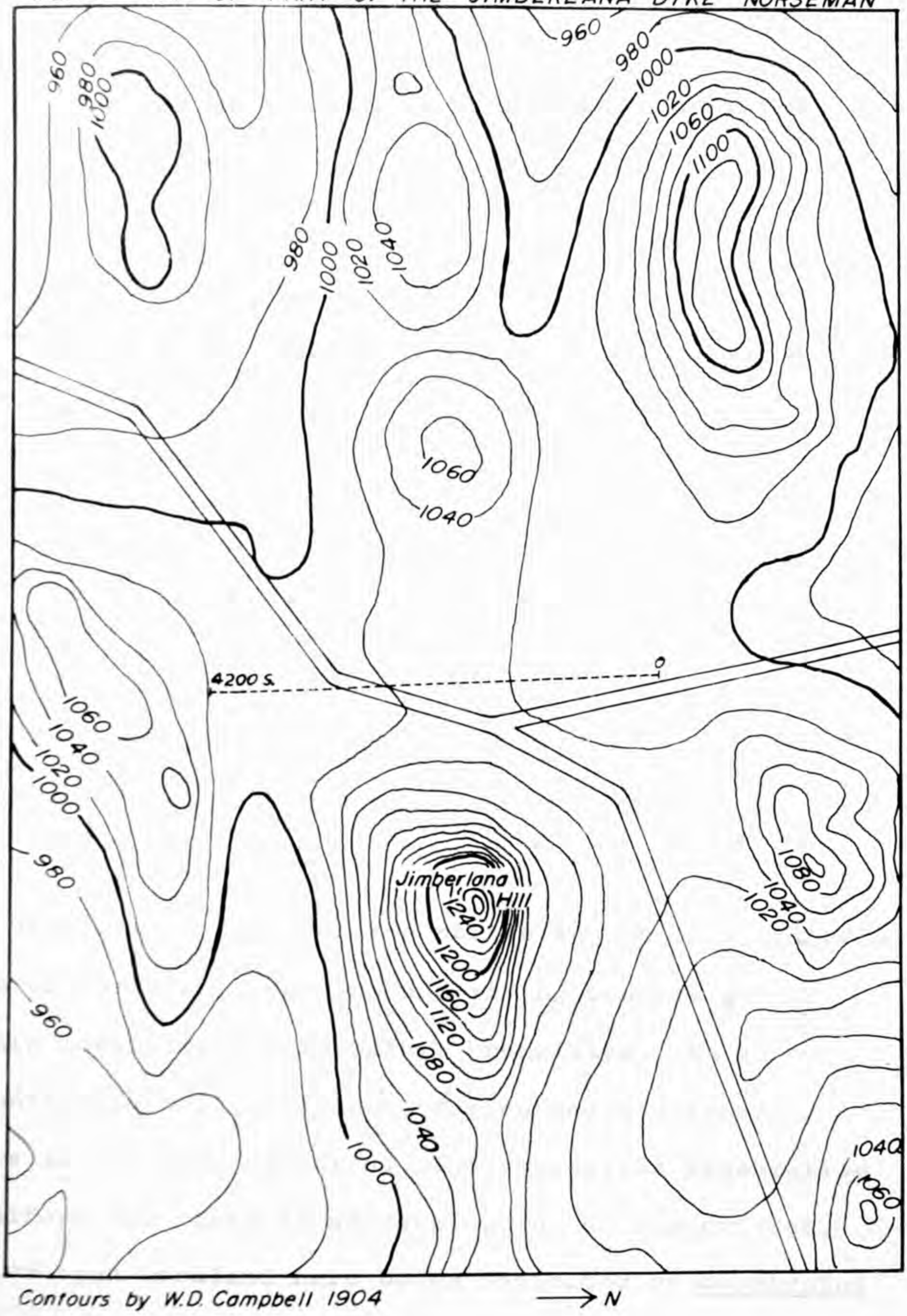


Figure 9

undergoing rounding by exfoliation, and this is producing belts of rubble and scree around their peripheries. The kopjes themselves are either completely devoid of soil or may hold shallow depths of soil between rock cracks. There are therefore three habitats on the main body of the dyke which are available for colonisation by shrubs and herbaceous species -- the kopjes, the scree covered pediments and the interjoining flatter areas. Each has its characteristic community. The degree to which vegetation will develop on the kopjes depends on the degree to which weathering has produced habitable conditions: where cracks in the rock are plentiful and there are small pockets of skeletal soil various shrubs develop to a remarkable extent and may grow with as great a density as that shown by the vegetation on adjacent, less rocky areas where the soil is deeper and better developed. The community characterising these outcrops is composed of Casuarina campestris, Melaleuca uncinata, Cryptandra ?glabriflora, Grevillea ?pinifolia, Melaleuca elliptica, Eremophila maculata and Lepidosperma brunonianum.

The rocky, scree-covered pediments which link the kopjes and the flats provide a second habitat. Soil is skeletal here but has developed to a somewhat greater

RELIEF MAP OF PART OF THE JIMBERLANA DYKE NORSEMAN



Contours by W.D. Campbell 1904

→ N

LEGEND

═══ Road

----- Approximate position of Transect 28

Scale 0 1000 2000 Feet

Figure 10

extent than on the kopjes. The community growing here is composed of the same species mentioned above, but other species have entered, including Eremophila serrulata and the small Eucalyptus Websteriana. The lower-lying, flatter parts of the dyke around and between the areas of outcrop are generally free of outcropping rock, although inevitably show a certain degree of float from the adjacent pediments. Soils are deeper, and have generally developed up to a depth of about twelve inches above bedrock. These areas provide a third habitat, and are characterised by a community in which the two most important members are Acacia cochliocarpa and Triodia scariosa, although other species mentioned above may occur here.

The flatter parts of the norite adjoin the peripheral areas of the dyke where the underlying bedrock is, in certain localities, feldspathic bronzitite. Soils here are uniformly well developed, for no major outcrop occurs in the areas studied. The vegetation association is uniform and there is no development of communities, the low open woodland here being dominated by Eucalyptus foecunda.

It can therefore be appreciated that the soils over the Jimberlana Dyke as a whole are shallow and immature. Those developing in pockets in areas of outcrop are necessarily skeletal, and may be only one or two inches deep, with a sandy veneer and nodular clay structure. Elsewhere over the dyke on the lower-lying flats the products of weathering are not removed so rapidly and deeper soils are allowed to develop. Bedrock may lie up to about twelve inches from the surface. There is no differentiation into horizons, although there may be a sandy veneer on the surface. The soil is reddish brown to dark reddish brown in colour (5YR 4/4 to 5 YR 3/4) and is a silty clay, often with a slight gritty texture. pH readings over the norite showed the soils to be generally acid in reaction (5.6 to 6.2), although one reading of pH 9.0 was obtained where travertine-coated pebbles were present.

The soils on the periphery of the dyke overlying feldspathic bronzitite are deeper, and can be classified as solonised brown soils. A sandy veneer is often present over the A horizon, which is reddish brown in colour (5YR 4/4) and may extend to a depth of twelve inches. The soil is a silty-clay loam and small weathered pebbles coated with travertine may occur. The B horizon is encountered at depths varying from four to twelve inches from the surface and is paler in colour, strong brown to reddish yellow (7.5YR 5/6 to 7.5YR 6/6). The texture is more powdery and looser, and travertine-coated pebbles persist throughout the profile. The soil is alkaline in reaction, and the highest pH reading was 9.3.

The importance of drainage in determining the development of the vegetation at the association level in this area is not thought to be of primary importance. Drainage factors in the environment are influenced by a number of variables, including relief, the density of the vegetation cover, and the degree to which the soils have developed. The degrees to which these factors operate on the dyke are as various as anywhere else in the Norseman locality. Besides the area of norite the greenstones in this region also form outcropping areas of relief, which grade to lower-lying soil covered terrain: vegetation density and soil development vary accordingly. Thus the amount of run-off and the water-holding capacity of the soil will be similar over certain areas on different rock types. Hence the primary importance of the bedrock here lies not so much in its own physical properties and those it imparts to the soils produced, but in its mineralogical and chemical status. This is considered below.

Drainage, however, appears to play an important part in determining the distribution of the plant communities which occur regularly over the dyke. The distribution of these communities, as noted above, is controlled by the degree to which the soil has developed. Skeletal soils support particular species, and deeper soils certain others. Drainage factors will differ between these localities. Skeletal soils on and around the kopjes have little water-retaining capacity, and run-off is rapid. By contrast, the soils occupying the lower-lying flats are better developed, and are able to retain water to a greater extent.

3. The relationships between plant distribution and the nickel and chromium status of the soils

The characteristic vegetation associations found on the dyke and its periphery are unique in their occurrence in the Norseman area, growing only in the locality of the dyke. The physical factors of the habitat provided by the norite -- the varying relief, the shallow and skeletal soils with their different water-holding capacities -- are common elsewhere where other rock types occur; yet these factors themselves do not give rise to the same associations which grow on the dyke. It appears that these distributions are related primarily to the chemical status of the soil, physical factors being of secondary importance.

Soil samples collected from the dyke and adjacent greenstones were analysed for nickel and chromium as these two elements are often particularly associated with norite. Results of the analyses are shown for transects 17 and 28 (Figures 11 and 12). In transect 17 the soil nickel content over the main body of norite varies from 60 ppm to 150 ppm, with higher values up to 325 ppm appearing at the southern end of the transect where there

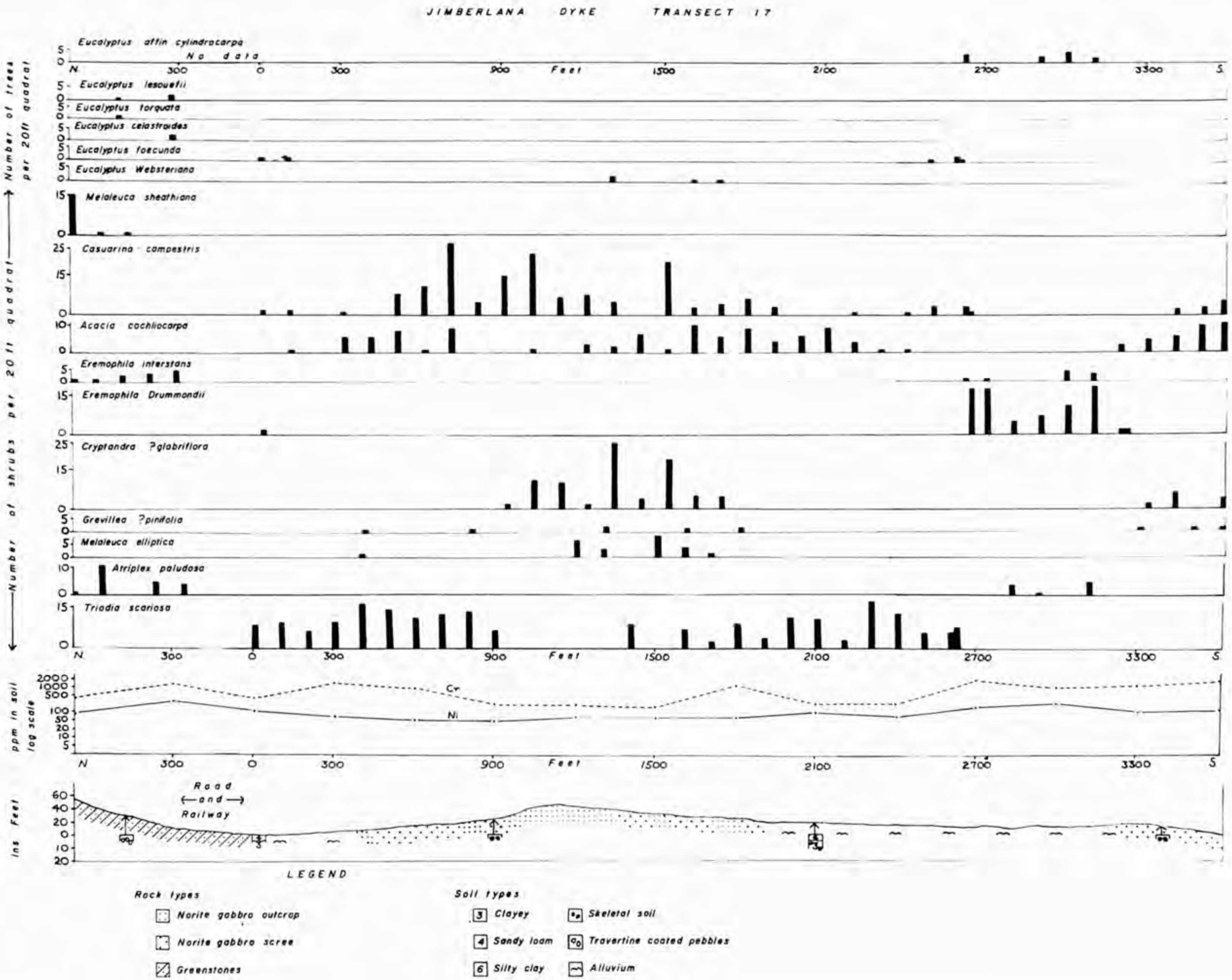

JIMBERLANA DYKE TRANSECT 17
Number of trees per 20ft quadrat
Number of shrubs per 20ft quadrat
Eucalyptus affin cylindrocarpa
No data
Eucalyptus lesouefii
Eucalyptus torquata
Eucalyptus celastroides
Eucalyptus foecunda
Eucalyptus Websteriana
Melaleuca sheathiana
Casuarina campestris
Acacia cochliocarpa
Eremophila interstans
Eremophila Drummondii
Cryptandra ?glabriflora
Grevillea ?pinifolia
Melaleuca elliptica
Atriplex paludosa
Triodia scariosa
N 300 0 300 900 Feet 1500 2100 2700 3300 S
ppm in soil log scale
Cr
Ni
Ins Feet
Road and Railway
LEGEND
Rock types
Norite gabbro outcrop
Norite gabbro scree
Greenstones
Soil types
3 Clayey
4 Sandy loam
6 Silty clay
Skeletal soil
Travertine coated pebbles
Alluvium

Figure 11

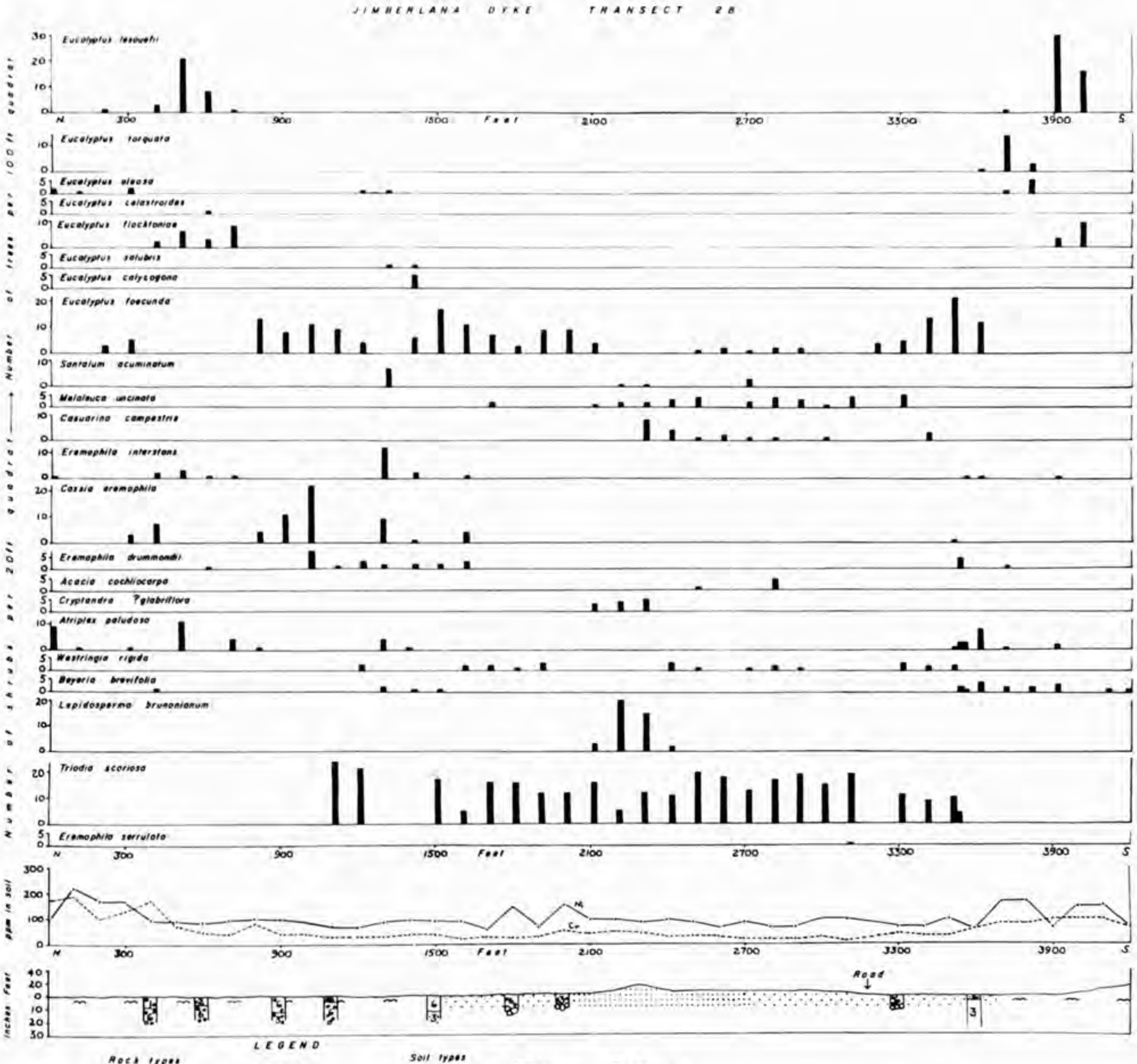

JIMBERLANA DYKE TRANSECT 28
Eucalyptus lesouefii
Eucalyptus torquata
Eucalyptus oleosa
Eucalyptus celastroides
Eucalyptus flocktoniae
Eucalyptus salubris
Eucalyptus calycogona
Eucalyptus foecunda
Santalum acuminatum
Melaleuca uncinata
Casuarina campestris
Eremophila interstans
Cassia eremophila
Eremophila drummondii
Acacia cochliocarpa
Cryptandra ?glabriflora
Atriplex paludosa
Westringia rigida
Beyeria brevifolia
Lepidosperma brunonianum
Triodia scariosa
Eremophila serrulata
Number of trees per 100ft quadrat
Number of shrubs per 20ft quadrat
Feet
ppm in soil
Road
Inches Feet
LEGEND
Rock types
Norite gabbro
Norite gabbro sand and rubble
Soil types
Sandy silt
Silty
Clayey
Silty clay
Weathered pebbles
Travertine coated pebbles
Alluvium

Figure 12

is a considerable depth of soil cover, and again at the northern end of transect 17 over the adjacent greenstones; here soil nickel values show a peak of 280 ppm. Somewhat similar results were obtained from transect 28. The soils from the adjacent greenstones to the north and south of the dyke contain greater amounts of nickel than the soils developed from the norite: whereas the average soil nickel content of the norite is about 80 ppm, that of the greenstones is 144 ppm.

The soil chromium content over the norite along transect 17 varies from 330 to 1750 ppm and there are no obvious differences in soil chromium content between soils from the norite and those from adjacent greenstones. Soil chromium values are much lower along transect 28, from 10 to 50 ppm, averaging about 30 ppm.

The soils developing from greenstones in this locality have a higher chromium content than does soil developing from the norite.

In view of these results it appears that the development of the noritic shrub association is not controlled specifically by the nickel and chromium content of the soil. Soil nickel content is not generally high, the soils from the adjacent greenstones containing similar or higher quantities. Nevertheless, the chemical environment of the soil appears to be of prime importance in controlling the vegetation associations for it differs from the chemical soil environment of other rock types in the area; the physical factors of the soil in different localities are similar. Nickel and chromium were the only two trace elements for which analysis was undertaken; analyses for a wider variety of elements may indicate those having a greater influence on the vegetation distribution.

Although the soils over the main part of the dyke do not show unusual amounts of nickel, anomalous values occur at the southern end of transect 17 over a distance of approximately 900 feet. The nickel content in the soil rises from 86.2 ppm to a peak of 325 ppm. The underlying bedrock in this area of higher anomalous nickel values is obscured by soil cover; the association characteristic of feldspathic bronzitite occurs on the northern side, and norite recurs on the southern.

The vegetation association growing in this anomalous area is of particular interest. As the nickel values rise the woodland association dominated by Eucalyptus foecunda cuts out and an entirely different association occurs, dominated by E. affin. cylindrocarpa, Eremophila interstans and E. drummondii, forming a belt of vegetation approximately 600 feet wide, and creating a complete contrast with the open woodland on its northern side and the noritic shrub association to the south. The nickel content of the soil here appears to be responsible for the abrupt change in the vegetation, for other environmental factors of soil depth, drainage and relief do not appear to change between that part of the dyke adjacent to the north and this area of anomalous nickel values. Besides the change in the vegetation association here, the morphological appearance of the Eucalypts growing in this belt also forms a noticeable contrast: whereas Eucalyptus foecunda has the mallee habit and hence an open crown, E. affin. cylindrocarpa has a single trunk with dense bushy crown. These features and the additional fact that the majority of the trees are approximately twenty feet high, only a few individuals surpassing this general level, gives the whole tree stratum the appearance of immaturity. This noticeable appearance may perhaps be accounted for by the amount of nickel in the soil having reached sufficiently high levels for this species to exhibit a biological response. Analysis of leaf material from one of these trees showed it to contain a high concentration of nickel (Table II). 420 ppm nickel was found in the ash, compared with 135 ppm in the ash of leaves from _E_. _foecunda_ growing in the adjacent association to the north.

The soil chromium content also rises at the southern end of transect 17. Values increase from 330 ppm to 1250 ppm and reach a peak of 1750 ppm on the norite lying beyond the belt of _E_. affin. _cylindrocarpa_. It appears that this association occupying the belt of anomalous values is more likely to be related to the high nickel content of the soil rather than to the high chromium content. Soil chromium content is high elsewhere along the transect, without correspondingly high values in the nickel content of the soil; yet these areas of higher chromium have not led to any changes in the characteristic norite scrub association.

Analysis of plant material for chromium indicated that the species analysed do not take up this metal to any marked extent, or that if they do it is possibly precipitated in the roots (no root material was collected here). Values range from 65 to 90 ppm in the ash of the majority of samples from transect 17, with a lower range of 5 to 20 ppm from plants along transect 28, these lower values corresponding with the lower chromium content of the soil.

A bulk soil sample from each vegetation association was analysed for the four major elements sodium, potassium, calcium and magnesium. The proportion of alkaline earths present in a sample is probably related to the level in the soil profile at which the sample was collected and may be highly variable throughout any single profile. However, the calcium-magnesium ratio in the soil appears to bear a general relationship to that in the underlying rocks. Results for major element analyses are presented in Table XII.

The importance of geological control over the development of the associations on the Jimberlana Dyke can be appreciated. The two associations which occupy the outcrop of the norite and the peripheral areas underlain by feldspathic bronzitite occur only in this locality. Factors of relief, drainage and soil depth can be only of secondary importance as the degree to which they operate here is similar to that in other areas. Although nickel and chromium do not play any great part in influencing the distribution of these two associations, the soil nickel concentration in particular appears to account for the presence of the belt of *Eucalyptus affin. cylindrocarpa* woodland at the southern end of the dyke in the vicinity of transect 17. The soil nickel values rise in this locality to become the highest along the dyke in the areas studied, and this is associated with the abrupt replacement of the open woodland association, dominated by *E. foecunda*, by that of the woodland dominated by *E.* affin. *cylindrocarpa*.

When considering the distribution of plants at the community level additional factors must be taken into account. The stage of soil development and the associated factors of drainage and soil water-holding capacity appear to determine the development of the communities here: whereas some species can thrive with little soil others require a deeper soil to sustain growth.

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	ppm, Ashed Cr	ppm, Oven-dried Ni	ppm, Oven-dried Cr	ppm, Soil Ni	ppm, Soil Cr	Rock Type
68	Eucalyptus foecunda	T 17 00	Leaves	4.9	135	90	6.6	4.4	I12	440	Feldspathic bronzitite
68	Eucalyptus foecunda	T 17 00	Fruit	5.8	70	90	4.0	5.2			"
68	Eucalyptus foecunda	T 17 00	Young twigs	6.1	125	90	7.6	5.4			"
68	Eucalyptus foecunda	T 17 00	Old twigs	4.1	135	80	5.5	3.2			"
73	Ricinocarpus stylosus	T 17 00	Leaves & stems	3.1	67	115	2.0	3.5			"
77	Eucalyptus affin cylindrocarpa	T 17 3000S	Leaves	4.6	420	95	19.3	4.2	325	1000	Soil covered
77	Eucalyptus affin cylindrocarpa	T 17 3000S	Young twigs	4.8	140	65	6.7	3.1			"
77	Eucalyptus affin cylindrocarpa	T 17 3000S	Old twigs	4.3	95	65	4.1	2.9			"
76	Eucalyptus celastroides	T 17 300N	Leaves	3.4	380	65	12.9	2.2	280	1500	Greenstones
76	Eucalyptus celastroides	T 17 300N	Young twigs	4.5	280	90	12.6	4.0			"

Analyses of unmilled, dry-ashed plant material.
NV and Dyke series samples.

TABLE II

NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	ppm, Ashed Cr	ppm, Oven-dried Ni	ppm, Oven-dried Cr	ppm, Soil Ni	ppm, Soil Cr	Rock Type
76	Eucalyptus celastroides	T 17 300N	Old twigs	3.6	225	90	8.1	3.2	280	1500	Greenstones
75	Eucalyptus torquata	T 17 400N	Leaves	4.1	225	90	9.2	3.6			"
75	Eucalyptus torquata	T 17 400N	Fruit	3.7	115	90	4.2	3.3			"
75	Eucalyptus torquata	T 17 400N	Young twigs	4.3	45	65	1.9	2.7			"
75	Eucalyptus torquata	T 17 400N	Old twigs	3.0	490	90	14.7	2.7			"
74	Melaleuca sheathiana	T 17 700N	Leaves & twigs	7.5	67	105	5.0	7.8	81	450	"
126	Eucalyptus foecunda	T 28 1200S	Leaves	5.2	82	5	4.2	0.2	67	30	Norite scree
127	Eucalyptus foecunda	T 28 1200S	Fruit	5.5	37	5	2.0	0.2			"
130	Eucalyptus foecunda	T 28 1200S	Young twigs	7.6	45	5	3.4	0.3			"
132	Eucalyptus foecunda	T 28 1200S	Old twigs	5.0	32	5	1.6	0.2	100	45	"
122	Eucalyptus foecunda	T 28 1500S	Leaves	4.9	57	5	2.7	0.2			"

Analyses of unmilled, dry-ashed plant material.
NV and Dyke series samples.

TABLE II cont.

NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	ppm, Oven-dried Ni	Cr	ppm, Soil Ni	Cr	Rock Type
124	Eucalyptus foecunda	T 28 1500S	Fruit	4.7	40	20	1.8	0.9			Norite scree
123	Eucalyptus foecunda	T 28 1500S	Young twigs	5.9	57	5	3.3	0.2			"
125	Eucalyptus foecunda	T 28 1500S	Old twigs	4.7	45	5	2.1	0.2			"
134	Melaleuca uncinata	T 28 2200S	Leaves	4.2	190	5	7.9	0.2	I00	50	Norite
135	Melaleuca uncinata	T 28 2200S	Fruit	0.4	75	-	0.3	-			"
133	Melaleuca uncinata	T 28 2200S	Twigs	4.2	150	5	6.3	0.2			"
137	Melaleuca uncinata	T 28 2400S	Leaves	6.7	72	5	4.8	0.3	102	25	"
138	Melaleuca uncinata	T 28 2400S	Fruit	0.5	82	5	0.4	0.02			"
136	Melaleuca uncinata	T 28 2400S	Twigs	3.6	120	15	4.3	0.5			"
131	Eucalyptus foecunda	T 28 3500S	Leaves	4.4	95	10	4.I	0.4	115	35	Norite scree
128	Eucalyptus foecunda	T 28 3500S	Young twigs	5.7	65	5	3.7	0.2			"

Analyses of unmilled, dry-ashed plant material.
NV and Dyke series samples.

TABLE II cont. NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed		ppm, Oven-dried		ppm, Soil		Rock Type
					Ni	Cr	Ni	Cr	Ni	Cr	
121	Eucalyptus foecunda	T 28 3500S	Old twigs	4.8	45	5	2.1	0.2	115	35	Norite scree
119	Eucalyptus lesouefii	T 28 4000S	Leaves	3.6	45	5	1.6	0.1	170	105	"
129	Eucalyptus lesouefii	T 28 4000S	Young twigs	4.2	30	5	1.2	0.2			Soil covered

Analyses of unmilled, dry-ashed plant material.
NV and Dyke series samples. TABLE II cont. NORSEMAN

(B) NORSEMAN REEF AREA

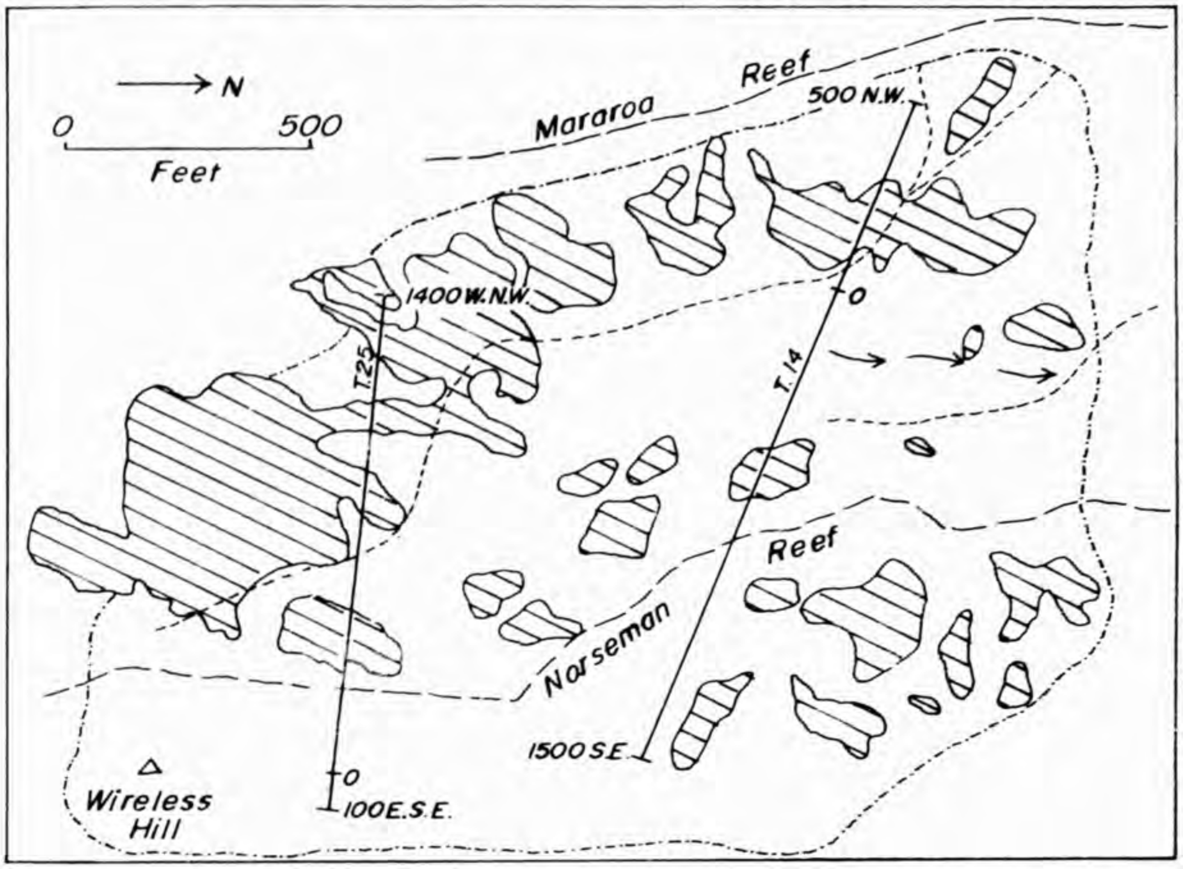
1. Distribution of vegetation associations

There are two main vegetation associations developed in the Norseman Reef area (Figure 13). The reef falls within the area underlain by the Mararoa pillow lavas, and the varying physical nature of the terrain appears to exert a predominating influence on the vegetation distribution. On the areas of lava outcrop where soils are skeletal and there is much scree a varied and dense shrub association occurs and trees are rare or absent. Species present include Grevillea nematophylla, Casuarina campestris, Acacia cochliocarpa, Eremophila maculata, Prostanthera aspalathoides, Dodonaea boroniaefolia, Cryptandra ?glabriflora, a myrtaceous shrub sp. J.B./W.A. 266, Dampiera trigona var. latealata, and Lepidosperma brunonianum, the frequency of occurrence varying between species.

In other adjacent areas the soil is better developed, although still somewhat stony and covered to varying degrees with float. In such localities the association differs, both in the species present and in the density of plants (Plate 3). Eucalypts grow in open woodland formation, the most frequent species being _E. lesouefii_, _E. flocktoniae_, _E. celastroides_ and _E. calycogona_. _E. salubris_ and _E. torquata_ occur occasionally. _Melaleuca sheathiana_ assumes importance here, usually growing in groves where it may achieve a high density. Other species occurring in these areas are the shrubs _Eremophila pachyphylla_, _Atriplex nummularia_, _Cassia eremophila_, _Scaevola spinescens_, _Beyeria brevifolia_, _Acacia erinacea_, _Atriplex paludosa_, _Ptilotus obovatus_, _Eremophila coerulea_ and _Westringia rigida_.

Along the line of the reef the ground has been disturbed to varying degrees but the disturbance is limited to a narrow discontinuous belt. Another patch of disturbed ground occupies the area along transect 14 from approximately 325 feet south-east to 535 feet south-east. Trees are uncommon here, possibly because of felling, and the low mounds and hollows resulting from the early gold workings here have been colonised by _Atriplex paludosa_, _Bassia patenticuspis_ and _Helipterum tenellum_; _Arthrocnemum halocnemoides_ occurs occasionally.

MAP TO SHOW THE DISTRIBUTION OF THE VEGETATION ASSOCIATIONS IN THE NORSEMAN REEF AREA, NORSEMAN.



LEGEND

Association of:
Grevillea nematophylla
Casuarina campestris
Acacia cochliocarpa
Eremophila maculata
Prostanthera aspalathoides
Dodonaea boroniaefolia
Cryptandra ?glabriflora
Sp. J.B./W.A. 266
Dampiera trigona var. *latealata*
Lepidosperma brunonianum

Mapping boundary of association of:
Eucalyptus lesouefii
Eucalyptus flocktoniae
Eucalyptus celastroides
Eucalyptus torquata
Melaleuca sheathiana
Cassia eremophila
Scaevola spinescens
Atriplex paludosa
Eremophila coerulea

Transect lines 14 and 25

Creek

Track

Figure 13

Vegetation association of Atriplex paludosa and Helipterum tenellum in the foreground, growing where the Mararoa lavas of the Norseman Reef area are soil covered. In the background is an association which includes Eucalyptus torquata, Dodonaea boroniaefolia and Ricinocarpus stylosus, growing where the lavas outcrop and the soils are shallower.

Vegetation association of Eucalyptus lesouefii, Melaleuca sheathiana (middle left) and Atriplex paludosa (foreground) growing where the Mararoa pillow lavas of the Norseman Reef area are soil covered. Beyond is an association which includes Dodonaea boroniaefolia, Ricinocarpus stylosus and Eremophila maculata, growing where the lavas outcrop and soils are skeletal.

Plate 3

2. Factors governing the distribution of the vegetation associations

(a) Relief and drainage

The Norseman Reef lies on the western slopes of a north-south ridge which is situated on the eastern side of the township (Figure 14). The ridge culminates in Wireless Hill, which reaches to a height of 1295 feet above sea level and forms one of the main features in the relief of the district. Drainage from the ridge is radial. The creeks cut backwards up the hillslopes during the short periods when they are in flood.

The reef therefore falls into an area of marked and varying relief, where the run-off of rain water is generally rapid. However, a survey of the distribution of the vegetation associations reveals that they are distributed without any marked reference to the topography or the degree of slope encountered. The two major associations here may lie adjacent to each other on the sides of the hill where the angle of slope and the drainage features have marked degrees of similarity. Both occur on the higher parts of the ridge and also at lower levels where slope may be more subdued or may still maintain a steep angle. It appears that these two environmental factors are not of primary importance in controlling distributions in this area.

RELIEF MAP OF THE NORSEMAN REEF AREA, NORSEMAN

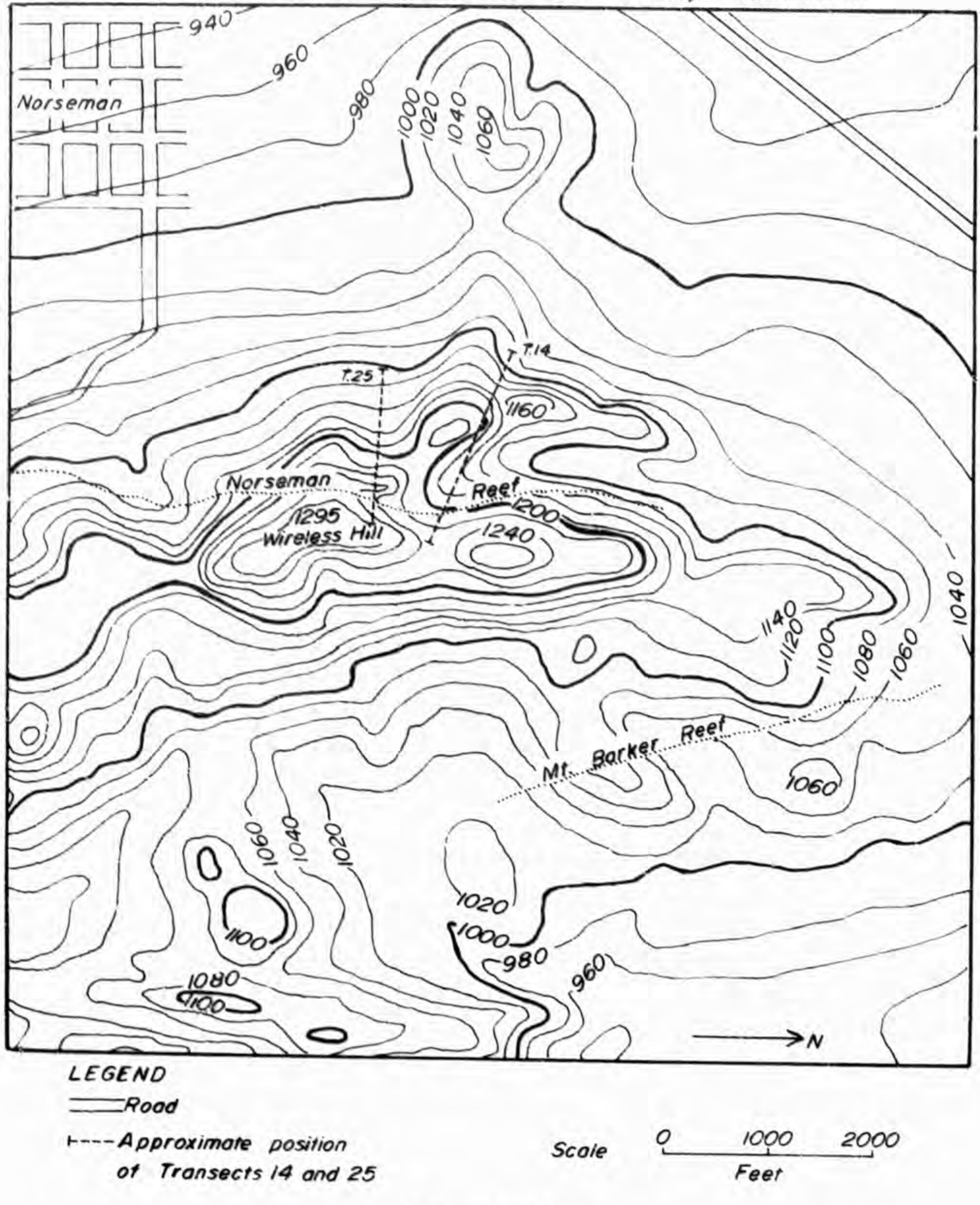


Figure 14

GEOLOGICAL MAP OF PART OF
THE NORSEMAN REEF AREA, NORSEMAN

(After Central Norseman Gold Corporation)

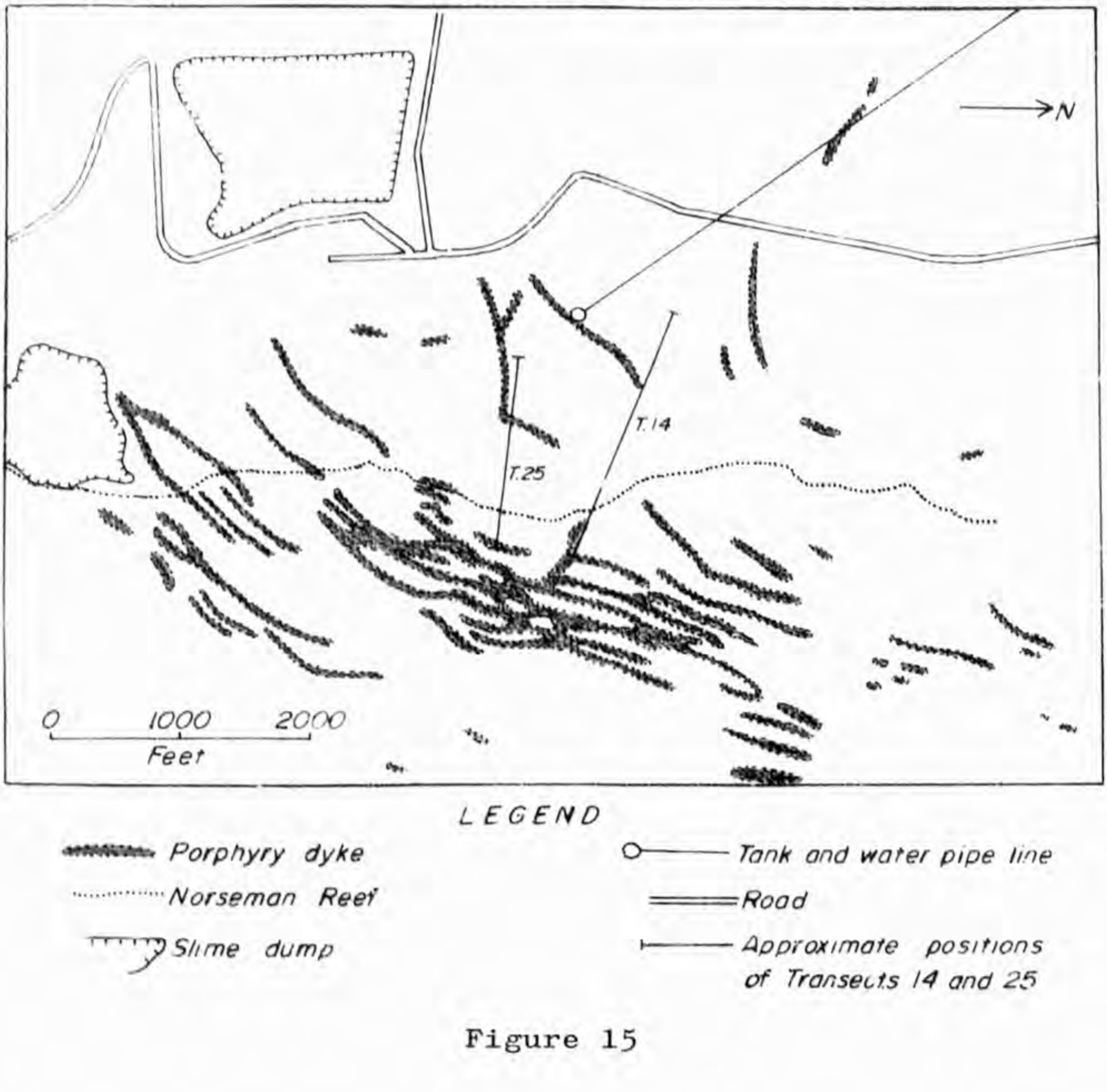


Figure 15

(b) Geology and soils

The Norseman Reef lies in a north-south direction within the area underlain by the Mararoa pillow lavas (Figure 15). This belt of lavas is several miles wide, and the main productive gold bearing reefs lie within it. The reefs are tabular bodies, lying along the plane of reverse faults. The Norseman Reef is transgressive in an easterly direction at 45°. It was once one of the biggest gold producing reefs, but with few exceptions the ore shoots exposed at the surface did not persist and the reef became worked out in the earlier days of the field.

Porphyry dykes have invaded the pillow lavas and have a north-east strike and are inclined at fifty degrees west or more. Small scattered outcrops occur within the field study area.

The lavas outcrop over small scattered parts of the area, producing much scree and giving rise to skeletal soils. These soils are by nature extremely shallow and are dark red to dark reddish brown in colour (2.5YR 3/6 to 5YR 3/4). They tend to be a sandy-silt to clay loam in texture and are slightly alkaline in reaction, pH readings approximating to 7.3.

Contrasting with these immature soils are those occurring on adjacent slopes where bedrock lies further from the surface and where weathering has proceeded to a greater degree. Deeper soils have been produced, although they tend to become increasingly stony with depth, thus prohibiting deep augering. The soils are markedly less red-brown in colour, varying from a yellowish red to a dark brown colour (5YR 4/8 to 7.5YR 3/2) in the surface horizon, becoming redder with depth (2.5YR 4/6 to 5YR 4/6). In texture they are a gritty clay and contain varying amounts of pebbles and stones which are often coated with travertine or magnesite.

These areas characterised by the skeletal and the more mature soils occupy adjacent parts of the terrain in the Norseman Reef locality. Their occurrence does not appear to correspond with factors of relief, but with the different rates at which weathering is proceeding over the pillow lavas, this being expressed in the degree of soil development. Where bedrock lies at or very near the surface and soils are thin, a distinctive association occurs composed of _Grevillea nematophylla_, _Casuarina campestris_, _Acacia cochliocarpa_, _Eremophila_ maculata, Prostanthera aspalathoides, Dodonaea boroniaefolia, Cryptandra ?glabriflora, a myrtaceous shrub sp. J.B./W.A. 266, Dampiera trigona var. latealata, and Lepidosperma brunonianum. Areas of deeper soils are characterised by a second association which contrasts sharply with the shrub association in its species composition and physiognomy, being one of open woodland dominated by Eucalyptus lesouefii, E. flocktoniae, E. celastroides and E. calycogona. Shrub species composing the association on the areas of lava outcrop appear either to tolerate or prefer shallow soils, with their consequently poor water retention capacity and lower cation exchange capacity. Trees and shrubs growing on the areas of better developed soils have a different rooting environment, and the soil water-holding capacity will be greater. In view of the limited variety in the bedrock and the predominance of one rock type in the Norseman Reef area the distribution of the vegetation associations here is obviously governed to a large extent by the physical nature of the soils.

3. The relationships between plant distributions and various trace elements in the soils

The depth and degree of development of the soil appears to govern plant distribution in this area, but related factors of soil metal content were also investigated: differences in the degree of weathering will influence the extent to which particular elements occur, and analysis was undertaken for various trace elements. These results are shown in Figures 16 and 17.

Copper, lead and zinc tend to maintain fairly uniform concentrations in the soil along transect 14. Lead averages about 30 ppm, zinc about 65 ppm and copper 75 ppm, although copper content rises to 130 ppm at 1000 feet south-east.

Results which are somewhat similar were obtained from transect 25, although the soil content of these three elements tends to fluctuate slightly more around the average. A marked anomaly in all three metals occurs at 200 feet north-west. Lead content at this point is 115 ppm, copper 175 ppm and zinc 1040 ppm. These anomalous values correspond with two features in the environment - the line of the Norseman Reef and with a creek. Without further field and analytical investigations it is difficult to attribute the anomaly to either one or the other of these features. The reef is not revealed by anomalous values appearing in transect 14, although similar amounts of workings and disturbance, with consequential contamination of the immediate soils, have occurred along the reef in both areas. Similarly, the presence of an adjacent creek at 280 feet north-west, transect 25, cannot be picked out by the occurrence of higher metal values. The concentrations of these three elements show no variation between areas of skeletal soils and areas of deeper soils, so the development of characteristic associations in these areas cannot be governed by these elements.

Soils were also analysed for chromium and nickel. Nickel averages about 80 ppm in the soil and fluctuates very little throughout the area covered by the two transects. Chromium values tend to be higher than this. Along transect 14 the average chromium content is about 125 ppm, and at 100 feet north-west and 600 to 700 feet south-east somewhat higher values occur, 170 ppm and 155 to 160 ppm respectively. The average soil chromium content along transect 25 is approximately 75 ppm. Slight peaks also occur here -- at 300 to 450 feet north-west, 900 feet north-west and 1100 feet north-west, where

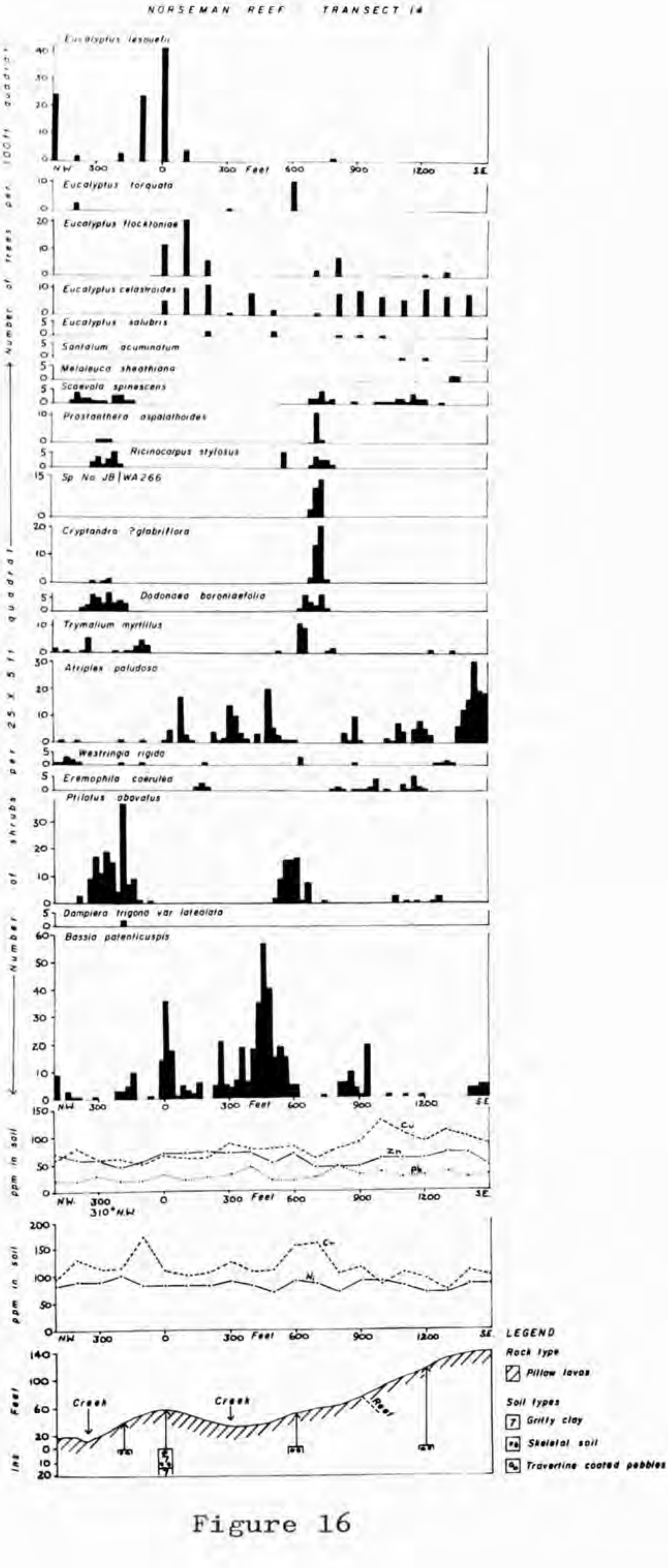
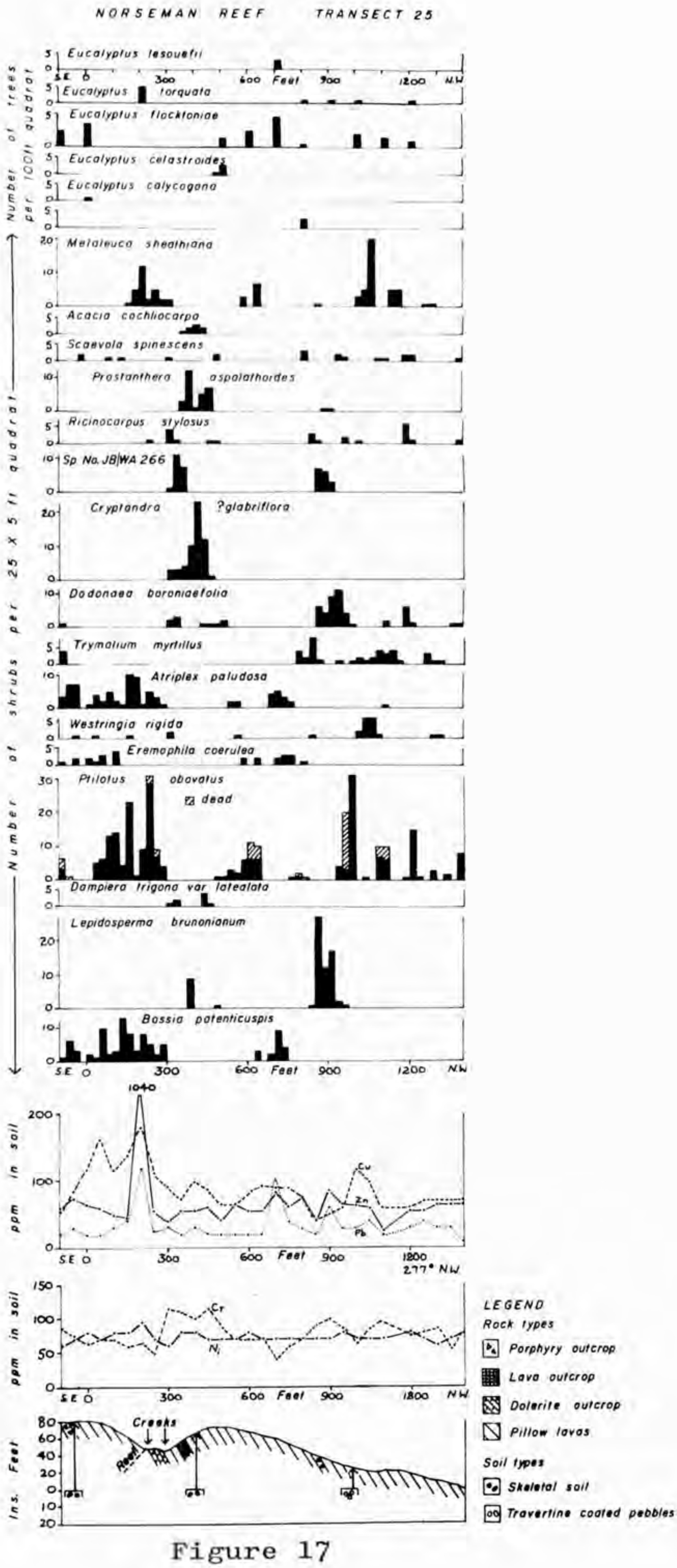

NORSEMAN REEF TRANSECT 14
Eucalyptus lesouefii
Eucalyptus torquata
Eucalyptus flocktoniae
Eucalyptus celastroides
Eucalyptus salubris
Santalum acuminatum
Melaleuca sheathiana
Scaevola spinescens
Prostanthera aspalathoides
Ricinocarpus stylosus
Sp No JB|WA266
Cryptandra ?glabriflora
Dodonaea boroniaefolia
Trymalium myrtillus
Atriplex paludosa
Westringia rigida
Eremophila caerulea
Ptilotus obovatus
Dampiera trigona var lateolata
Bassia patenticuspis
Number of trees per 100ft quadrat
Number of shrubs per 25 x 5 ft quadrat
NW 300 0 300 Feet 600 900 1200 SE
ppm in soil
Cu
Zn
Pb
310° NW
Ni
Feet
Ins
Creek
Reef
LEGEND
Rock type
Pillow lavas
Soil types
Gritty clay
Skeletal soil
Travertine coated pebbles

Figure 16



NORSEMAN REEF TRANSECT 25
Number of trees per 100ft quadrat
Eucalyptus lesouefii
Eucalyptus torquata
Eucalyptus flocktoniae
Eucalyptus celastroides
Eucalyptus calycogona
Number of shrubs per 25 X 5 ft quadrat
Melaleuca sheathiana
Acacia cochliocarpa
Scaevola spinescens
Prostanthera aspalathoides
Ricinocarpus stylosus
Sp No. JB/WA 266
Cryptandra ?glabriflora
Dodonaea boroniaefolia
Trymalium myrtillus
Atriplex paludosa
Westringia rigida
Eremophila coerulea
Ptilotus obovatus
dead
Dampiera trigona var latealata
Lepidosperma brunonianum
Bassia patenticuspis
S.E. 0 300 600 Feet 900 1200 NW
ppm in soil
1040
Cu
Zn
Pb
277° NW
Cr
Ni
Feet
Creeks
Reef
LEGEND
Rock types
Porphyry outcrop
Lava outcrop
Dolerite outcrop
Pillow lavas
Soil types
Skeletal soil
Travertine coated pebbles

Figure 17

respective values are 115 ppm, 100 ppm and 95 ppm. With the exception of the reading obtained from 100 feet north-west along transect 14, it is interesting to note that each of these higher chromium values corresponds to an area where the soil is skeletal and the association is one of varied shrub species.

Soil analyses were also undertaken for arsenic, but all results were negative, including those from samples collected over and in the vicinity of the line of the reef.

From these results it can be seen that chromium is the only trace element, of those for which analysis was undertaken, to show slight differences in concentration between those areas characterised by skeletal soils and their associated shrub vegetation, and adjacent areas of deeper soils which support open woodland. This factor may have some importance in determining the species composition of the associations, for the particular species which grow where chromium soil values exceed the average concentration in this locality may be able to tolerate these concentrations better than others. Chromium is not a necessary plant nutrient and does not usually occur in anything but small amounts in the aerial parts of plants. No plants from the Norseman Reef were analysed for this element, but only 5 to 20 ppm were found in the ash of plants from the Jimberlana Dyke. It is possible that most of this element absorped is usually precipitated within the roots.

Plant samples of selected species were analysed for copper and zinc (Table III). Zinc is concentrated in all species sampled, excepting for *Atriplex paludosa*, which often gave negative results for this metal. Copper is also concentrated within the plants, but to a lesser extent, and again *A. paludosa* is the exception.

In assessing the importance of the various environmental factors involved in determining vegetation distributions here, field observations and analytical results indicate that these distributions are controlled primarily by the degree to which weathering of the Mararoa pillow lavas has occurred and to the extent to which soils have developed. Shallow, skeletal soils invariably support a particular shrub association dominated by *Grevillea nematophylla*, *Casuarina campestris*, *Acacia cochliocarpa*, *Eremophila maculata*, *Prostanthera aspalathoides*, *Dodonaea boroniaefolia*, *Cryptandra ?glabriflora*, a myrtaceous shrub sp. J.B./W.A. 266, *Dampiera trigona* var. *latealata* and *Lepidosperma brunonianum*, while deeper soils are characterised by a completely different association of open woodland, where the dominant species are *Eucalyptus lesouefii*, *E. flocktoniae*, *E. celastroides*, and *E. calycogona*, with *Eremophila pachyphylla*, *Scaevola spinescens*, *Atriplex paludosa* and *Eremophila coerulea*. Analysis showed that, of the metals examined, chromium was the only trace element in the soil to show some distributional concentrations with reference to these two types of physical environment, values slightly above background concentration tending to occur where soils are shallow. However, this pattern is not completely constant, as higher chromium concentrations failed to be revealed over an area of skeletal soils along transect 14, extending over a distance of about 250 feet. It is also noticeable that the higher chromium soil content at 100 feet north-west along transect 14 does not correspond with the development of the shrub association, but with open woodland and deeper soils. The species comprising this woodland association are therefore able to tolerate these higher chromium concentrations in the soil, and it appears that the main controlling factor in plant distribution at this point and, indeed, throughout the locality, is soil depth. The shrub association growing where soils are skeletal are able to flourish in this type of physical environment, whereas the *Eucalyptus* species and their associated shrubs prefer to grow where soils are better developed and have a greater water-holding capacity and cation exchange capacity.

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Zn	ppm, Ashed Cu	ppm, Oven-dried Zn	ppm, Oven-dried Cu	ppm, Soil Zn	ppm, Soil Cu	Rock Type
56	Dodonaea boroniaefolia	T 14 200NW	Leaves & stems	3.3	560	150	18.4	4.9	45	62	Pillow lavas
65	Ricinocarpus stylosus	T 14 200NW	Leaves & stems	3.6	230	145	8.2	5.2			"
63	Dodonaea boroniaefolia	T 14 300NW	Leaves & stems	4.0	350	125	14.0	5.0	60	60	"
64	Ricinocarpus stylosus	T 14 300NW	Leaves & stems	3.6	230	115	8.2	4.1			"
41	Eucalyptus flocktoniae	T 14 100SE	Leaves	2.9	350	115	10.1	3.3	70	62	"
41	Eucalyptus flocktoniae	T 14 100SE	Young twigs	3.6	350	115	12.6	4.1			"
41	Eucalyptus flocktoniae	T 14 100SE	Old twigs	3.3	290	115	9.5	3.7			"
37	Melaleuca sheathiana	T 14 100SE	Leaves & twigs	7.7	150	55	11.5	4.2			"
151	Eremophila coerulea	T 14 195SE	Leaves & twigs	4.5	300	175	13.5	7.8			"
42	Eucalyptus celastroides	T 14 200SE	Leaves	2.7	600	100	16.2	2.7	73	62	"
42	Eucalyptus celastroides	T 14 200SE	Young twigs	3.3	600	90	19.8	2.9			"

Analyses of unmilled, dry-ashed plant material.
NV and Reef series samples.

TABLE III

NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Zn	ppm, Ashed Cu	ppm, Oven-dried Zn	ppm, Oven-dried Cu	ppm, Soil Zn	ppm, Soil Cu	Rock Type
42	Eucalyptus celastroides	T 14 200SE	Old twigs	2.8	560	90	15.6	2.5	73	62	Pillow lavas
147	Atriplex paludosa	T 14 300SE	Leaves & stems	19.0	10	40	1.9	7.6	70	88	"
156	Atriplex paludosa	T 14 500SE	Leaves & stems	22.5	0	30	0	6.7	52	78	"
57	Ricinocarpus stylosus	T 14 560SE	Leaves & stems	3.5	250	110	8.7	3.8			"
153	Atriplex paludosa	T 14 600SE	Leaves & stems	20.5	0	30	0	6.1	70	82	"
55	Dodonaea boroniaefolia	T 14 700SE	Leaves & stems	2.8	460	150	12.8	4.2	45	62	"
150	Eremophila coerulea	T 14 800SE	Leaves & stems	5.1	280	265	14.2	13.5	45	78	"
152	Eremophila coerulea	T 14 993SE	Leaves & stems	4.0	330	190	13.2	7.6			"
44	Eucalyptus celastroides	T 14 1000SE	Young twigs	4.2	500	65	21.0	2.7	60	130	"
146	Atriplex paludosa	T 14 1100SE	Leaves & stems	17.0	50	50	8.5	8.5	60	108	"
145	Atriplex paludosa	T 14 1200SE	Leaves & stems	19.5	10	45	1.9	8.7	60	88	"

Analyses of unmilled, dry-ashed plant material.
NV and Reef series samples. TABLE III cont. NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Zn	ppm, Ashed Cu	ppm, Oven-dried Zn	ppm, Oven-dried Cu	ppm, Soil Zn	ppm, Soil Cu	Rock Type
157	Atriplex paludosa	T 14 1400SE	Leaves & stems	18.1	90	45	16.2	8.1	70	100	Pillow lavas
45	Melaleuca sheathiana	T 14 1400SE	Leaves & stems	6.6	190	100	12.5	6.6			"
46	Eucalyptus celastroides	T 14 1450SE	Leaves	3.9	660	90	25.7	3.5			"
46	Eucalyptus celastroides	T 14 1450SE	Young twigs	4.5	460	100	20.7	4.5			"
46	Eucalyptus celastroides	T 14 1450SE	Old twigs	3.9	350	90	13.6	3.5			"
142	Atriplex paludosa	T 14 1500SE	Leaves & stems	16.3	60	50	9.7	8.1	45	85	"
154	Atriplex paludosa	T 25 100NW	Leaves & stems	16.4	40	40	6.5	6.5	50	118	"
155	Melaleuca sheathiana	T 25 200NW	Leaves & twigs	7.9	110	50	8.6	3.9	1040	178	"
140	Unidentified sp JB/WA 266	T 25 350NW	Leaves & stems	4.1	230	95	9.4	3.8	55	72	"
169	Melaleuca sheathiana	T 25 650NW	Leaves & twigs	7.1	160	100	11.3	7.1	55	90	"
141	Ricinocarpus stylosus	T 25 848NW	Leaves & stems	3.9	460	125	17.9	4.8	65	90	Porphyry

Analyses of unmilled, dry-ashed plant material.
NV and Reef series samples.

TABLE III cont. NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Zn	ppm, Ashed Cu	ppm, Oven-dried Zn	ppm, Oven-dried Cu	ppm, Soil Zn	ppm, Soil Cu	Rock Type
148	Unidentified sp JB/WA 266	T 25 894NW	Leaves & stems	4.3	280	90	12.0	3.8	85	50	Pillow lavas
143	Melaleuca sheathiana	T 25 1050NW	Leaves & twigs	5.6	180	65	10.0	3.6	60	98	"
144	Ricinocarpus stylosus	T 25 1200NW	Leaves & stems	3.7	230	125	8.5	4.6	60	62	"
139	Ricinocarpus stylosus	T 25 1394NW	Leaves & stems	3.8	330	125	12.5	4.7	65	72	"

Analyses of unmilled, dry-ashed plant material.
NV and Reef series samples.

TABLE III cont. NORSEMAN

(C) IRON KING AREA

1. Distribution of vegetation associations

The distribution of the various plant associations growing in the Iron King area (Figure 18) is described with some reference to their location in respect to the different rock units occurring in this area.

The association developed on the ridges formed by the Hopetoun, Lady Miller and Attlee jaspilites shows a variety of species which is unequalled elsewhere in this locality. The shrub stratum is the most important here, and tree species are not frequent. Eucalyptus Stricklandi is the only Eucalypt of general occurrence, although E. torquata and E. celastroides may attain dominance locally. Shrub species present include Grevillea nematophylla, Casuarina campestris, Myoporum platycarpum, Alyxia buxifolia, Ricinocarpus stylosus, ?Grevillea didymobotrya, Calothamnus chrysantherus, Prostanthera aspalathoides, Scaevola spinescens, Trymalium myrtillus, Hibbertia ?pungens, Dodonaea stenozyga, D. boroniaefolia, Acacia erinacea and Westringia rigida (Plate 4).

The association developed on the Lady Mary Formation and the Marell schist contrasts with the above in its relative simplicity. The most important species here are Melaleuca sheathiana, Eremophila dempsteri and Atriplex paludosa, and there is some development of small Chenopods -- Bassia patenticuspis and Kochia species. Eucalypts are not important members of the association; Eucalyptus torquata, E. flocktoniae and E. lesouefii occur very occasionally on the Lady Mary Formation, and E. Stricklandi on the Marell schist.

An association of open woodland occurs on the westerly limit of the transect area, beyond the Iron King open cut. Eucalyptus leptophylla is the dominant species in the tree stratum, and E. salubris, E. celastroides and E. lesouefii occur sporadically. Melaleuca sheathiana, Eremophila dempsteri and Atriplex paludosa grow in the shrub layer.

Open woodland also occurs at the eastern end of the area on the lower flatter ground beyond the ridge of the Attlee jaspilite. Eucalyptus leptophylla is again widespread, E. salubris and E. Stricklandi forming the subdominant tree species. M. sheathiana, Eremophila dempsteri, Scaevola spinescens and A. paludosa are prominent in the shrub stratum, while less frequent species here are Exocarpus aphylla, Olearia muelleri and Eremophila drummondii.

MAP TO SHOW THE DISTRIBUTION
OF THE VEGETATION ASSOCIATIONS
IN THE IRON KING AREA, NORSEMAN

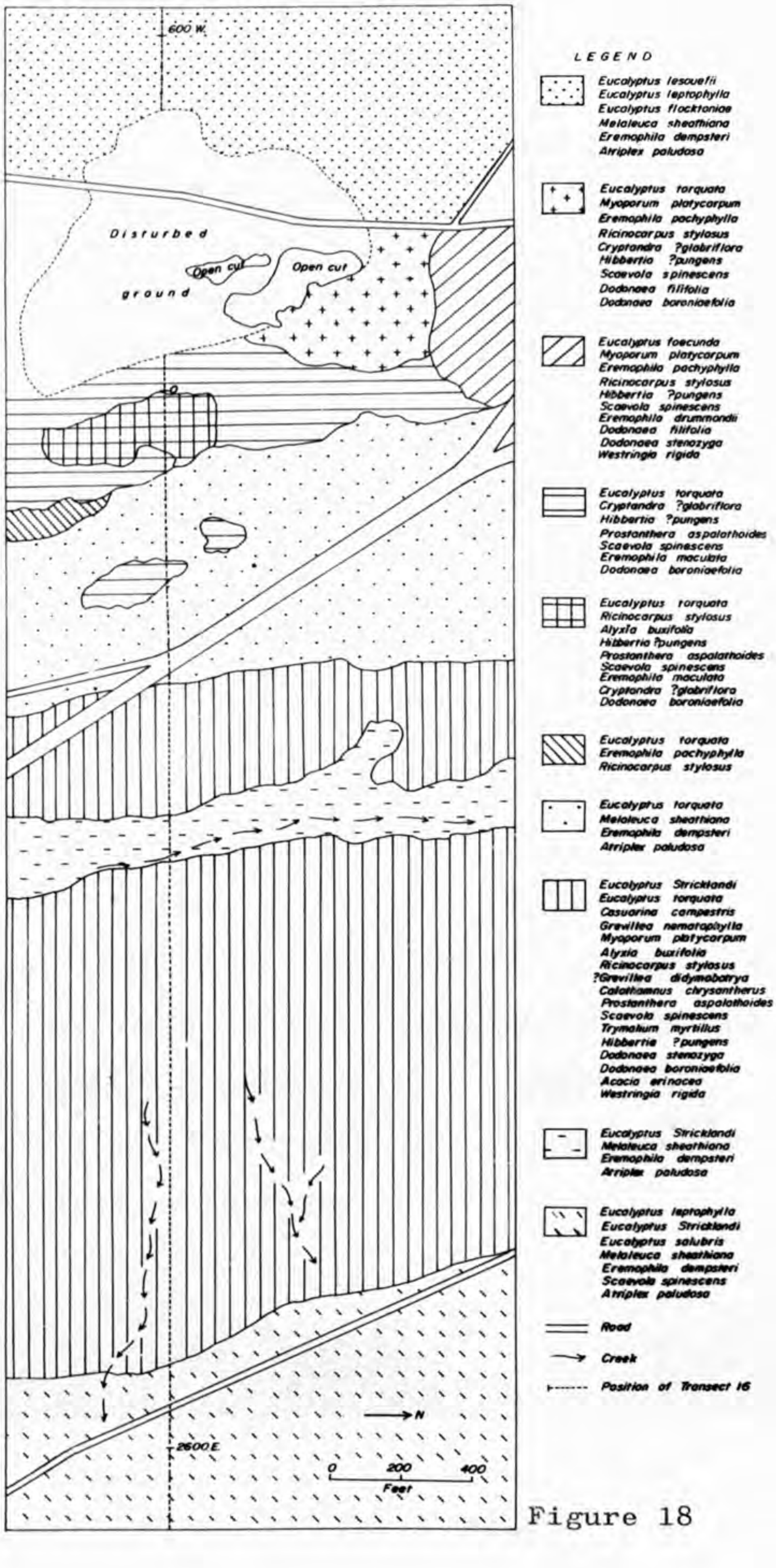
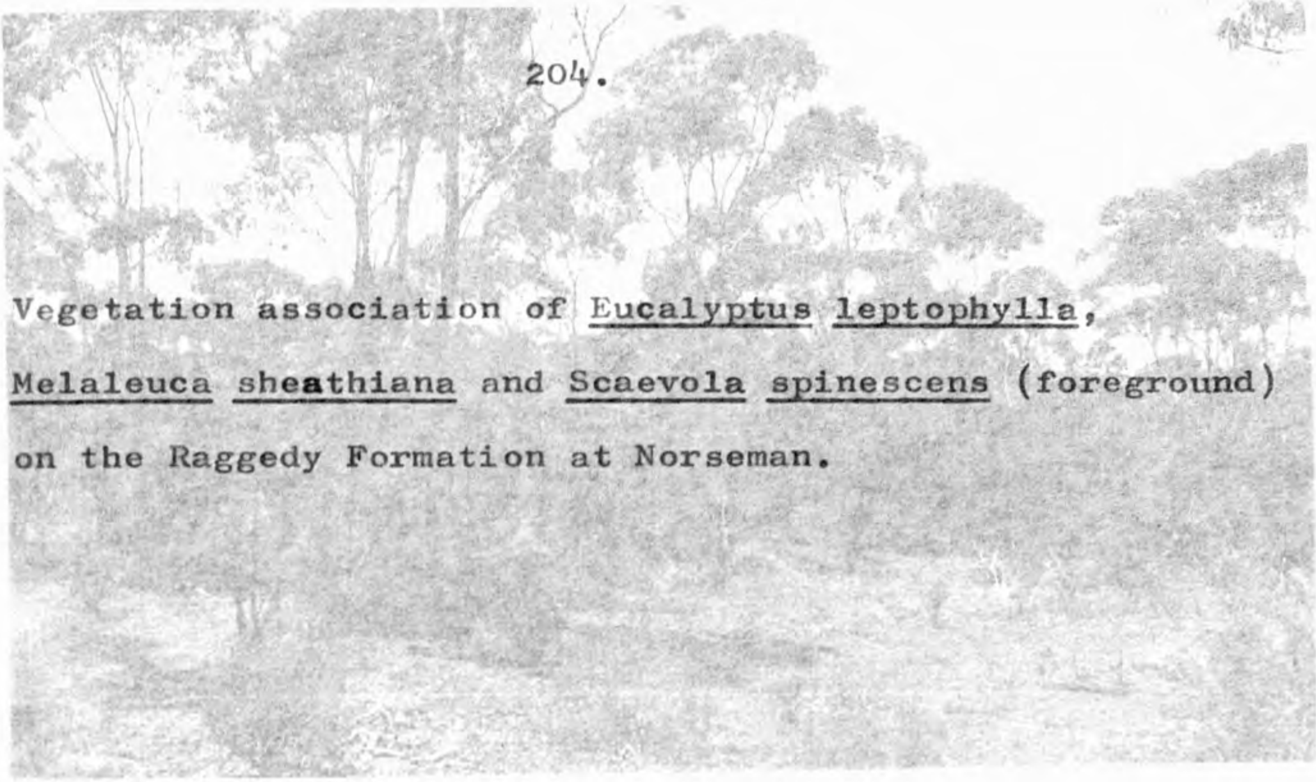
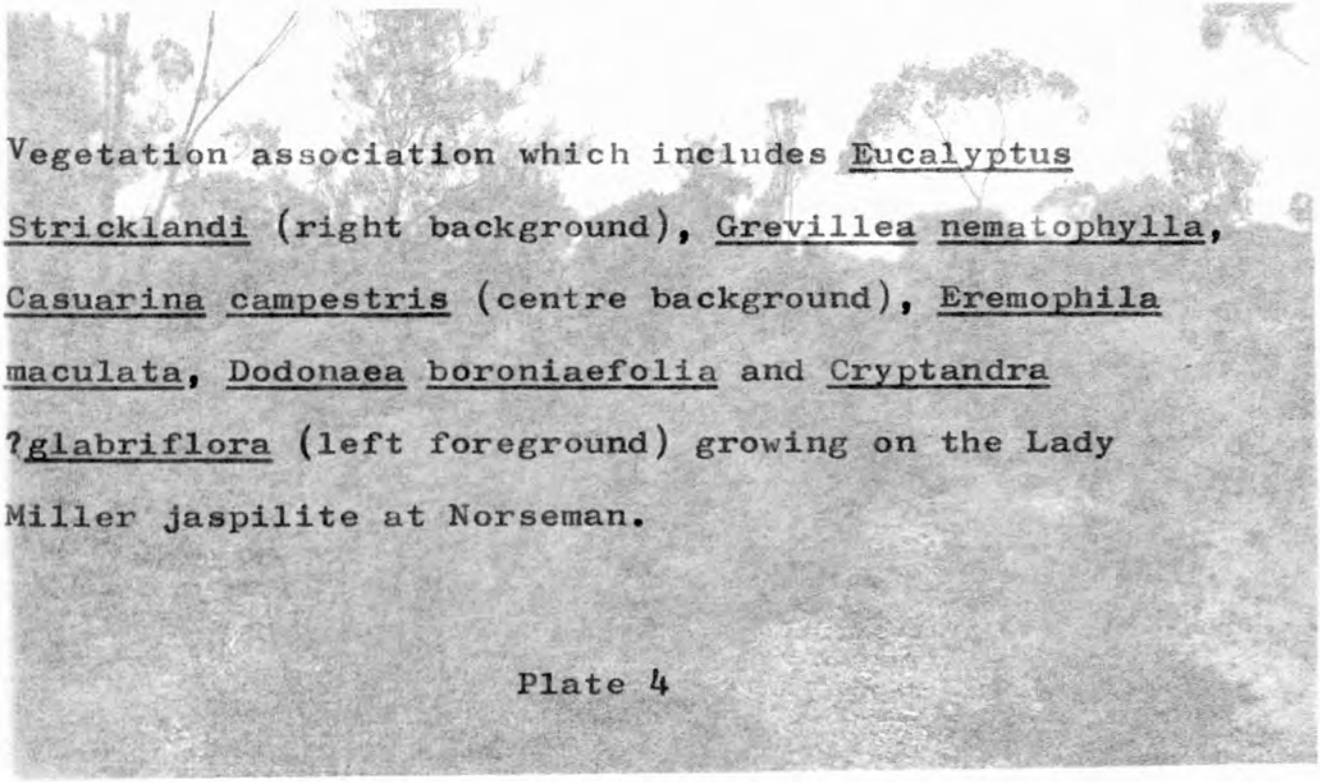


Figure 18

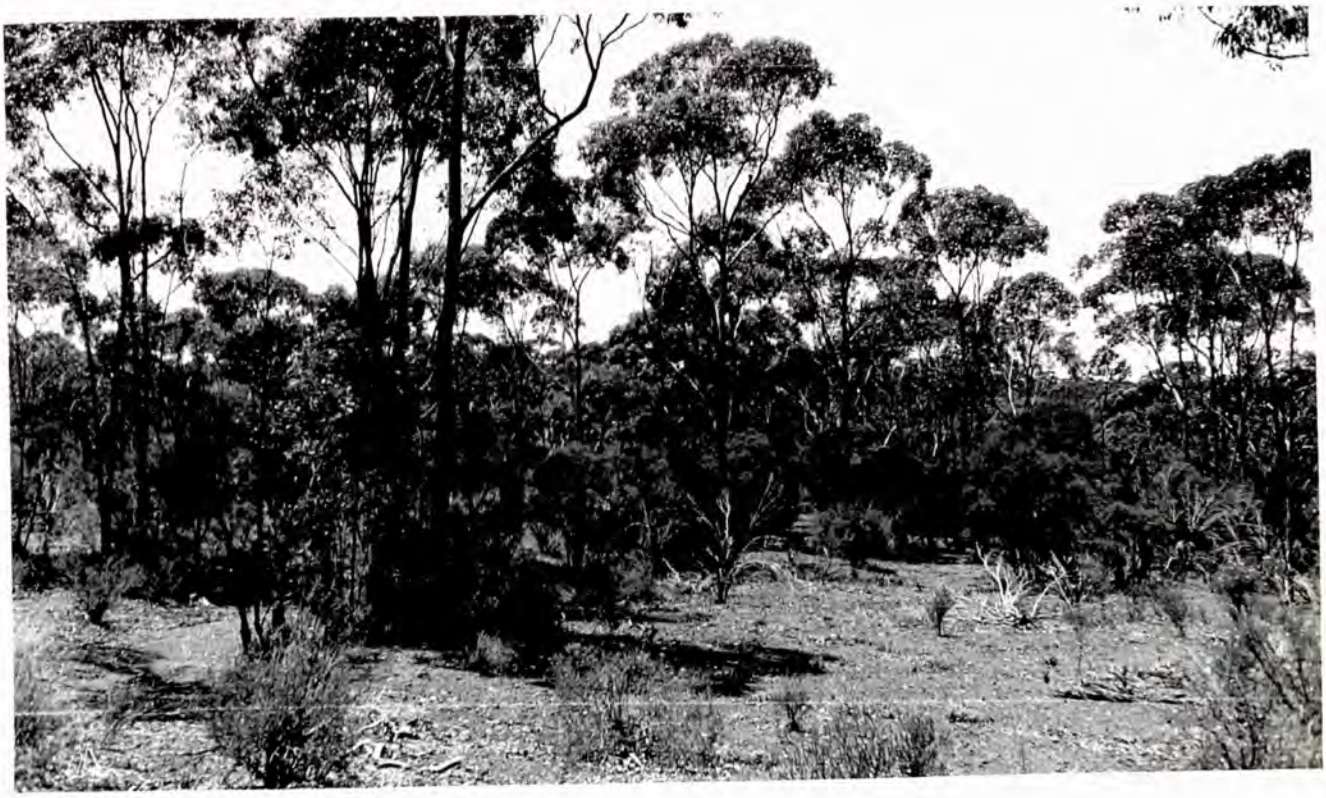


Vegetation association of Eucalyptus leptophylla, Melaleuca sheathiana and Scaevola spinescens (foreground) on the Raggedy Formation at Norseman.



Vegetation association which includes Eucalyptus Stricklandi (right background), Grevillea nematophylla, Casuarina campestris (centre background), Eremophila maculata, Dodonaea boroniaefolia and Cryptandra ?glabriflora (left foreground) growing on the Lady Miller jaspilite at Norseman.

Plate 4



2. Factors governing the distribution of the vegetation associations

(a) Relief and drainage

The Iron King area is one of varying relief (Figure 19). Ridges of higher ground, aligned in a north-south direction, are situated where the underlying rocks are metajaspilites, which is more resistant to erosion than many of the other rock types occurring in the area. The Attlee metajaspilite forms the highest of these ridges, exceeding 1200 feet above sea level, although outside the Iron King area it becomes a less prominent feature in the relief. Valleys lie between the ridges, and in the field area slope from the south in a northerly direction. To the east and west the topography becomes subdued and is gently undulating where the Kingswood basalts and Raggedy Formation form the underlying rock units.

Creeks drain the ridges and open into the valleys which form the main drainage channels. Here the creeks may follow the strike of the rocks.

Relief and drainage in the Iron King area are varied but are not considered to form major environmental factors in governing the distribution of the vegetation associations. Field observations reveal that parts of the tops of the ridges and their sloping sides support one particular association, and the valleys support another; however, the valley association does not occur only within the valley bottom, but often extends up the sides of confining ridges where conditions of slope and drainage contrast with the lower-lying ground.

(b) Geology and soils

A variety of geological units is represented in the Iron King area (Figure 20). A series of more or less parallel metajaspilite bands extends throughout the locality, having a north-north-east strike and a dip of 50° to 55° to the west. These bands usually outcrop strongly, for they are resistant to erosion, and often form prominent features in the relief. The metajaspilite bands are separated by belts of metagabbros and metadolerites, schists, slates and metaconglomerates. These various rock types outcrop only occasionally, and are generally obscured by varying depths of soil cover. They all dip to the west at approximately 45°. The area of study extended onto the Kingswood basalts in the west to the Raggedy Formation in the east. There follows a

RELIEF MAP OF THE IRON KING AREA NORSEMAN

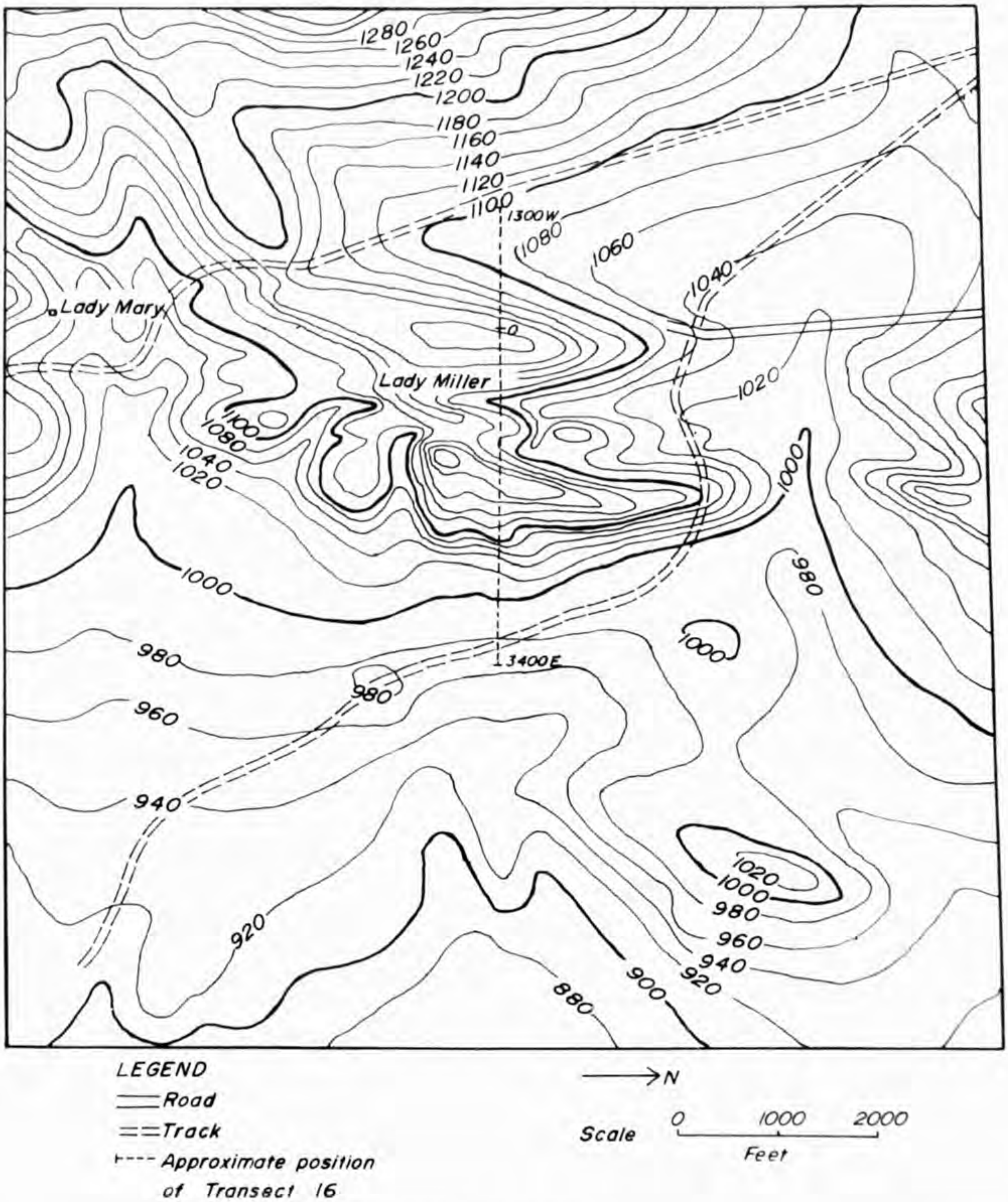


Figure 19

summary of the lithology of the various rock types encountered here (after C. Bekker).

Kingswood basalt - metabasalts with some pillow structures

Holstein jaspilite - metajaspilite

Iron King Formation - metaconglomerate, sandstone, graphitic slate

Hopetoun jaspilite - metajaspilite

Lady Mary Formation - sill of metagabbro and metadolerite

Lady Miller jaspilite - metajaspilite with minor bedded quartz-sulphide lodes

Marell schist - fine grained grunerite schist

Attlee jaspilite - metajaspilite

Raggedy Formation - metaconglomerate, metajaspilite, chert, biotite-andalusite schist, garnet-chlorite schist

From field observation it can be seen that the underlying bedrock obviously plays an important role in determining the distribution of the vegetation associations in this area. The boundaries between the various associations coincide with those between the different rock types. The metajaspilites support a particular association composed of few Eucalypts and numerous shrub species, which include Grevillea nematophylla, Casuarina campestris, Myoporum platycarpum, Alyxia buxifolia, Ricinocarpus stylosus, ?Grevillea didymobotrya, Calothamnus chrysantherus, Prostanthera aspalathoides, Scaevola spinescens, Trymalium myrtillus, Hibbertia ?pungens, Dodonaea stenozyga, D. boroniaefolia, Acacia erinacea and Westringia rigida (Plate 4). No other rock type in the area supports such a rich assemblage of species. In some localities on the metajaspilite trees assume more importance and grow with a greater frequency. Where the metajaspilite abuts onto adjacent rock types the change in vegetation is often very striking.

The Lady Mary Formation and the Marell schist can be traced by their associations, in which Melaleuca sheathiana, Eremophila dempsteri and Atriplex paludosa are the most important species (Plate 5), contrasting strongly with the associations growing on the adjacent metajaspilites. Eucalyptus torquata, E. flocktoniae and E. lesouefii have an infrequent distribution on the Lady Mary Formation, and E. Stricklandi grows occasionally on the Marell schist.

GEOLOGICAL MAP OF THE IRON KING AREA, NORSEMAN
(After Central Norseman Gold Corporation)

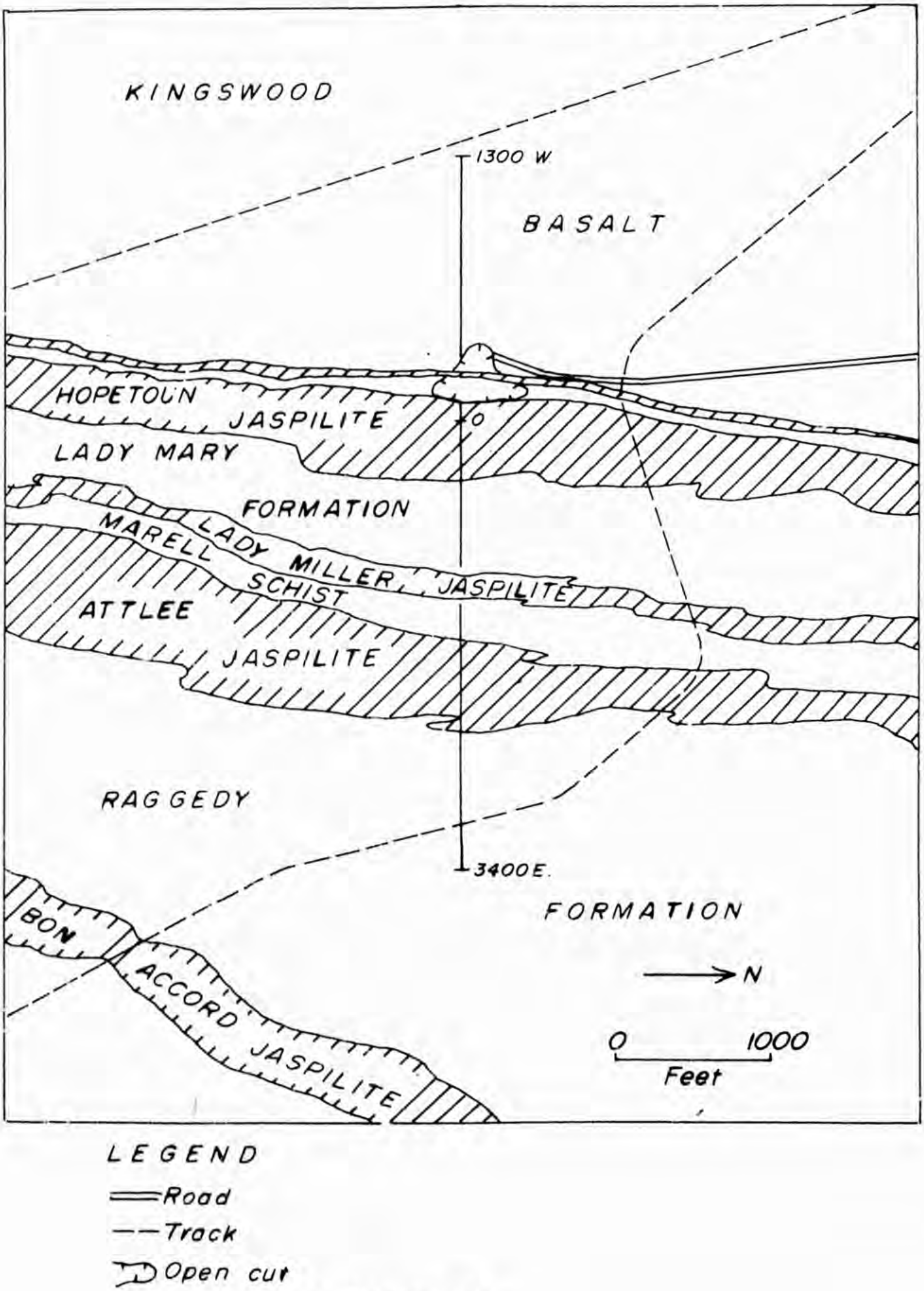
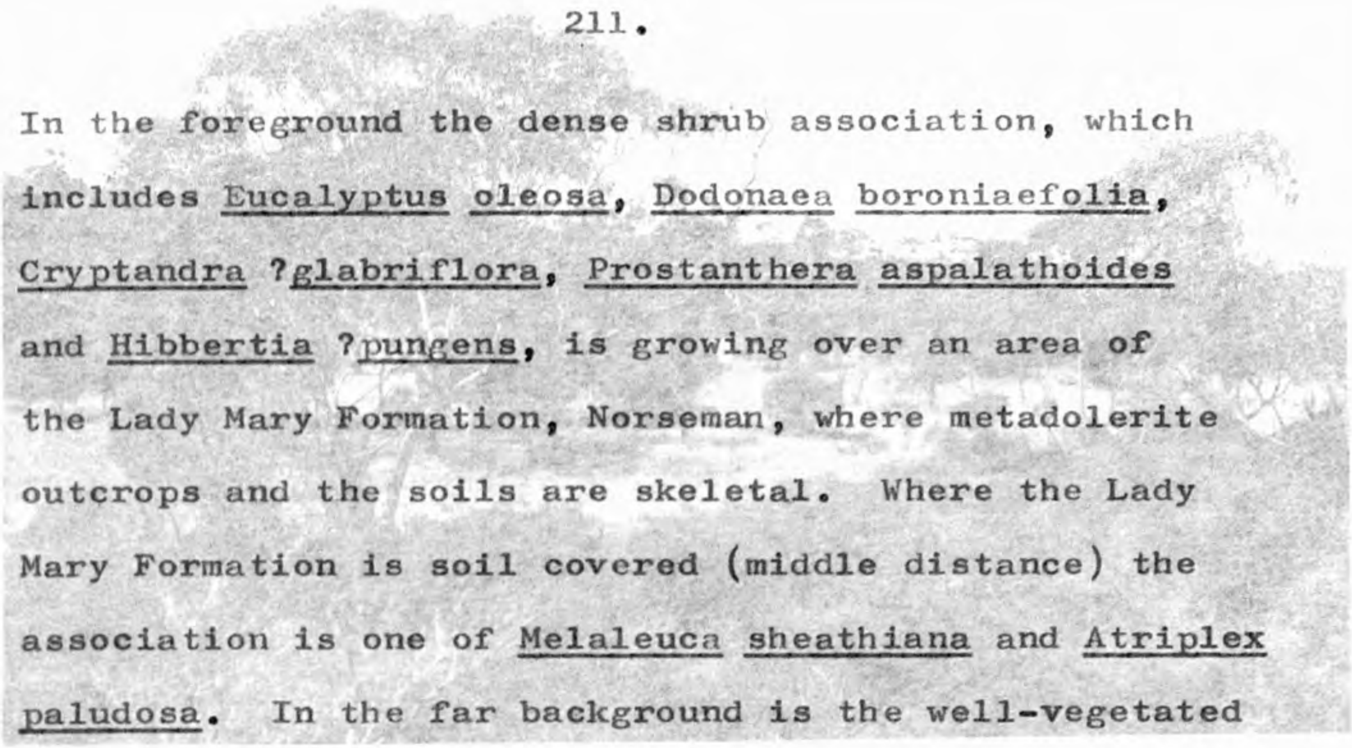
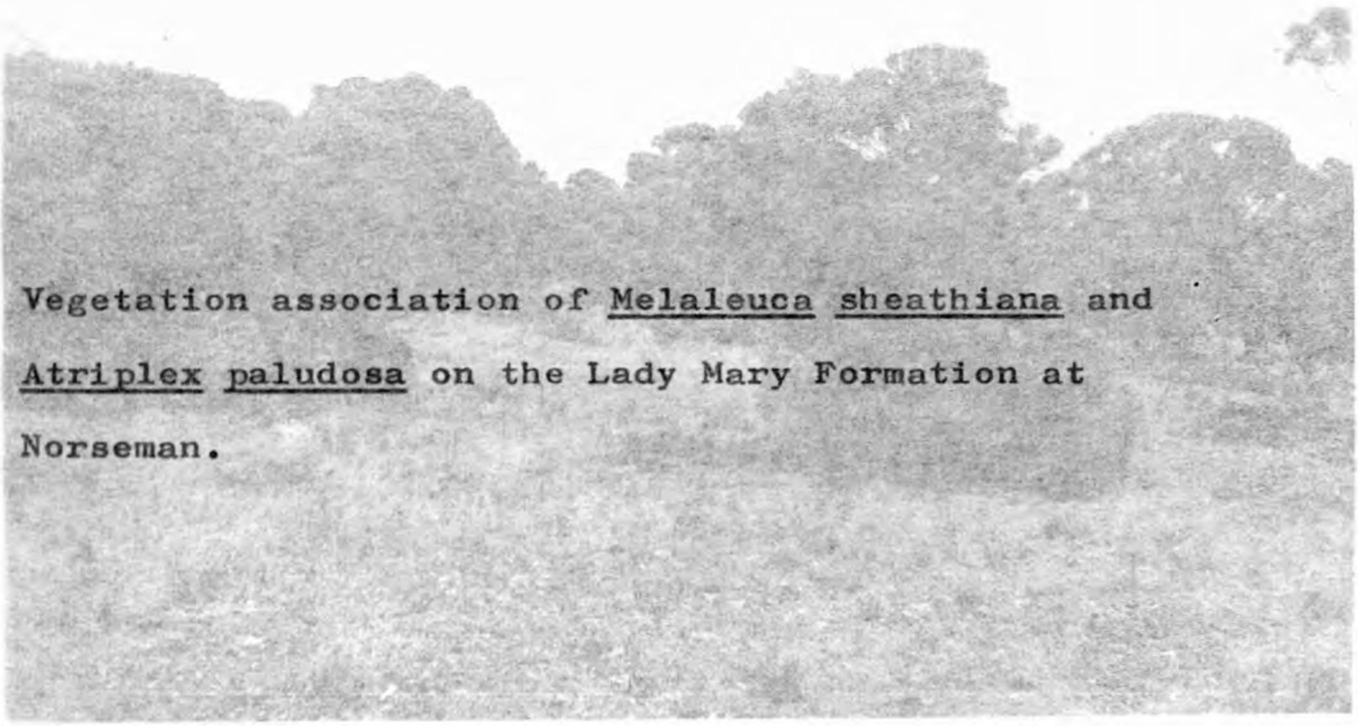


Figure 20



In the foreground the dense shrub association, which includes Eucalyptus oleosa, Dodonaea boroniaefolia, Cryptandra ?glabriflora, Prostanthera aspalathoides and Hibbertia ?pungens, is growing over an area of the Lady Mary Formation, Norseman, where metadolerite outcrops and the soils are skeletal. Where the Lady Mary Formation is soil covered (middle distance) the association is one of Melaleuca sheathiana and Atriplex paludosa. In the far background is the well-vegetated ridge of the Lady Miller jaspilite.



Vegetation association of Melaleuca sheathiana and Atriplex paludosa on the Lady Mary Formation at Norseman.

Plate 5

The Kingswood basalts support open woodland, dominated by _Eucalyptus leptophylla_, _Melaleuca sheathiana_, _Eremophila dempsteri_ and _Atriplex paludosa_. The Raggedy Formation in the east is also characterised by a similar, although more diversified, woodland association (Plate 4). _Eucalyptus leptophylla_ dominates the tree stratum; _Melaleuca sheathiana_, _Eremophila dempsteri_, _Scaevola spinescens_, _Atriplex paludosa_ and other shrubs occur in the understorey.

The physical and chemical conditions which are provided by the various rock types and which find their expression in the soils developed constitute part of the external environment of the plant. The metajaspilites outcrop strongly and are characterised by skeletal soils. The rock weathers slowly and iron-stained scree is abundant. Soil tends to be held in small pockets and never exceeds more than a few inches in depth. It is dark reddish brown in colour (5YR 3/4) and acid in reaction; the pH range encountered was 5.6 to 6.8.

Elsewhere soils are generally better developed. The other rock units do not outcrop so strongly and tend to occupy the lower-lying parts of the Iron King area. Weathering products are able to build up to a greater degree and deeper soils are forming. A profile examined over the Raggedy Formation, where relief is gently undulating, revealed a type of solonised brown soil, containing less apparent lime than the typical soil of this type. The A horizon extends to four inches depth and is dark reddish brown in colour (2.5YR 3/4 to 5YR 3/4). The soil is a silty-clay, and occasional travertine coated pebbles occur. The B horizon extends from four to seventeen inches and continuing, and is reddish brown to yellowish red in colour (5YR 4/4 to 5YR 4/6). The texture becomes more clayey, and travertine coated pebbles are uncommon. A similar type of solonised brown soil occurs over the Kingswood basalt.

Soils over the Lady Mary Formation and the Marell schist are less well developed and generally too stony to allow augering to any depth. Soils on the hillslopes of the Lady Mary were examined to eight inches depth. The profile is that of a solonised brown soil, with an A horizon extending to four inches depth, dark reddish brown in colour (5YR 3/4), with a loamy texture. The soil in this horizon shows a slightly alkaline reaction, with a pH reading of 7.2. The B horizon extends to eight inches and deeper, becoming paler in colour (5YR 5/6) with a markedly more powdery and clayey texture. Lime coated nodules are abundant and prohibit deep augering.

Laterite has been developed in the vicinity of the Iron King open cut. The A horizon has been removed by erosion and the illuvial lateritic B horizon is undergoing weathering. Much of the surface here is covered with ironstone nodules and haematite gravel, which overlie the indurated layer. The soil developing here on the B horizon is very shallow and reddish brown in colour (2.5YR 3/6). It has an acid reaction, a pH of 6.6 being recorded.

3. The relationships between plant distribution and various trace elements in the soils

Soils along the transect were analysed for six trace elements (Figure 21). Geochemical values for copper, zinc and lead are shown together on the same graph. The amount of lead in the soil varies little: the range of this element here is from 15 ppm to 35 ppm, and averages about 30 ppm. Copper and zinc tend to fluctuate more, within a range of 40 ppm to 150 ppm. It appears that the soils analysed from the metajaspilites have these elements in values which fall into the lower part of this range, while soils from the Kingswood basalt and the Raggedy Formation show a slightly higher background. A peak in copper concentration is apparent from 500 feet east to 600 feet east, this tending to correspond with a small area of rocky and stony terrain occurring within the general area of the Lady Mary Formation. This small, scree-covered area contrasts markedly with the rest of the Lady Mary; soil is skeletal and a darker reddish brown in colour, and supports its own community of plants for a distance of 115 feet along the transect (Plate 5). This community comprises a variety of shrub species, including <u>Dodonaea boroniaefolia</u>, <u>Cryptandra ?glabriflora</u>, <u>Prostanthera aspalathoides</u>, <u>Hibbertia ?pungens</u>, <u>Scaevola</u>

<u>spinescens</u>, <u>Eremophila maculata</u> and <u>Lepidosperma brunonianum</u>. <u>Eucalyptus oleosa</u> grows infrequently. It seems unlikely that this community is related to the increase of copper in the soil at this point. The occurrence of these shrubs is probably a response primarily to the physical environment rather than to the trace element content of the soil. Each of the shrub species enumerated above grows elsewhere in the Iron King area where soils are skeletal and the ground surface is rocky, with bed-rock either outcropping or lying near the surface. The metajaspilites, for example, support these species, yet do not contain as much copper in the soil as does this small area of the Lady Mary Formation.

The copper and zinc in the soils overlying the Kingswood basalts and the Raggedy Formation show a slightly higher background than the rest of the area in general. This increase in background, however, is not considered to be an influential factor of prime importance in plant distribution. Both elements are required by plants in minute amounts only, and sufficient requirements are present throughout the transect area without toxic levels being reached. The growth of open woodland here may well be a response primarily to the deeper soils rather than

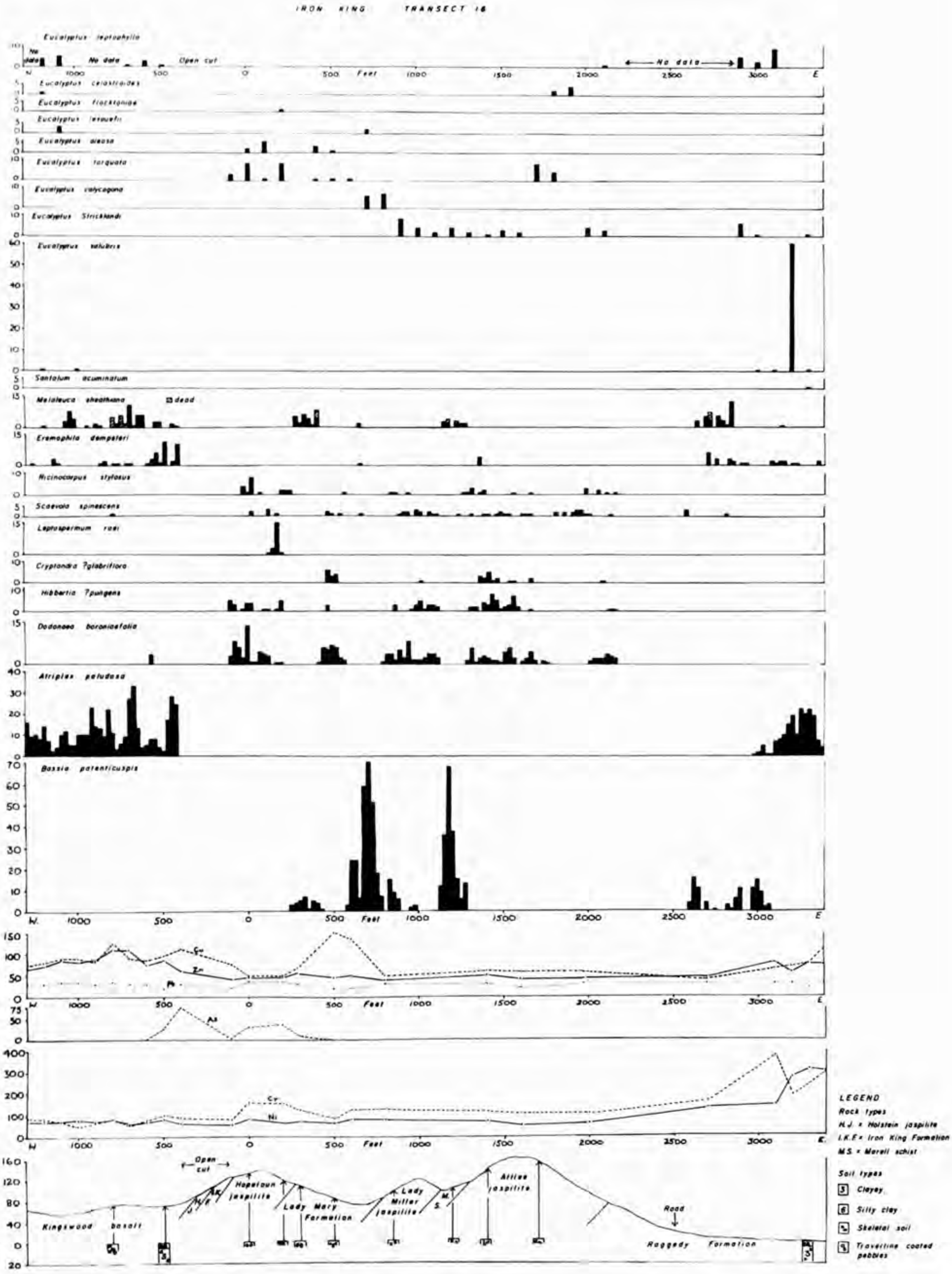

IRON KING TRANSECT 16
Eucalyptus leptophylla
No data
No data
Open cut
No data
Eucalyptus celastroides
Eucalyptus flocktoniae
Eucalyptus lesouefii
Eucalyptus oleosa
Eucalyptus torquata
Eucalyptus calycogona
Eucalyptus Stricklandi
Eucalyptus salubris
Santalum acuminatum
Melaleuca sheathiana
dead
Eremophila dempsteri
Ricinocarpus stylosus
Scaevola spinescens
Leptospermum roei
Cryptandra ?glabriflora
Hibbertia ?pungens
Dodonaea boroniaefolia
Atriplex paludosa
Bassia patenticuspis
Number of trees per 100 ft quadrat
Number of shrubs per 25 x 5 ft quadrat
Feet
Cu
Zn
Pb
As
ppm in soil
Cr
Ni
Open cut
Hopetoun jaspilite
Lady Mary Formation
Lady Miller jaspilite
Atlas jaspilite
Kingswood basalt
Road
Raggedy Formation
LEGEND
Rock types
H.J. = Holstein jaspilite
I.K.F = Iron King Formation
M.S. = Morell schist
Soil types
Clayey
Silty clay
Skeletal soil
Travertine coated pebbles

Figure 21

to any particular geochemical factor, although of course the geochemical soil environment must present conditions which allow normal growth to proceed. Provided that the various essential elements are present and available in the soil plant growth can continue, the actual species growing within a given area depending to a certain extent upon the physical conditions provided by the underlying rock type.

The concentration of nickel and chromium in the soil does not show a great deal of variation along the transect. There is a slight rise in chromium values over the Hopetoun jaspilite and values remain fairly level up until the eastern end of the transect, where soils collected from the Raggedy Formation show a sudden rise in the concentration of these two elements. This increased concentration cannot, however, be adequately assessed without further soil sampling. This part of the Raggedy Formation may have a higher background for these two elements. It is difficult to say whether this increased concentration has any particular effect upon the species present. The association here bears some resemblance to that on the Kingswood basalt, where the nickel and chromium soil values are much lower. The main difference between the vegetation over these two rock units is the more diversified association on the Raggedy Formation.

A small arsenic anomaly is present in the soil from 500 feet west to 300 feet east, and can probably be correlated with gold mineralisation in quartz-sulphide lodes in the Hopetoun and Holstein metajaspilites. The aresenic does not appear to have any significant relationship with the plant distribution.

A soil sample from each rock unit was analysed for the major elements sodium, potassium, calcium and magnesium. These results are shown in Table XII.

Eucalyptus torquata was selected for sampling where it occurred along the transect. Results of biogeochemical analyses (Table IV) indicate that this species concentrates zinc and, to a lesser extent, copper within its tissues. Melaleuca sheathiana also concentrates zinc, as do other shrubs analysed for this metal. M. sheathiana, however, usually contains less copper than the total amount present in the soil. This is in contrast to the other shrubs, which concentrate the element, although to a smaller degree than is the case with zinc.

Over the greater part of the Iron King transect area the vegetation associations change and are demarcated without apparent relation to the six trace elements in the soil. It is clear that the basic controlling factor in the vegetation distribution is the geology, for each rock type supports a particular association. Each area of metajaspilite carries a similar association, characterised by a varied and dense shrub layer which includes Grevillea nematophylla, Casuarina campestris, Myoporum platycarpum, Alyxia buxifolia, Ricinocarpus stylosus, ?Grevillea didymobotrya, Calothamnus chrysantherus, Prostanthera aspalathoides, Scaevola spinescens, Trymalium myrtillus, Hibbertia ?pungens, Dodonaea stenozyga, D. boroniaefolia, Acacia erinacea, and Westringia rigida. The only Eucalypt of widespread occurrence here is Eucalyptus Stricklandi, but its density is low. This rock type outcrops strongly and provides a physical environment which is apparently favourable to or preferred by those species supported. It seems that the plants are responding primarily to the physical rather than the soil chemical environment; many of these shrub species grow also over the small occurrence of metadolerite scree on the Lady Mary Formation, where soils are similarly skeletal.

The association changes abruptly where the metajaspilites abut onto the Lady Mary Formation and the Marell schist, becoming less varied in the species supported. Soils, although not well developed, have a greater depth than do those over the metajaspilites, and although they tend to be rather stony do not have the scree and rubble of the adjacent rock types. Melaleuca sheathiana, Eremophila dempsteri and Atriplex paludosa are the most important species, Eucalypts appearing infrequently. It seems that these species prefer to grow where soils are better developed, for these areas cannot be differentiated from the adjacent areas by the results of the geochemical analyses. Other elements may play a more important role in influencing plant distributions; for example, the distribution of Melaleuca sheathiana seems to be related to some extent to the presence of calcium carbonate in the soil, but how far this is a controlling factor is not known. The underlying rock type must present a favourable chemical environment for growth to proceed normally, and the Marell schist and the rocks of the Lady Mary Formation provide an overall environment which favours the growth of the particular species supported.

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Zn	ppm, Ashed Cu	ppm, Oven-dried Zn	ppm, Oven-dried Cu	ppm, Soil Zn	ppm, Soil Cu	Rock Type
165	Melaleuca sheathiana	T 16 300W	Leaves & twigs	6.4	160	40	10.2	2.5	85	95	Metabasalt
166	Melaleuca sheathiana	T 16 500W	Leaves & twigs	5.8	160	65	9.2	3.7	110	90	"
168	Melaleuca sheathiana	T 16 700W	Leaves & twigs	6.8	170	100	11.5	6.8	85	83	"
167	Melaleuca sheathiana	T 16 1000W	Leaves & twigs	5.8	230	50	13.3	2.9	85	78	"
67	Ricinocarpus stylosus	T 16 15E	Leaves & stems	2.9	300	100	8.7	2.9	45	50	Meta-jaspilite
66	Dodonaea boroniaefolia	T 16 15E	Leaves & stems	3.5	460	120	16.1	4.2			"
62	Eucalyptus torquata	T 16 40E	Leaves	5.3	190	70	11.4	3.7			"
62	Eucalyptus torquata	T 16 40E	Fruit	4.1	180	100	9.5	4.1			"
62	Eucalyptus torquata	T 16 40E	Young twigs	6.0	280	75	11.2	4.5			"
62	Eucalyptus torquata	T 16 40E	Old twigs	4.1	180	100	7.3	4.1			"
170	Leptospermum roei	T 16 200E	Leaves & stems	3.4	350	145	13.6	4.9	45	52	Meta-dolerite

Analyses of unmilled, dry-ashed plant material.
NV and IK series samples.

TABLE IV

NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Zn	ppm, Ashed Cu	ppm, Oven-dried Zn	ppm, Oven-dried Cu	ppm, Soil Zn	ppm, Soil Cu	Rock Type
54	Melaleuca sheathiana	T 16 300E	Leaves & stems	7.0	180	60	8.1	4.2	55	78	Metagabbro
59	Ricinocarpus stylosus	T 16 790E	Leaves & stems	3.1	330	175	10.2	5.4			Meta-jaspilite
60	Dodonaea lobulata	T 16 800E	Leaves & stems	1.9	560	200	16.2	3.8	45	52	"
69	Melaleuca sheathiana	T 16 1200E	Leaves & stems	7.6	150	75	11.4	5.7			Schist
71	Ricinocarpus stylosus	T 16 1480E	Leaves & stems	2.8	400	200	28.0	5.6			Meta-jaspilite
58	Eucalyptus torquata	T 16 1630E	Leaves	4.0	280	70	12.3	2.8			"
58	Eucalyptus torquata	T 16 1630E	Fruit	4.4	160	50	8.9	2.2			"
58	Eucalyptus torquata	T 16 1630E	Young twigs	5.6	280	75	15.4	4.2			"
58	Eucalyptus torquata	T 16 1630E	Old twigs	4.4	230	90	10.1	3.9			"
70	Ricinocarpus stylosus	T 16 1990E	Leaves & stems	3.0	280	160	5.3	4.8	40	58	"
61	Melaleuca sheathiana	T 16 2570E	Leaves & stems	6.4	280	40	17.9	2.5			Schist and chert

Analyses of unmilled, dry-ashed plant material.
NV and IK series samples.

TABLE IV cont. NORSEMAN

(D) SOUTH NORSEMAN

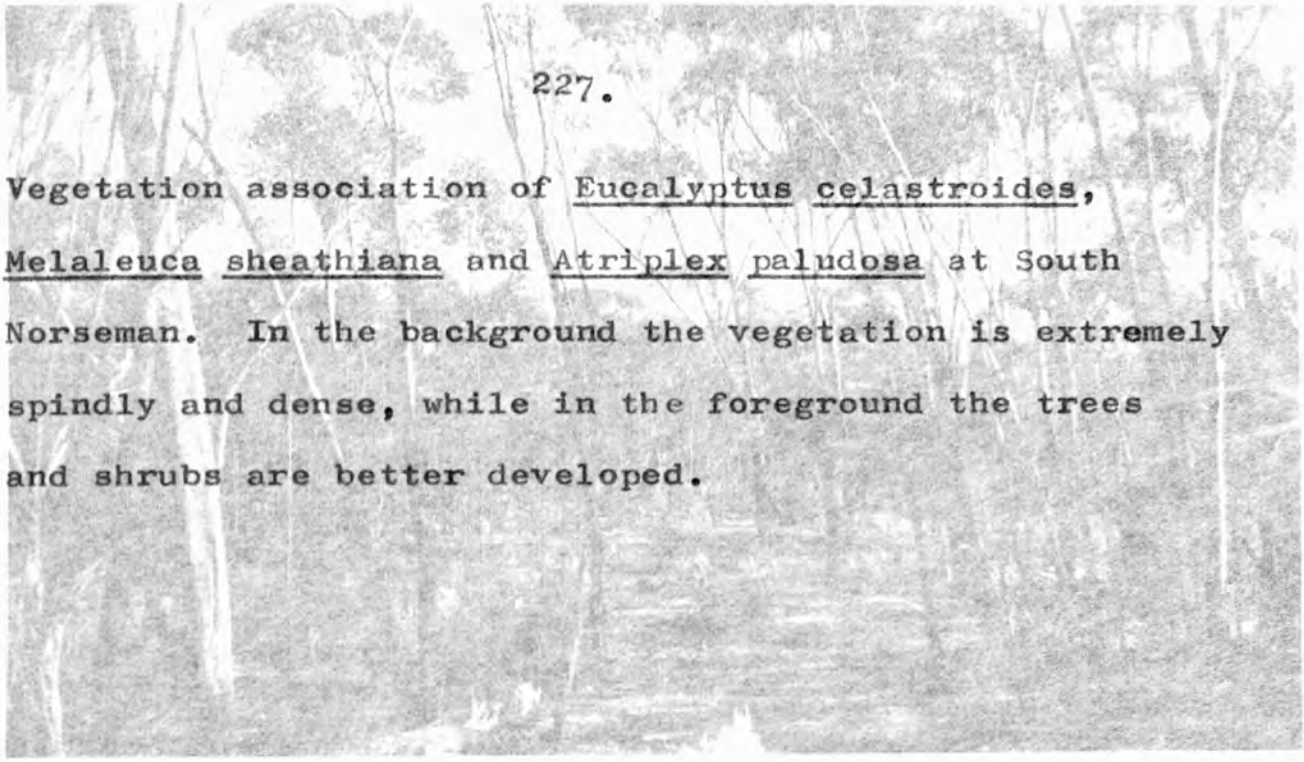
1. Distribution and physiognomy of the vegetation associations

The vegetation in this area consists of open woodland dominated by Eucalyptus species which are associated with a variety of shrubs. The various Eucalyptus species become dominant locally and concede dominance in different localities within the woodland. The shrub species composing the understorey also vary throughout the area, the change in species occurring gradually as certain plants assume a higher frequency and others become less prominent in accordance with the varying ecological factors.

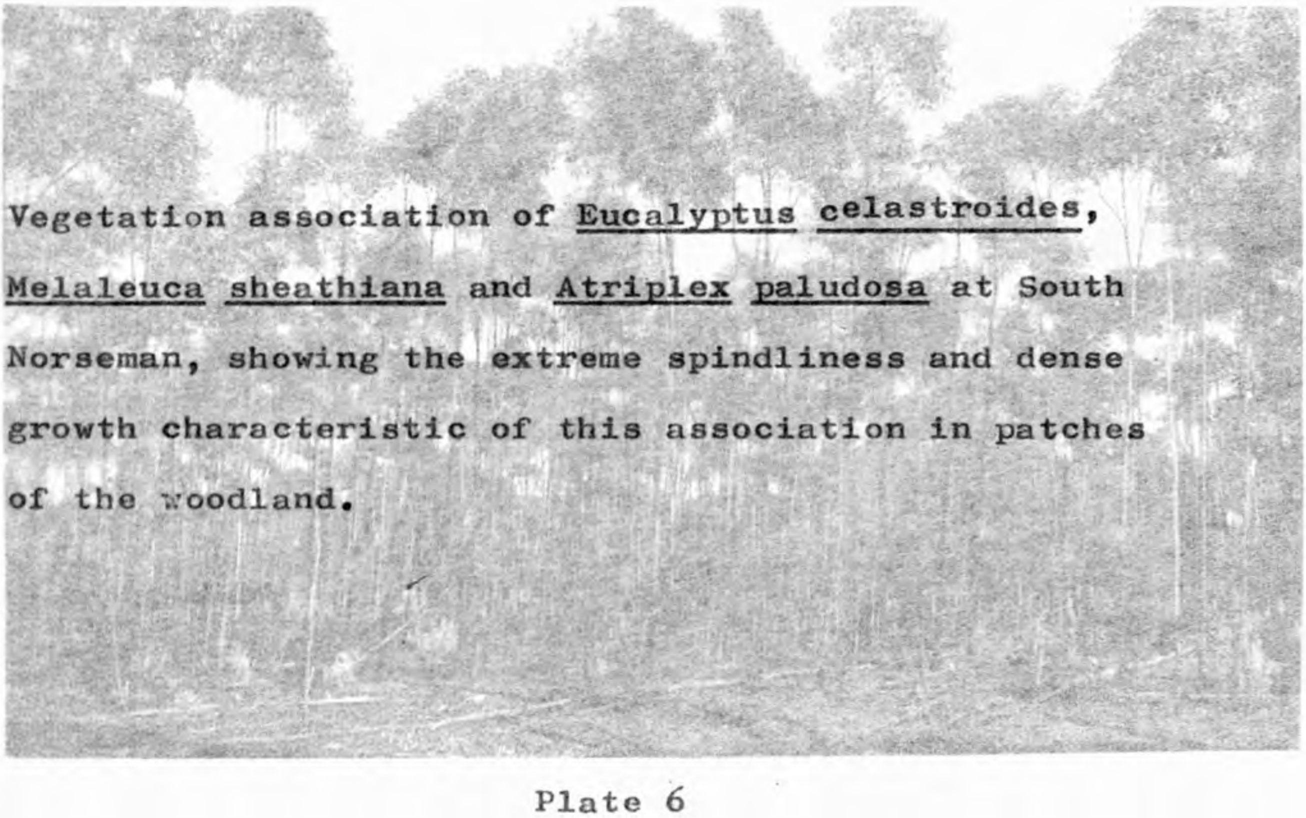
Eucalyptus oleosa, growing up to fifty feet in height, occurs with E. lesouefii in an association characterised by the shrubs Melaleuca sheathiana, Eremophila interstans, Acacia merrallii var. tamminensis, Cratystylis conocephala and Atriplex paludosa. Other species which occur less frequently are Eucalyptus oleosa var. longicornis, Cassia eremophila and Scaevola spinescens. In adjacent areas Eucalyptus flocktoniae assumes dominance in the woodland, associated with a shrub layer of modified composition. *M. sheathiana*, *S. spinescens* and *A. paludosa* are still present, but in addition other shrub species grow, including *Eremophila pachyphylla*, *Eriostemon* sp. J.B./W.A.70, *Dodonaea stenozyga*, *Westringia rigida* and *Bassia patenticuspis*.

In certain localities of the woodland the association becomes poor in total number of species, composed only of the two *Eucalyptus* species *flocktoniae* and *celastroides*, and the shrubs *Melaleuca sheathiana* and *Atriplex paludosa*. Moreover, in such associations the density of the trees and shrubs tends to be extremely high, and the physiognomy of the plants is markedly different (Plate 6). The two *Eucalyptus* species reach to a general height of approximately twenty feet and are extremely spindly in appearance, with trunk circumferance at breast height as little as four inches in living trees. A number of dead trunks still standing are marked by an even greater degree of spindliness; one such dead trunk of eighteen feet height had a circumference of two and three-quarters inches, while another stood at twenty feet with a circumference of three inches. The spindly nature of the trunks is matched by the small development of the crowns.

The ti trees (*M. sheathiana*) also appear in the understorey in dwarf form, averaging a height of four to five feet; it is not unusual for such plants to grow up to twenty feet. The saltbush, _A. paludosa_, is not marked by unusual morphological features, appearing as a small shrub averaging a normal height of about two feet. These species grow with normal physiognomy in areas adjacent to the patches of spindly growth, the Eucalypts attaining heights of thirty to forty feet. Here these associations are provided with some degree of plant variety; _Eremophila interstans_, _Scaevola spinescens_, _Olearia muelleri_, _Ptilotus obovatus_ and _Rhagodia gaudichaudiana_ grow occasionally.



Vegetation association of Eucalyptus celastroides, Melaleuca sheathiana and Atriplex paludosa at South Norseman. In the background the vegetation is extremely spindly and dense, while in the foreground the trees and shrubs are better developed.



Vegetation association of Eucalyptus celastroides, Melaleuca sheathiana and Atriplex paludosa at South Norseman, showing the extreme spindliness and dense growth characteristic of this association in patches of the woodland.

Plate 6

2. Factors governing the distribution and physiognomy of the vegetation associations

(a) Relief and drainage

Much of the area of South Norseman is either gently undulating or more or less flat. The ground relief falls very gently to the west, but to the east rises steadily to form a fairly high ridge, culminating in Woolyeenyer Hill, which, at 1580 feet above sea level, is the highest point in the Norseman area. There is no marked relief in the localities covered by the transects as these lie to the west of the Woolyeenyer ridge, where the relief is subdued and mainly flat. This factor of the environment is therefore sufficiently constant in the areas studied to have little, if any, effect on the distribution of the associations here, or on the physiognomic variation found in the plants composing them.

No marked drainage channels or creek beds were observed here. Drainage from Woolyeenyer Hill and the eastern ridge is radial and the drainage in the flatter country lying to the west is in a westerly direction, following the subdued fall of the ground. The water-holding capacity of the soils is considered to vary very little where the relief is not marked, for a considerable depth of soil has built up in these flatter areas and presents more or less uniform qualities of texture. Soils are referred to in greater detail below.

(b) Geology and soils

The area is underlain by greenstones. These are probably lavas extending southwards from those occurring in the vicinity of the township of Norseman. There is very little, if any, outcrop in the localities covered by the field work, and the geology is masked by soil cover.

The soils occupying the flatter ground belong to that type of solonised brown soil which contains less apparent free lime than is found in the usual soil of this type. The A horizon, which may extend down to a depth of twelve inches, is a dark brown to very dark greyish brown (7.5YR 3/2 to 10YR 3/2) silty loam. Travertine coated pebbles are present. The B horizon is encountered at depths ranging from four to twelve inches, and extends to beyond a depth of eighteen inches. The soil is brown to strong brown in colour (7.5YR 4/4 to 7.5YR 5/6), and clayey in texture. Bedrock was not encountered during augering, which was possible to a depth of eighteen inches only, owing to the looseness of the soil. The soil type does not change significantly within the localities studied. The soil properties do not alter to any degree which would affect the species distribution or physiognomy.

3. The relationships between the distribution of the vegetation associations and their physiognomic variations and various trace elements in the soil

Any marked variations existing in the metal content of the soil may influence the distribution of particular species and hence the nature of the associations developed. Toxic concentrations of certain elements can lead to the production of unusual morphological features in plants, and preliminary field observations suggested that the spindly nature of the Eucalypts and ti trees in parts of the woodland was a possible example of the result of such a factor. Certain areas of South Norseman are known to contain arsenic within the soil profile, and values in excess of 100 ppm have been found by Central Norseman Gold Corporation. The arsenic tends to be concentrated in the iron-rich basal clay horizon of the solonised brown soil profile, and in the near-surface calcareous horizon (Mazzucchelli 1965). Arsenic is adsorbed and combined chemically with iron-oxides. The latter have been leached, resulting in the presence of an iron- and arsenic-rich area at depth. The concentration of arsenic in the calcareous horizon is attributed to the fact that arsenic is also adsorbed onto clay minerals, for calcium itself has no significant effect on arsenic fixation. Some of the carbonate which is precipitated near or at the surface comes from ascending ground waters: this probably brings arsenic up from deeper within the soil and deposits it here. The arsenic would revert to iron or aluminium arsenate which would not easily undergo leaching.

Transects were located to pass across areas of arsenic anomalies located on Traverse lines 43000S and 37000S, and also across areas where no arsenic had been found in the soil profile, Traverse line 25000S (Figure 22).

Soil analyses for arsenic along transect 12, located in one of the anomalous areas, revealed that the highest values occurred deeper within the soil profile rather than near the surface (Figure 23). Values up to 75 ppm were obtained at a depth of sixteen to seventeen inches. Some of the highest anomalies coincided with the patches of dense spindly vegetation growth. The association here comprises _Eucalyptus flocktoniae_, _E. celastroides_, _Melaleuca sheathiana_ and _Atriplex paludosa_ -- one of little variety, but generally of marked density and spindliness. The low growth of Melaleuca sheathiana, providing the understorey to the Eucalypts, often becomes so dense as to exclude the growth of A. paludosa beneath it. At the southern end of transect 12 the appearance of the vegetation becomes normal in its physiognomy and its density becomes lower. There is a slight diversification in the species present; Eucalyptus oleosa var. longicornis occurs, but rather infrequently; Eremophila interstans, E. glabra, Ptilotus obovatus and Rhagodia gaudichaudiana appear occasionally in the shrub layer, and Bassia patenticuspis in the ground layer.

Transect 26, situated in a second area where arsenic anomalies had been found, shows fewer and smaller patches of spindly growth and tree density in the vicinity is generally low (Figure 24). The dominant Eucalypt is Eucalyptus flocktoniae, with E. salubris, Eucalyptus sp. J.B./W.A.316, E. lesouefii, E. celastroides and E. oleosa occurring sporadically. Melaleuca sheathiana and Atriplex paludosa grow throughout the area. No arsenic was found in the soil samples collected along this transect.

An area where no arsenic had been found in the soil was also examined (Figure 25). Here the trees are all well developed, growing to a normal height and size, and the density of the vegetation is that characteristic of the open woodland of the district. The most important species in the association are Eucalyptus celastroides, E. flocktoniae, E. oleosa var. longicornis, Melaleuca sheathiana and Atriplex paludosa. Sub-dominant plants are Eremophila interstans, Olearia muelleri, Kochia georgei, K. radiata and Bassia patenticuspis.

Plant material from Eucalyptus flocktoniae, E. celastroides and Melaleuca sheathiana was analysed for arsenic, but every result was negative (Table V). Toxic elements may be absorbed by plants but are often precipitated in the roots so that little is transported to the aerial parts of the plant. Root material was analysed from both Eucalyptus species and from M. sheathiana, but no arsenic was revealed in any of the samples. Arsenic is of no value to plants and a high concentration may be detrimental, the reaction to this element varying between species. Studies over soil arsenic anomalies in Sierra Leone showed that the twig and leaf ash of Ricinodendron africanus from these areas contained very low amounts of arsenic; with a soil

LOCALITY MAP OF SOUTH NORSEMAN

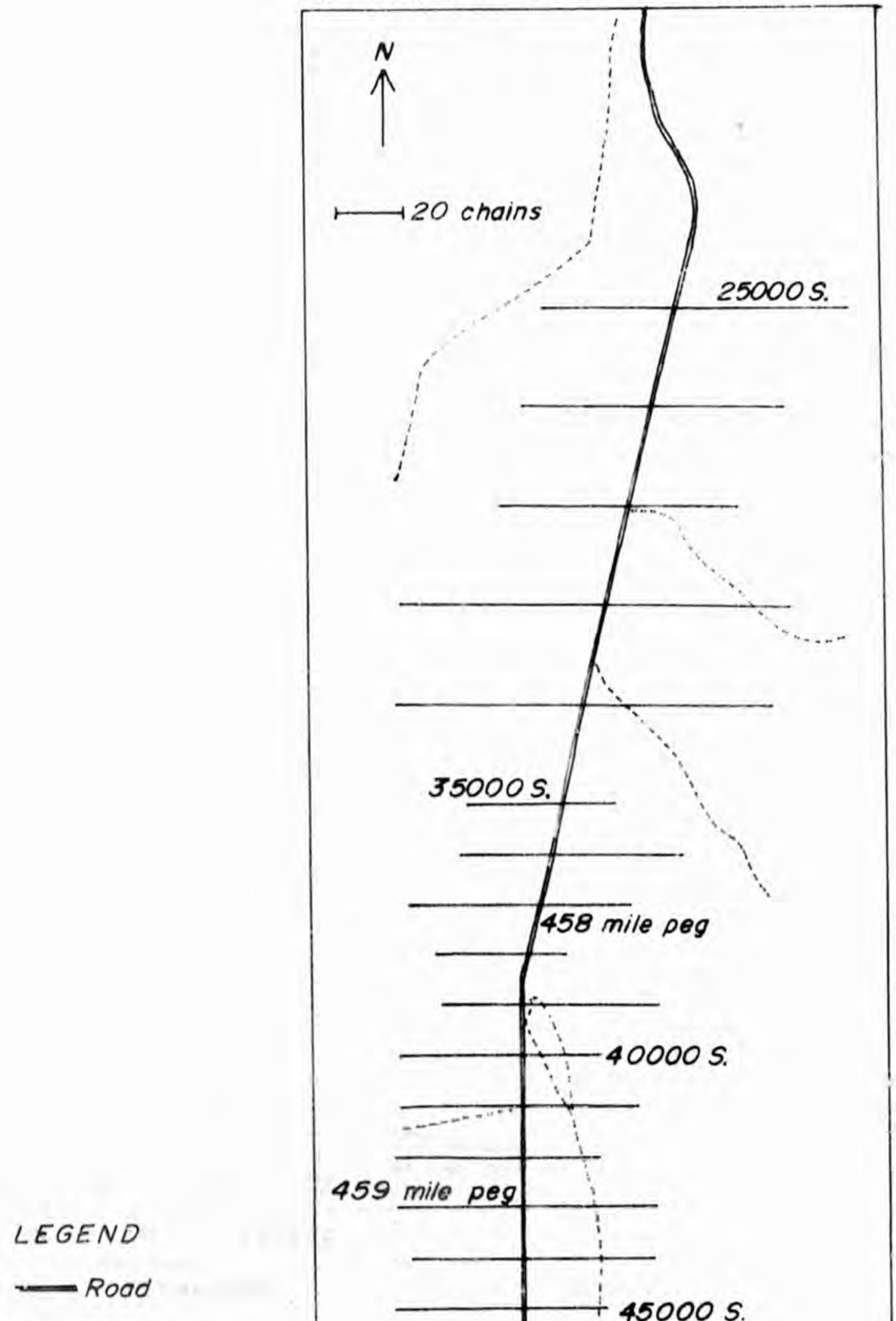


Figure 22

(After Central Norseman Gold Corporation)

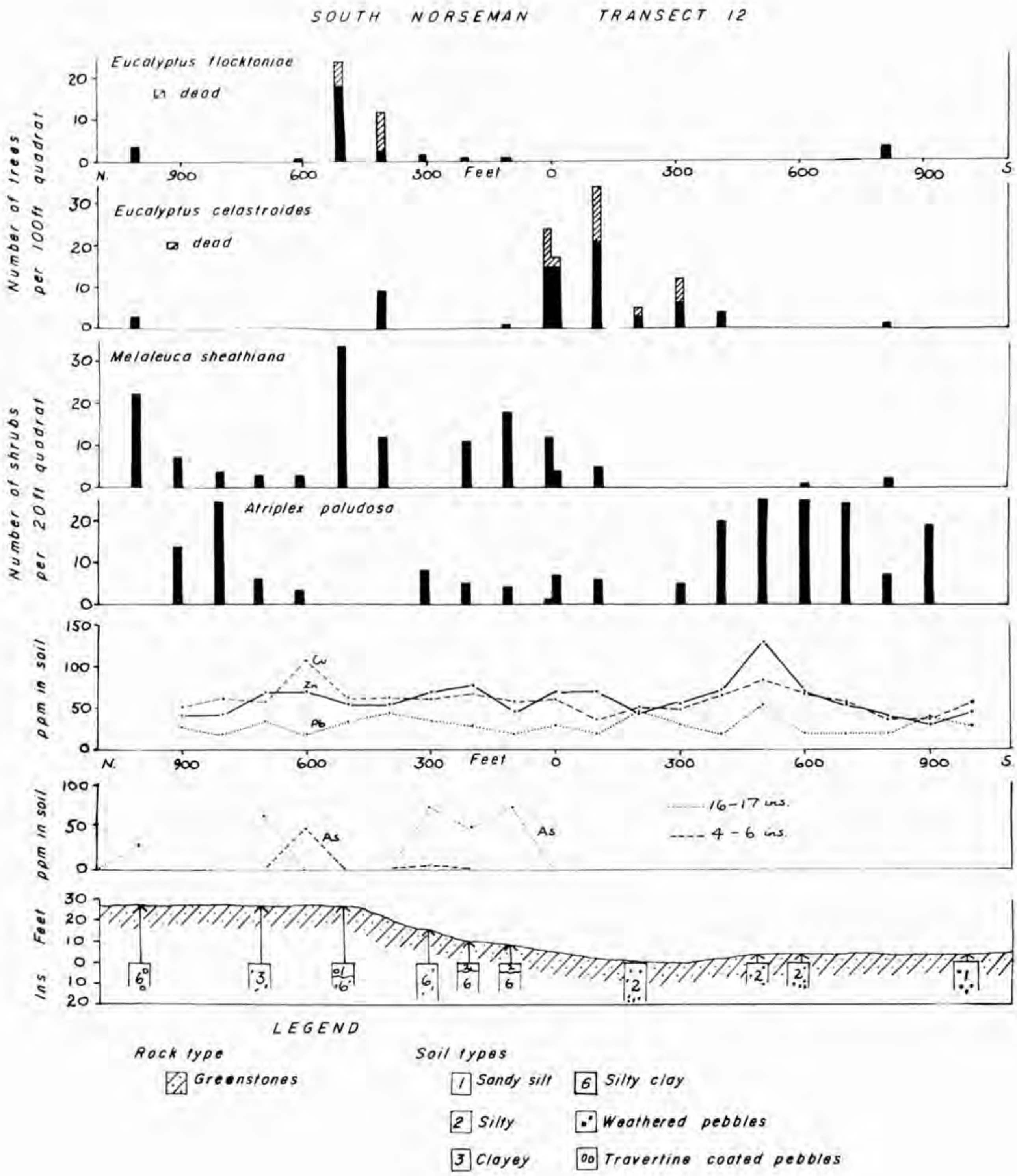

SOUTH NORSEMAN TRANSECT 12
Eucalyptus flocktoniae
dead
Number of trees per 100ft quadrat
Eucalyptus celastroides
dead
Melaleuca sheathiana
Number of shrubs per 20ft quadrat
Atriplex paludosa
ppm in soil
Cu
Zn
Pb
As
16-17 ins.
4 - 6 ins.
N.
S.
Feet
Ins
LEGEND
Rock type
Greenstones
Soil types
1 Sandy silt
2 Silty
3 Clayey
6 Silty clay
Weathered pebbles
Travertine coated pebbles

Figure 23

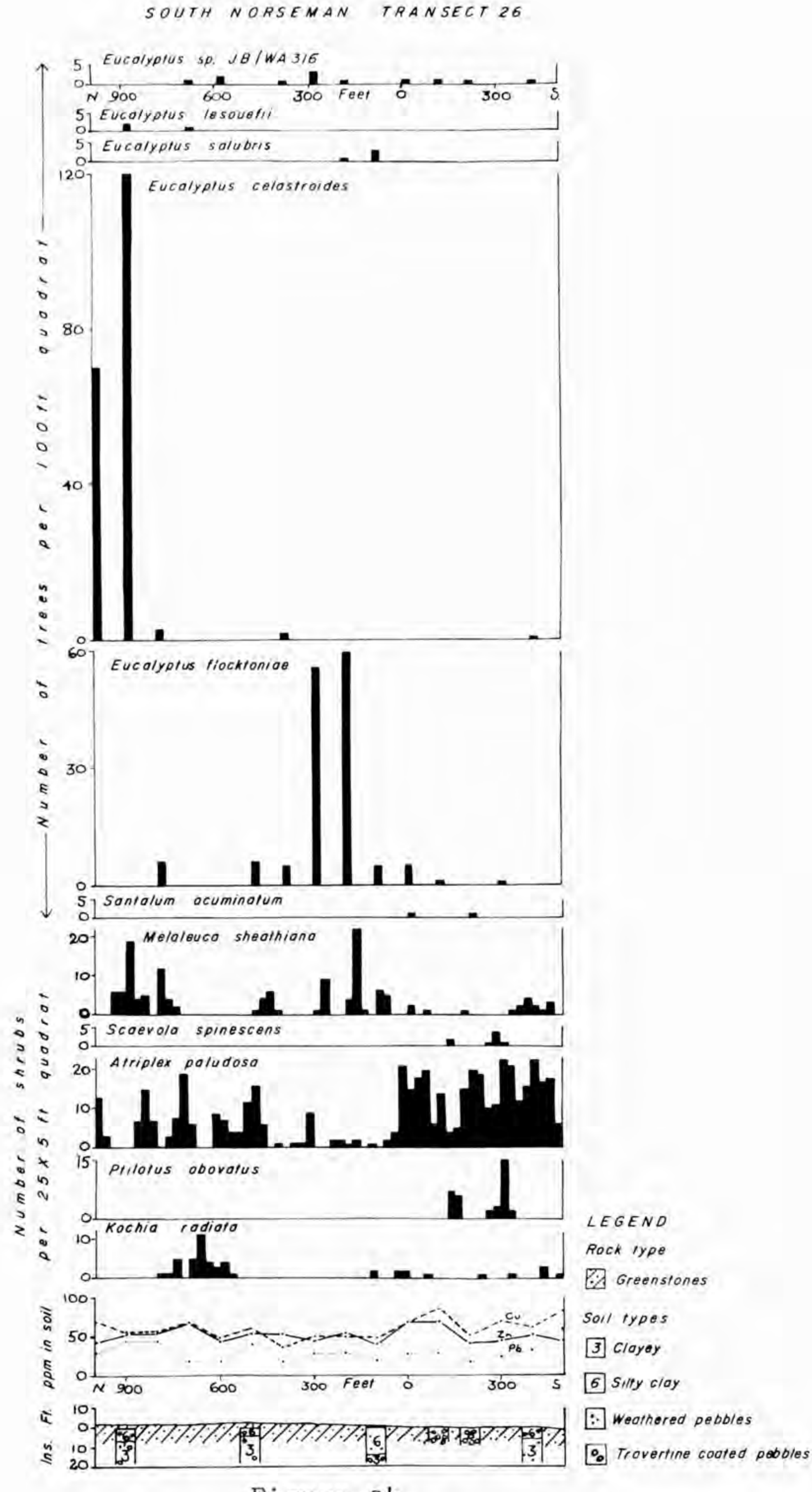

SOUTH NORSEMAN TRANSECT 26
Eucalyptus sp. JB/WA 316
Eucalyptus lesouefii
Eucalyptus salubris
Eucalyptus celastroides
Eucalyptus flocktoniae
Santalum acuminatum
Number of trees per 100 ft. quadrat
Melaleuca sheathiana
Scaevola spinescens
Atriplex paludosa
Ptilotus obovatus
Kochia radiata
Number of shrubs per 25 X 5 ft quadrat
ppm in soil
Cu
Zn
Pb
Ins. Ft.
N 900 600 300 Feet 0 300 S
LEGEND
Rock type
Greenstones
Soil types
3 Clayey
6 Silty clay
Weathered pebbles
Travertine coated pebbles

Figure 24

arsenic content of 1140 ppm the arsenic contents in the ash of twigs and leaves were 2 ppm and 5 ppm respectively (Mather 1959). No morphological abnormalities or differences in species distribution over mineralised and unmineralised areas were noted.

0.6 to 230 ppm arsenic has been reported in grass growing over arsenic-rich soils (Grimmett 1939, quoted by Mather 1959), while quantities of up to 500 ppm arsenic have been found in the ash of beech humus (Goldschmidt and Peters, quoted by Onishi and Sandell 1955). Warren *et al*. (1964) have shown from work in Canada over an area of arsenical gold and base metal mineralisation that samples of Douglas Fir (*Pseudotsuga menziesii*) may absorb very large quantities of arsenic. 10,000 ppm arsenic was found in the ash of present year tips of this species. The corresponding figure for needles of the previous year was 9,400 ppm. In an unmineralised area the ash of Douglas Fir needles or stems was usually less than 1 ppm. Although other common tree species gave arsenic anomalies over mineralised ground the amounts of the element in the ash were much lower.

It appears that the arsenic present in the soil at

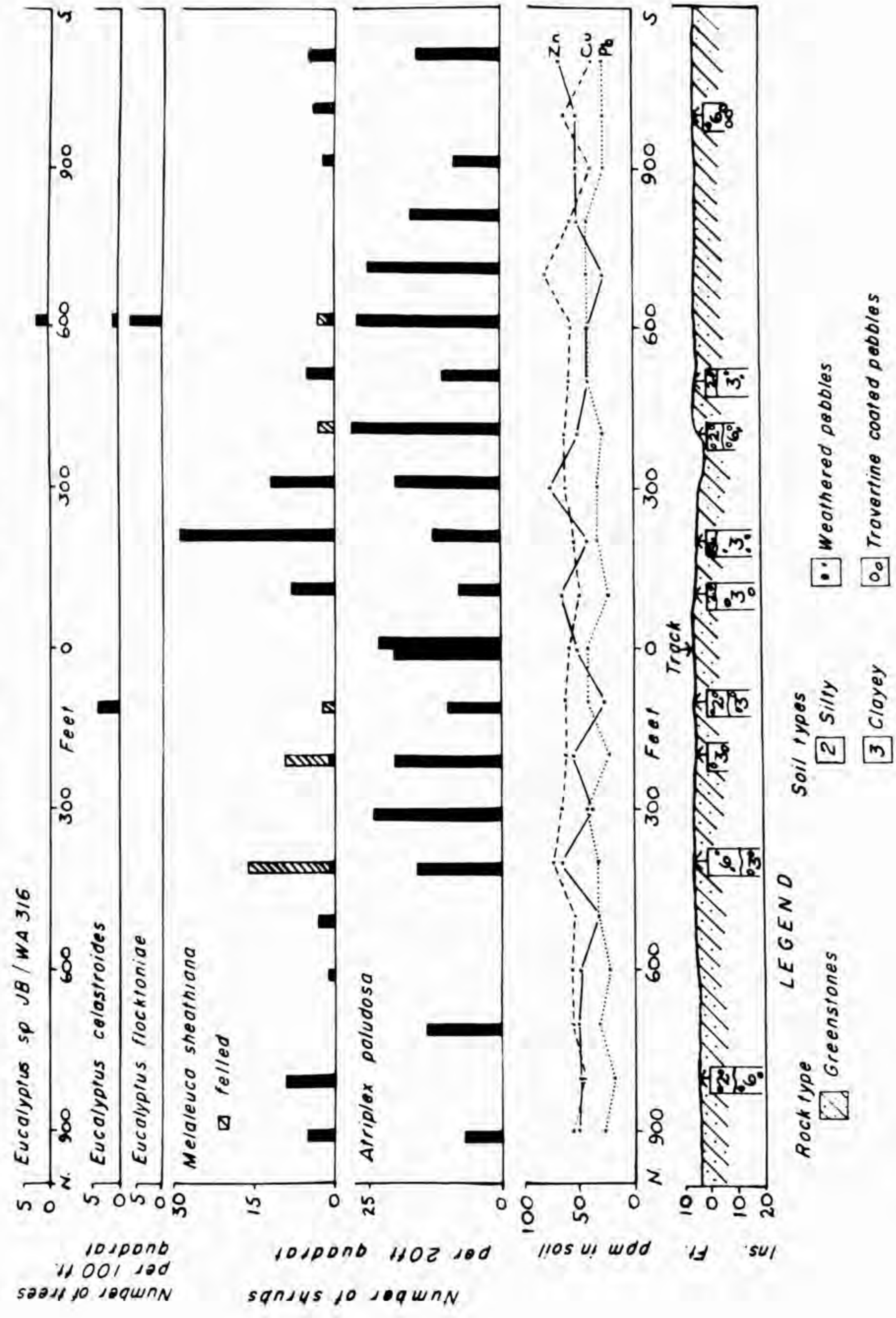

SOUTH NORSEMAN TRANSECT 15
Eucalyptus sp JB / WA 316
Eucalyptus celastroides
Eucalyptus flocktoniae
Melaleuca sheathiana
felled
Atriplex paludosa
Number of trees per 100 ft. quadrat
Number of shrubs per 20ft quadrat
ppm in soil
Zn
Cu
Pb
Ins. Ft.
N.
S
900
600
300
0
Feet
Track
LEGEND
Rock type
Greenstones
Soil types
2 Silty
3 Clayey
6 Silty clay
Weathered pebbles
Travertine coated pebbles

Figure 25

South Norseman is not available for uptake by the plants, as none was revealed in any of the plants which were analysed. Although the physiognomy of the species composing the association appeared to show some correlation with the presence of the arsenic anomalies in the soil, preliminary field observations appearing to indicate that some of the denser, spindly patches of vegetation grew where high values of the element were encountered, analysis indicated that these features cannot be attributed directly to arsenic poisoning.

The possibility of other elements existing in the soil in unusual quantities was investigated. The soil samples were analysed for copper, zinc and lead. Soil values of these metals did not vary to any marked extent between the field localities studied. The soil contents averaged about 30 ppm lead, 50 ppm zinc and 60 ppm copper, with no apparent differences in the soil metal content between spindly and non-spindly patches of woodland.

The plant ash content of these three elements maintained a more or less uniform range throughout the transect areas. In samples of Atriplex paludosa copper did not exceed 70 ppm in the ash, and zinc did not exceed

130 ppm in the ash, values for the latter element bein generally less than 100 ppm. Melaleuca sheathiana revealed 25 to 100 ppm copper in the ash, and 100 to 140 ppm zinc. Analysis of Eucalyptus celastroides and E. flocktoniae revealed that the aerial parts of these species varied from 65 to 225 ppm copper in the ash, the average amount approximating to 100 ppm. The copper did not appear to be specifically concentrated in any particular organ. Concentration of zinc in the Eucalyptus ash tended to be relatively higher, and varied from 90 to 800 ppm. Leaf ash usually contained higher amounts of this element than did the twigs or the fruit.

None of the plants analysed contained any lead. Root material from Eucalyptus flocktoniae, E. celastroides and Melaleuca sheathiana was analysed for this element, in addition to the aerial organs, but results were negative.

In spite of the relatively large range found in the concentrations of copper and zinc in some of the species analysed, no relationship was apparent between these varying metal concentrations and the plant distribution and physiognomy. Both higher and lower values in the ranges encountered here occurred in all areas examined.

The factors governing the physiognomic variations in the vegetation associations in this area cannot at present be determined. In spite of anomalous concentrations of arsenic in the soil in certain parts of the localities studied, no arsenic was revealed in the plant material and it therefore appears that this element is present in a form in the soil which is unavailable for plant uptake. The concentration of copper, zinc and lead in the soil was more or less constant throughout the area, and these elements cannot account for the unusual morphology found in parts of the woodland.

The previous history of South Norseman was checked with the Forests Department at Kalgoorlie, and it was established that there had been no major forest fire within the area for thirty to forty years. The Department has no re-afforestation programme in the district owing to the lack of regular good seasons. The low height and spindly nature of the Eucalypts therefore cannot be attributed to immaturity. Other observable factors in the external environment appear to be sufficiently uniform as to be unable to explain the physiognomic variations. Similar areas of woodland, containing patches of spindly trees, were noted elsewhere within the Eastern

Goldfields, for example, fourteen miles south of Widgiemooltha, and in the vicinity of Kambalda. Further investigations could usefully be carried out in such localities, in addition to areas at South Norseman.

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	As	ppm, Oven-dried Pb	Zn	Cu	As	ppm, Soil Pb	Zn	Cu	As	Rock Type
110	Atriplex paludosa	T 12 00	Leaves & stems	19.8	0	60	40	0	0	11.8	7.9	0	30	70	60	0	Green-stones
25	Eucalyptus celastroides	T 12 00	Leaves	2.8	0	280	100	0	0	7.2	2.8	0					"
25	Eucalyptus celastroides	T 12 00	Young twigs	2.9	0	660	175	0	0	9.2	5.0	0					"
25	Eucalyptus celastroides	T 12 00	Old twigs	2.6	0	230	190	0	0	6.6	4.9	0					"
17	Melaleuca sheathiana	T 12 00	Leaves & twigs	7.1	0	20	75	0	0	8.5	5.3	0					"
92	Melaleuca sheathiana	T 12 00	Roots	6.5	0	500	45	0	0	32.5	2.9	0					"
21	Eucalyptus celastroides	T 12 00	Leaves	3.2	0	800	40	0	0	25.6	1.2	0					"
21	Eucalyptus celastroides	T 12 00	Young twigs	3.1	0	600	100	0	0	18.6	3.1	0					"
91	Eucalyptus celastroides	T 12 00	Roots	8.8	0	190	50	0	0	16.7	4.4	0					"
23	Eucalyptus celastroides	T 12 100N	Leaves	2.9	0	90	115	0	0	8.4	3.3	0	20	45	58		"
23	Eucalyptus celastroides	T 12 100N	Fruit	3.5	0	280	90	0	0	9.8	3.1	0					"

Analyses of unmilled, dry-ashed plant material.
S.Norse series samples.

TABLE V

NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	As	ppm, Oven-dried Pb	Zn	Cu	As	ppm, Soil Pb	Zn	Cu	As	Rock Type
23	Eucalyptus celastroides	T 12 100N	Old twigs	3.1	0	280	125	0	0	8.6	3.8	0	20	45	58	0	Green-stones
15	Melaleuca sheathiana	T 12 100N	Leaves & twigs	6.9	0	130	75	0	0	8.8	5.1	0					"
95	Eucalyptus flocktoniae	T 12 100N	Roots	8.0	0	50	65	0	0	4.0	5.2	0					"
116	Atriplex paludosa	T 12 200N	Leaves & stems	16.1	0	60	35	0	0	9.6	5.6	0	30	80	66	0	"
4	Eucalyptus flocktoniae	T 12 200N	Leaves	3.5	0	280	90	0	0	9.8	3.1	0					"
4	Eucalyptus flocktoniae	T 12 200N	Fruit	4.7	0	190	140	0	0	8.9	6.5	0					"
4	Eucalyptus flocktoniae	T 12 200N	Young twigs	4.0	0	130	125	0	0	5.2	5.0	0					"
4	Eucalyptus flocktoniae	T 12 200N	Old twigs	3.8	0	110	140	0	0	4.1	5.3	0					"
118	Atriplex paludosa	T 12 300N	Leaves & stems	16.4	0	90	50	0	0	14.7	8.1	0	35	70	60	0	"
22	Eucalyptus flocktoniae	T 12 300N	Leaves	2.6	0	130	65	0	0	3.3	1.6	0					"
22	Eucalyptus flocktoniae	T 12 300N	Young twigs	3.3	0	100	75	0	0	3.3	2.4	0					"

Analyses of unmilled, dry-ashed plant material.
S.Norse series samples.

TABLE V cont. NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	As	ppm, Oven-dried Pb	Zn	Cu	As	ppm, Soil Pb	Zn	Cu	As	Rock Type
22	Eucalyptus flocktoniae	T 12 300N	Old twigs	2.8	0	90	80	0	0	2.5	2.2	0	35	70	60	0	Green-stones
14	Melaleuca sheathiana	T 12 400N	Leaves & twigs	5.6	0	130	65	0	0	7.2	3.6	0	45	55	62	0	"
161	Eucalyptus celastroides	T 12 400N	Leaves	3.1	0	460	65	0	0	14.2	2.0	0					"
3	Eucalyptus celastroides	T 12 400N	Young twigs	4.2	0	330	115	0	0	13.8	4.8	0					"
3	Eucalyptus celastroides	T 12 400N	Old twigs	3.4	0	230	60	0	0	7.8	2.0	0					"
53	Eucalyptus flocktoniae	T 12 500N	Leaves	3.2	0	230	75	0	0	11.9	2.4	0	35	55	62	0	"
53	Eucalyptus flocktoniae	T 12 500N	Fruit	5.2	0	230	100	0	0	8.5	5.2	0					"
53	Eucalyptus flocktoniae	T 12 500N	Young twigs	3.7	0	230	75	0	0	8.1	2.7	0					"
53	Eucalyptus flocktoniae	T 12 500N	Old twigs	3.5	0	130	25	0	0	7.3	2.6	0					"
50	Melaleuca sheathiana	T 12 500N	Leaves & twigs	-	0	90	40	0	0	-	-	0					"
16	Melaleuca sheathiana	T 12 600N	Leaves & twigs	7.0	0	130	60	0	0	9.1	4.2	0	20	425	108	50	"

Analyses of unmilled, dry-ashed plant material.
S.Norse series samples.

TABLE V cont. NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	As	ppm, Oven-dried Pb	Zn	Cu	As	ppm, Soil Pb	Zn	Cu	As	Rock Type
107	Atriplex paludosa	T 12 600N	Leaves & stems	18.6	0	50	40	0	0	9.3	7.4	0	20	425	108	50	Green-stones
49	Melaleuca sheathiana	T 12 700N	Leaves & twigs	6.3	0	280	35	0	0	7.8	2.2	0	35	70	58	0	"
114	Atriplex paludosa	T 12 700N	Leaves & stems	19.1	0	80	40	0	0	15.2	7.6	0					"
115	Atriplex paludosa	T 12 800N	Leaves & stems	20.2	0	10	20	0	0	2.0	4.0	0	20	42	62	0	"
171	Melaleuca sheathiana	T 12 900N	Leaves & twigs	7.4	0	100	75	0	0	7.4	5.5	0	28	40	52	0	"
24	Eucalyptus celastroides	T 12 100S	Leaves	2.8	0	660	100	0	0	9.2	2.8	0	20	70	38	0	"
24	Eucalyptus celastroides	T 12 100S	Young twigs	3.4	0	230	95	0	0	7.8	3.2	0					"
24	Eucalyptus celastroides	T 12 100S	Old twigs	3.2	0	330	150	0	0	10.5	4.8	0					"
94	Eucalyptus celastroides	T 12 100S	Roots	9.4	0	100	45	0	0	9.4	4.2	0					"
19	Melaleuca sheathiana	T 12 100S	Leaves & twigs	6.0	0	220	75	0	0	13.2	4.5	0					"
93	Eucalyptus celastroides	T 12 200S	Roots	7.0	0	100	45	0	0	7.0	3.1	0					"

Analyses of unmilled dry-ashed plant material.
S.Norse series samples.

TABLE V cont. NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	As	ppm, Oven-dried Pb	Zn	Cu	As	ppm, Soil Pb	Zn	Cu	As	Rock Type
2	Eucalyptus celastroides	T 12 300S	Leaves	3.1	0	350	75	0	0	10.8	2.3	0	30	55	50	0	Green-stones
2	Eucalyptus celastroides	T 12 300S	Young twigs	3.5	0	280	175	0	0	9.8	6.1	0					"
112	Atriplex paludosa	T 12 300S	Leaves & stems	10.5	0	90	75	0	0	9.4	7.8	0					"
20	Eucalyptus celastroides	T 12 400S	Leaves	3.4	0	260	125	0	0	8.8	4.2	0	20	70	66	0	"
20	Eucalyptus celastroides	T 12 400S	Young twigs	4.5	0	400	175	0	0	18.0	7.8	0					"
20	Eucalyptus celastroides	T 12 400S	Old twigs	3.8	0	400	125	0	0	15.2	4.7	0					"
117	Atriplex paludosa	T 12 400S	Leaves & stems	11.0	0	100	55	0	0	11.0	6.0	0					"
103	Atriplex paludosa	T 12 500S	Leaves & stems	14.3	0	110	65	0	0	15.7	9.2	0	55	130	82	0	"
18	Melaleuca sheathiana	T 12 600S	Leaves & twigs	10.3	0	100	70	0	0	8.6	4.3	0					"
118a	Melaleuca sheathiana	T 12 600S	Roots	6.4	0	460	90	0	0	29.4	5.7	0	20	70	66	0	"
111	Atriplex paludosa	T 12 600S	Leaves & stems	10.3	0	100	70	0	0	10.3	7.2	0					"

Analyses of unmilled, dry-ashed plant material.
S.Norse series samples.

TABLE V cont. NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	As	ppm, Oven-dried Pb	Zn	Cu	As	ppm, Soil Pb	Zn	Cu	As	Rock Type
109	Atriplex paludosa	T 12 700S	Leaves & stems	15.7	0	90	45	0	0	14.1	7.0	0	20	55	58	0	Green-stones
89	Melaleuca sheathiana	T 12 800S	Leaves & twigs	6.7	0	140	45	0	0	9.3	3.0	0	20	40	38	0	"
113	Atriplex paludosa	T 12 900S	Leaves & stems	15.0	0	70	40	0	0	10.5	6.0	0	40	30	38	0	"
86	Atriplex paludosa	T 15 00	Leaves & stems	20.5	0	0	30	0	0	0	6.1	0	45	55	62	10	"
39	Eucalyptus celastroides	T 15 150N	Leaves	3.2	0	130	125	0	0	4.1	4.0	0					"
39	Eucalyptus celastroides	T 15 150N	Fruit	3.6	0	80	125	0	0	2.8	4.4	0					"
39	Eucalyptus celastroides	T 15 150N	Young twigs	4.2	0	90	225	0	0	3.7	9.4	0					"
39	Eucalyptus celastroides	T 15 150N	Old twigs	3.3	0	80	200	0	0	2.6	6.6	0					"
35	Melaleuca sheathiana	T 15 200N	Leaves & twigs	7.7	0	30	45	0	0	2.3	3.4	0	25	60	66	0	"
81	Atriplex paludosa	T 15 200N	Leaves & stems	21.0	0	10	35	0	0	2.1	7.3	0					"
34	Melaleuca sheathiana	T 15 400N	Leaves & twigs	7.1	0	0	65	0	0	0	4.6	0	35	70	78	0	"

Analyses of unmilled, dry-ashed plant material.
S.Norse series samples.

TABLE V cont. NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	As	ppm, Oven-dried Pb	Zn	Cu	As	ppm, Soil Pb	Zn	Cu	As	Rock Type
164	Atriplex paludosa	T 15 400N	Leaves & stems	19.7	0	30	40	0	0	5.9	7.8	0	35	70	78	0	Greenstones
33	Melaleuca sheathiana	T 15 500N	Leaves & stems	7.6	0	10	65	0	0	0.7	4.9	0	35	35	58	0	"
160	Melaleuca sheathiana	T 15 600N	Leaves & twigs	7.4	0	120	60	0	0	8.8	4.4	0	25	52	60	0	"
80	Atriplex paludosa	T 15 700N	Leaves & stems	17.5	0	30	40	0	0	5.2	7.0	0	35	55	60	0	"
162	Melaleuca sheathiana	T 15 800N	Leaves & twigs	6.6	0	130	100	0	0	8.5	6.6	0	20	52	50	0	"
163	Melaleuca sheathiana	T 15 900N	Leaves & twigs	9.0	0	130	65	0	0	11.7	5.8	0	30	55	60	0	"
28	Melaleuca sheathiana	T 15 100S	Leaves & twigs	5.6	0	30	25	0	0	1.6	1.4	0	25	70	52	0	"
159	Atriplex paludosa	T 15 100S	Leaves & stems	14.9	0	60	0	0	0	8.9	0	0	25	70	52	0	"
29	Melaleuca sheathiana	T 15 200S	Leaves & twigs	6.0	0	90	35	0	0	5.4	2.1	0	35	45	58	0	"
83	Atriplex paludosa	T 15 200S	Leaves & stems	18.5	0	30	40	0	0	5.5	7.4	0					"
30	Melaleuca sheathiana	T 15 300S	Leaves & twigs	6.1	0	50	45	0	0	2.0	1.8	0	35	80	66	0	"

Analyses of unmilled, dry-ashed plant material.
S.Norse series samples.

TABLE V cont. NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	As	ppm, Oven-dried Pb	Zn	Cu	As	ppm, Soil Pb	Zn	Cu	As	Rock Type
85	Atriplex paludosa	T 15 400S	Leaves & stems	19.5	0	10	35	0	0	1.9	6.8	0	30	55	60	0	Green-stones
31	Melaleuca sheathiana	T 15 500S	Leaves & twigs	5.6	0	70	35	0	0	3.9	1.9	0	45	45	62	0	"
32	Melaleuca sheathiana	T 15 600S	Leaves & twigs	6.3	0	0	40	0	0	0	2.5	0	45	45	60	0	"
78	Atriplex paludosa	T 15 600S	Leaves & stems	19.4	0	30	35	0	0	5.8	6.7	0					"
40	Eucalyptus celastroides	T 15 650S	Leaves	3.6	0	230	65	0	0	8.2	2.1	0					"
40	Eucalyptus celastroides	T 15 650S	Young twigs	4.6	0	130	75	0	0	5.9	3.4	0					"
40	Eucalyptus celastroides	T 15 650S	Old twigs	4.3	0	90	75	0	0	3.8	3.2	0					"
36	Eucalyptus flocktoniae	T 15 650S	Young twigs	5.2	0	80	45	0	0	4.1	2.3	0					"
36	Eucalyptus flocktoniae	T 15 650S	Old twigs	4.7	0	30	50	0	0	1.4	2.3	0					"
87	Atriplex paludosa	T 15 700S	Leaves & stems	20.4	0	0	30	0	0	0	6.1	0	45	30	85	0	"
79	Atriplex paludosa	T 15 800S	Leaves & stems	20.4	0	0	20	0	0	0	4.0	0	45	55	60	0	"

Analyses of unmilled, dry-ashed plant material.
S.Norse series samples.

TABLE V cont. NORSEMAN

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	As	ppm, Oven-dried Pb	Zn	Cu	As	ppm, Soil Pb	Zn	Cu	As	Rock Type
88	Melaleuca sheathiana	T 15 900S	Leaves & twigs	5.9	0	100	90	0	0	5.9	5.3	0	30	55	40	0	Green-stones
90	Melaleuca sheathiana	T 15 1000S	Leaves & twigs	8.5	0	130	70	0	0	11.0	5.9	0	30	55	66	0	"
82	Atriplex paludosa	T 15 1100S	Leaves & stems	22.0	0	40	35	0	0	8.8	7.7	0	30	70	40	0	"
105	Atriplex paludosa	T 26 00	Leaves & stems	16.5	0	90	45	0	0	14.8	7.4	0	30	70	70	0	"
97	Atriplex paludosa	T 26 200N	Leaves & stems	19.6	0	10	45	0	0	1.9	8.8	0	30	55	52	0	"
100	Atriplex paludosa	T 26 500N	Leaves & stems	19.4	0	80	45	0	0	15.5	8.7	0	40	55	62	0	"
102	Atriplex paludosa	T 26 600N	Leaves & stems	21.8	0	50	35	0	0	10.9	7.6	0	20	45	50	0	"
98	Atriplex paludosa	T 26 700N	Leaves & stems	16.2	0	30	45	0	0	4.8	7.2	0	20	70	70	0	"
104	Atriplex paludosa	T 26 100S	Leaves & stems	14.2	0	130	70	0	0	18.4	9.9	0	30	70	88	0	"
106	Atriplex paludosa	T 26 200S	Leaves & stems	18.2	0	80	50	0	0	14.5	9.1	0	20	42	52	0	"
99	Atriplex paludosa	T 26 300S	Leaves & stems	15.2	0	60	45	0	0	9.1	6.8	0	28	45	70	0	"

Analyses of unmilled, dry-ashed plant material.
S.Norse series samples.

TABLE V cont. NORSEMAN

PART 4

THE COOLGARDIE - KALGOORLIE AREA

1. Climate

The mean maximum temperature for Coolgardie for the year is 77.0°F. and the mean minimum temperature is 52.1°F. (Table VI). January is the hottest month, with a mean maximum of 91.9°F. February is also hot, but by March the days are becoming noticeably shorter and the mean maximum has fallen to 84.8°F. July is the coldest month, the mean maximum being 61.0°F. and the minimum 41.3°F. By September the temperatures often exceed 70.0°F. and by December the hot weather has set in again.

The mean maximum and minimum temperatures for Kalgoorlie slightly exceed those for Coolgardie (Table VII), the figures for the year being 78.2°F. and 53.7°F respectively.

Rainfall broadly follows the pattern set out for the Eastern Goldfields (Part 1, section 1), being generally unreliable and irregular from year to year, with scarcely any correspondence between the same months of different years. Sometimes dry spells may occur and may last for up to three or four years. Some of the winter rainfall may be experienced as drizzle, as well as heavy downpours, the summer falls coming mainly as thunderstorms. Exceptionally heavy rains have been known to occur, such as those during February 1948, when twelve inches were recorded at Coolgardie in twenty four hours. The rain temporarily filled the dry lakes and caused pronounced erosion. Heavy falls were also experienced on January 23, 1967, when over six inches (608 points) were recorded in Kalgoorlie. However, surface water never remains for long, owing to the high rates of evaporation, the mean annual figure for which is 84 inches at Coolgardie.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean maximum	91.9	90.7	84.8	76.9	65.5	62.0	61.0	64.4	71.6	77.2	85.0	90.3	77.0
Mean minimum	62.5	62.4	59.1	53.4	47.4	43.5	41.3	42.5	46.2	50.4	56.2	60.5	52.1

Temperature (degrees F.).
No of years of record = 44.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average annual
Monthly average for 52 years	53	77	104	100	119	114	88	104	60	77	64	71	1,037

Average monthly rainfall, (points).

Data supplied by the Deputy Director, Commonwealth Weather Bureau, Perth, W.A.

TABLE VI CLIMATIC DATA FOR COOLGARDIE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean maximum temperature °F	93.4	91.8	85.8	78.3	69.2	63.0	62.1	65.6	71.7	78.5	86.9	91.6	78.2
Mean minimum temperature °F	64.0	64.0	60.5	55.1	48.6	45.0	42.6	44.0	47.8	52.2	58.4	62.4	53.7
Relative humidity 9 am	46	49	55	59	66	74	74	66	53	48	44	43	56
Relative humidity 3 pm	27	30	34	39	46	52	50	44	34	31	28	27	37
Rainfall (points)	57	65	109	86	112	107	83	95	45	70	56	66	951
Evaporation (points)	1270	985	750	527	326	232	250	315	500	719	980	1240	8094

Data supplied by the C.S.I.R.O.

TABLE VII CLIMATIC DATA FOR KALGOORLIE

2. Geology

The Coolgardie-Kalgoorlie area, lying within the area of Precambrian rocks of Western Australia, consists essentially of two series of basic igneous rocks, the older and younger greenstone series. Kalgoorlie is the type area of the Precambrian greenstones described by the Western Australian Geological Survey as the Kalgoorlie Series. Extensive invasion by granite is characteristic of the Kalgoorlie Series in most parts of the State, but there is no granite in the immediate vicinity of Kalgoorlie, and the nearest occurrence is at Mungari. Larger areas of granite occur to the north and west of Coolgardie. A detailed account of the geology of the Coolgardie area is given first; this is followed by a consideration of the Kalgoorlie area.

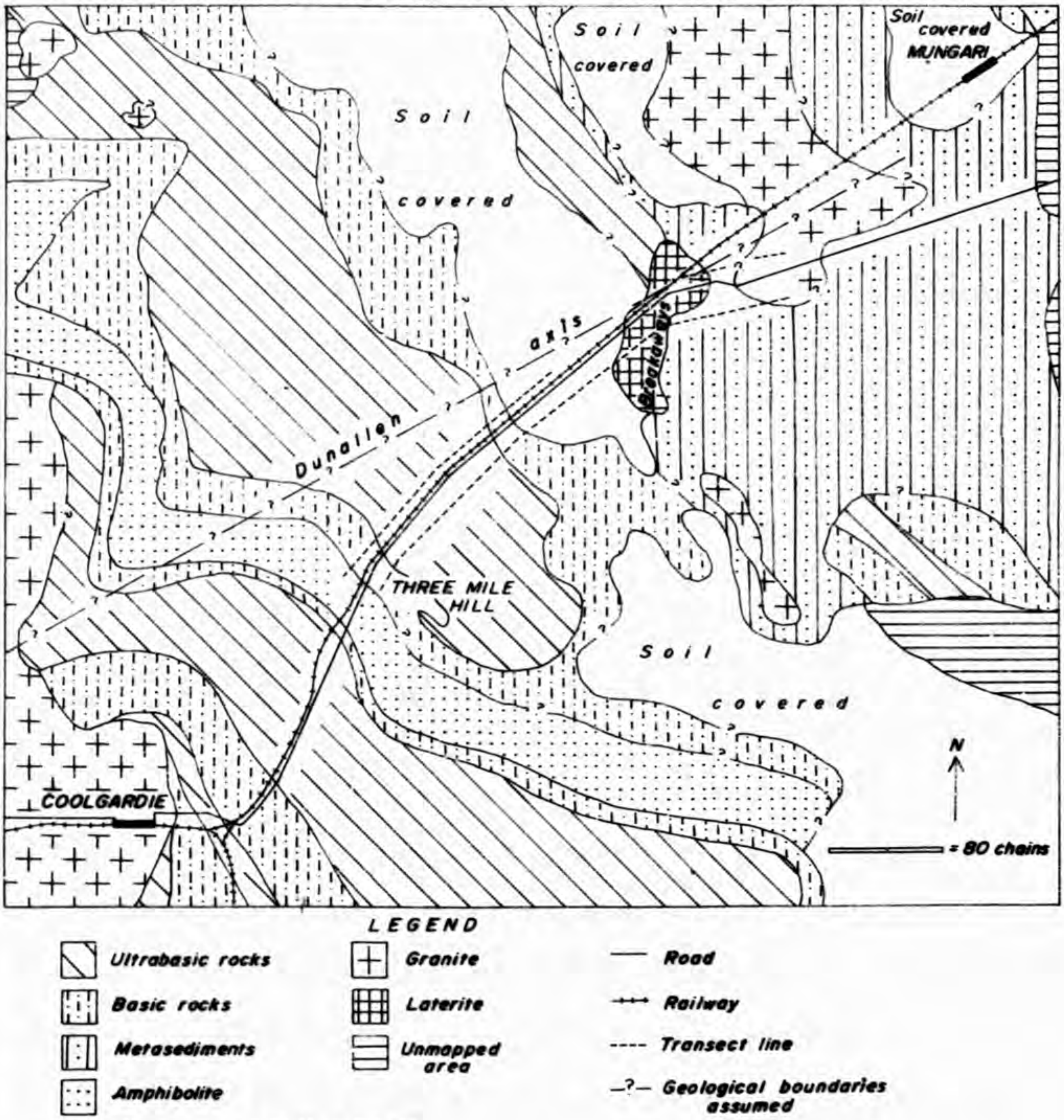
Three major lithological elements are apparent in the Coolgardie area (Figure 26); folded and metamorphosed igneous and sedimentary rocks; granites and gneisses; and Tertiary to Recent lacustrine and aeolian deposits, laterites and alluvium (McMath 1953).

The folded and metamorphosed rocks can be divided into older and younger greenstones and metasediments, which may be tentatively correlated with the whitestones.

These make up the Yilgarn-Kalgoorlie System which is assumed to be Precambrian in age.

Within the Coolgardie district the older greenstones occur in a belt passing from the north of the township through Coolgardie and Londonderry to the Nepean outlier south-west of Londonderry. There is also a western extension of these rocks occupying the Gibraltar-Gnarlbine-Mercer's Find triangle. They are composed of basic and ultrabasic igneous rocks. In detail, the basic rocks consist of fine- to medium-grained igneous rocks, breccias and agglomerates, amygdaloidal, porphyritic and pillow lavas. There is an example of pillow lavas at the Gorge, one and a half miles south-south-east of Coolgardie, and thin horizons of graphitic schists and slates may be found. The basic lavas have undergone a low grade regional metamorphism and are relatively hard compact rocks. In this respect they form a contrast with the ultrabasic rocks which are often softer and well-jointed, and this has contributed to the ultrabasics forming the most favoured host rocks for gold mineralisation in the Coolgardie district. The ultrabasic rocks consist of actinolite, actinolite-tremolite, anthophyllite rocks and schists, fuchsite schists and serpentine.

GEOLOGICAL MAP OF THE THREE MILE HILL - MUNGARI AREA, COOLGARDIE



After Matheson and McMath (1953)

Figure 26

The basic and ultrabasic rocks form alternating belts in the district.

The metasedimentary series immediately overlie the older greenstones, and possibly belong to the whitestone series of the Yilgarn goldfield. They occur by Mungari, and to the west of Coolgardie by Bullabulling. They include slates, schists, grits and quartzites. They are unimportant as gold-bearing rocks, probably owing to their higher stratigraphic position, lying at a possible vertical limit of gold mineralisation; gold production from these rocks has been small, and confined to a very limited zone centred about Mungari.

The greenstones and metasediments have been intruded by a series of basic igneous sills and dykes which seem to show a relation to the younger greenstones of the Kalgoorlie Series. They occur in the Mungari locality and at Gibraltar, amongst other places. The metagabbros found in the Coolgardie district are included in these later basic rocks, and in certain areas, such as Three Mile Hill, sulphide mineralisation has occurred together with gold mineralisation, although the tenor of the ore is generally low.

The greenstones and metasediments have also been invaded by acid rocks which comprise minor porphyritic sills and dykes, major granite intrusives, aplitic rocks, pegmatites and quartz veins.

The porphyries are the oldest of these acid intrusives, apparently confined to the older greenstones. They usually occur as sills and have been regionally folded, sheared and jointed.

The granites comprise magmatic granites, for example, those at Mungari and Bullabulling, and granitoid gneisses which tend to form flat pavements. Examples of granitoid gneisses occur at Yellari and Nepean. Most of the major granites, apart from that at Mungari, are confined to the central and western parts of the area.

The youngest of these acid igneous rocks are the aplitic and alaskitic dykes, pegmatites, and quartz veins. The aplitic rocks form small dykes in the older greenstones and may be closely associated with gold and sulphide mineralisation. They occur at Gibraltar and Bonnie Vale. The pegmatites generally occur as dykes, ranging in width from four inches to about thirty feet. They may carry a wide diversity of minerals, such as feldspar, lithium and beryllium. Those containing minerals have only been recorded from the older greenstones, while those devoid of mineralisation are almost invariably associated with gneiss and granite.

Quartz veins are widely distributed, and vary from fine films to reefs and large quartz blows, such as the "Big Blow" a mile north of Tindal's Gold Mine. The reefs are lenticular masses of quartz enclosed by rocks of either the older greenstones or metasediments, although they occur more commonly in the older greenstones. At the Lord Bob's and Bonnie Vale gold mining centres the reefs occur in the margins of intrusive granites, but these are exceptional cases. Many of the quartz veins contain gold and have formed the ore bodies in a number of mines in the district. The gold occurs in the free state or associated with such metallic sulphides as pyrites, arseno-pyrites and pyrrhotite. The mineral associations with auriferous quartz include compounds of the elements iron, arsenic, bismuth, copper, zinc, lead, molybdenum, tungsten, vanadium and silver. Other than gold few minerals occur in quantities of economic importance, although some pegmatites have been worked, such as those occurring at Londonderry. Here the main mineral assemblage is microcline, lepidolite, petalite, beryl, columbite, biotite, topaz and albite. Today only microcline is quarried, although in the past occasional parcels of beryl, columbite and petalite were obtained.

Superficial recent deposits occur over a large part of the Coolgardie district and as they consist of residual and transported soils and laterites they are considered in detail in a following section on soils.

Many of these rock types occur around Kalgoorlie. The Kalgoorlie Series is composed mainly of basaltic lavas, pillow lavas, tuffs and thin bands of sediments. These comprise the older greenstones. They have been invaded by an intrusive sill of quartz-dolerite belonging to the younger greenstones. Many acid and basic porphyry dykes intrude these rocks, but occur mainly in the younger greenstones. Some of these dykes are up to a hundred feet wide, but many are less than ten feet. Ancient sediments, the Black Flag Beds, lie on the east side of the Kalgoorlie goldfield, and a series of porphyritic rocks occurs along its western margin. The region has been subjected to greenschist facies metamorphism, converting some of the older igneous rocks into chlorite, talc and chloritoid schists. Superimposed on this regional metamorphism are local phases of metasomatic metamorphism, producing bleached greenstones and bleached dykes and calc-schists, which is the local name for highly carbonated rocks.

The Black Flag Beds form the uppermost horizon in the rock succession at Kalgoorlie. They are approximately 10,000 feet thick, and consist of tuffs, acid to intermediate lavas and agglomerate, sandstone, shale, slate and quartzite. They are characterised by porphyritization.

Various greenstone horizons underlie the Black Flag Beds. The uppermost is the Golden Mile dolerite, a sill of meta-quartz dolerite and meta-quartz gabbro, with smaller more basic sections. The main gold ore bodies occur here.

The second greenstone horizon forms the Paringa basalt, of meta-basaltic lavas with many bands of pillow lavas. Tuffaceous bands between lava flows may contain thin slate bands, many of which show poorly auriferous pyrite. Some of these pyritised slates have been converted into haematite quartzites or banded iron formations. The metamorphism to which these lavas have been subjected has produced secondary amphibolites, mainly actinolite. The uppermost part of this horizon has been brecciated and highly carbonated, and the whole horizon is sometimes called calc-schist.

The Paringa basalt is underlain by the Williamstown dolerite, a sill of meta-dolerite and meta-gabbro, transitional to meta-quartz dolerite near the top and becoming a more basic hornblendite at its base.

A narrow band of graphitic slate, the Kapai slate, approximately ten feet thick, separates the Williamstown dolerite from the Devon Consols basalt. This consists of meta-basaltic lavas, typically pillow lavas, approximately two hundred to five hundred feet thick.

Hannan's Lake serpentinite forms the lowest of the rock units in the succession, consisting of 1,000 to 3,000 feet of massive fine-grained serpentinite.

The area of the Golden Mile consists of anticlines and synclines. The most important economic gold deposits come from the Kalgoorlie syncline where the Black Flag Beds are tightly infolded. The Golden Mile dolerite is the most productive unit but some mineralisation also occurs in the Paringa basalt, which has been bleached to a quartz-carbonate-sericite rock in the main productive area of the Golden Mile. Two types of gold mineralisation are found. The Kalgoorlie lode formations are the most important, carrying free gold and gold tellurides. The lodes have no definite boundaries and the gold may pass out gradually in decreasing concentrations into the country rock. Most of the main lodes are more or less lenticular in shape, but there may be considerable variation in the width of a lode over a short distance.

The second type of gold mineralisation contains no tellurides and more quartz is present. It is of minor importance in comparison with the gold-telluride mineralisation. The gold-quartz type ore occurs as stockworks of quartz veins, as at Mt. Charlotte, or as replacement type lodes along shears. Both gold-telluride and gold-quartz mineralisation occur only in chloritised host rocks.

3. Physiography

The area is situated on the great inland plateau of Western Australia and, consequently, the topography is gently undulating with occasional areas of higher ground. Coolgardie itself is centred in a median belt of low hills which rarely rises over 300 feet above the surrounding country. Eight miles north of the town stands Mt. Burges, rising as a flat-topped hill from the general level of the country, and providing one of the best examples of a mesa in the Coolgardie district. Further eastwards is the Mt. Robinson hill group. Other relief features constitute ridges of higher ground, often composed of lavas, with scree covered slopes.

The Kalgoorlie district has no particularly outstanding features of relief. A low broad ridge, whose average height is about 100 feet above the surrounding countryside, extends from the Golden Mile, lying at its southern end, for a distance of about four miles, the northern continuation of the ridge being known as the North End. The ridge is accentuated by a line of low hills which includes Maritana Hill, Mt. Charlotte, Hannan's Hill, Cassidy's Hill and Mt. Gleddon, the highest of these, standing at 1378 feet above sea level.

There are a number of breakaways in the area, one of the best examples being that situated approximately seven miles north-east of Coolgardie. The steep scarp face, over thirty feet high in places, links the surfaces of the Old and New Plateaux. Smaller, less pronounced breakaways may be found in various parts of this area, including those lying sixteen miles north of Kalgoorlie on the Menzies road, and others to the south of Mt. Hunt on the Kambalda road.

In the immediate Coolgardie-Kalgoorlie area there are no major salt lakes, although the area has its share of smaller lakes and clay pans. Brown Lake lies in the Mt. Robinson hill group, while Hannan's Lake lies to the east of Mt. Hunt. The Gidgee Lakes are situated to the north of Kalgoorlie, while to the east, beyond Bulong, is Lake Yindarlgooda. These lakes form local base levels for drainage. Valleys tend to be broad and wide, and filled with alluvium. Small creeks, only a few feet in depth and width, occur throughout the area, forming run-off channels from the areas of sloping and higher ground.

4. Soils

The main soil types considered in Part 1, section 4, occur within this area. Ridges and areas of higher ground, which are often formed by the basic lavas of the older greenstones, have weathered to produce much angular scree, usually coated with hydrated iron oxides and sometimes with travertine. Soils developed in these localities are consequently skeletal. They are yellowish red in colour (5YR 4/6) and there may be much lime present; the highest pH recorded in such soils was 9.7.

Solonised brown soils occur in the lower, flatter parts of the area. They are also a yellowish red colour and have a pH which is alkaline in reaction, values averaging about 8.5. The A horizon contains varying proportions of clay. Sometimes the surface soil may show cracking, and patches of gilgai also occur. The crests and hollows of this form of micro-relief are developed to various degrees but the vertical extension is not usually greater than about two feet. The B horizon also contains a fairly high proportion of clay, and sometimes shows a certain degree of mottling from inclusions of white magnesite, such inclusions varying in diameter from under one to over six inches. The high lime content of these soils and the present climatic conditions, whereby evaporation rates exceed rainfall, often lead to the precipitation of sheets of travertine at the surface, or else to the formation of calcareous nodules. Such cements may bind surface rubble and scree, and although widely distributed are seldom of great extent.

Lateritic soils are fairly widely distributed. They occur where there are remains of the Old Plateau surface, such as on mesas and at breakaways, where the lateritic profile is exposed on the scarp face. The best example of this profile occurs at the breakaway situated about seven miles north-east of Coolgardie, about a quarter of a mile east from the road. The A horizon has been removed, and the B horizon is formed of indurated laterite, approximately eight inches thick. Below the lateritic horizon is a highly mottled zone, with blue-grey and red mottles within the white kaolin. This passes into the kaolinised C horizon. Hills and ridges in the area may have lateritic cappings. The nature of the laterites varies with the underlying rock. Ferruginous types have developed over the greenstones, while aluminous types are associated with the granitoid rocks and metasediments. In most areas of sediments hard laterite caps are not developed and their place is commonly taken by haematite gravel scree, locally known as desert varnish. Haematite gravel occurs as a veneer in several places in the area, usually on broad flats where it may occur with weathered quartz.

Alluvial soils occur in drainage channels and in the salinas, where they may be associated with lacustrine deposits such as aeolian dunes composed of kopai or sand, the dunes situated particularly along the east and south-east margins of the salt lakes.

5. Vegetation

The vegetation formation developed in this area is characteristically open *Eucalyptus* woodland, its species composition changing from one locality to another as environmental conditions alter. *Eucalyptus campaspe* is the dominant tree in certain localities around Coolgardie, and here the height and density of the woodland is characteristically low and its composition relatively simple. *Atriplex paludosa* is the only widespread species in the shrub layer, forming a low dense understorey beneath the trees.

Contrasting in form are the areas of woodland dominated by *Eucalyptus salmonophloia* and *E. transcontinentalis*. Both these species differ in habit from *E. campaspe*, having taller, straighter trunks and different coloured bark and foliage. The shrub layer associated with these trees has a low density and is composed predominantly of *Exocarpus aphylla*, *Eremophila interstans* and *Atriplex paludosa*.

Low shrub associations dominated by *Acacia acuminata* occur over limited areas, the *Acacia* species occasionally forming small patches of fairly dense thicket and being associated with *Eremophila granitica* and/or *E. ?gibsoni* and Ptilotus obovatus. Acacia quadrimarginea is also moderately common in restricted localities of the area. It is usually associated with Eremophila duttoni or Eremophila sp. J.B./W.A. III, Dodonaea lobulata or D. boroniaefolia, and P. obovatus; Helipterum adpressum and Prostanthera wilkieana are sometimes associated with these species.

Patches of more open country occur in certain areas. For example, about six miles north of Kalgoorlie the tree stratum in the association assumes less importance. Eucalypts may still grow, but their density is low. Casuarina species are present, and Eremophila interstans, Acacia graffiana, Cratystylis sp. and Atriplex paludosa form the shrub layer.

Sandplains occur within the area. The vegetation supported here is characteristically one of dense and varied shrub species, the shrubs forming a more important stratum than do the trees, which usually grow very infrequently. During the springtime the flowering Verticordia, Wehlia, Thryptomene and other species transform these areas to some of the most colourful in the region. Triodia may grow on the sandplains but is not limited to this type of habitat; it also grows near Mt. Robinson, at Mt. Hunt and in other scattered localities.

Halophytic floras occur in areas of salinity, such as is found to the east of Mt. Hunt near Hannan's Lake. Trees usually become rare, restricted to local areas of higher ground, and communities develop dominated by such salt-tolerant plants as *Atriplex paludosa*, *Frankenia interioris*, *Arthrocnemum halocnemoides*, and *Disphyma australe*.

6. Areas of detailed field study

(A) THE THREE MILE HILL - MUNGARI AREA, COOLGARDIE

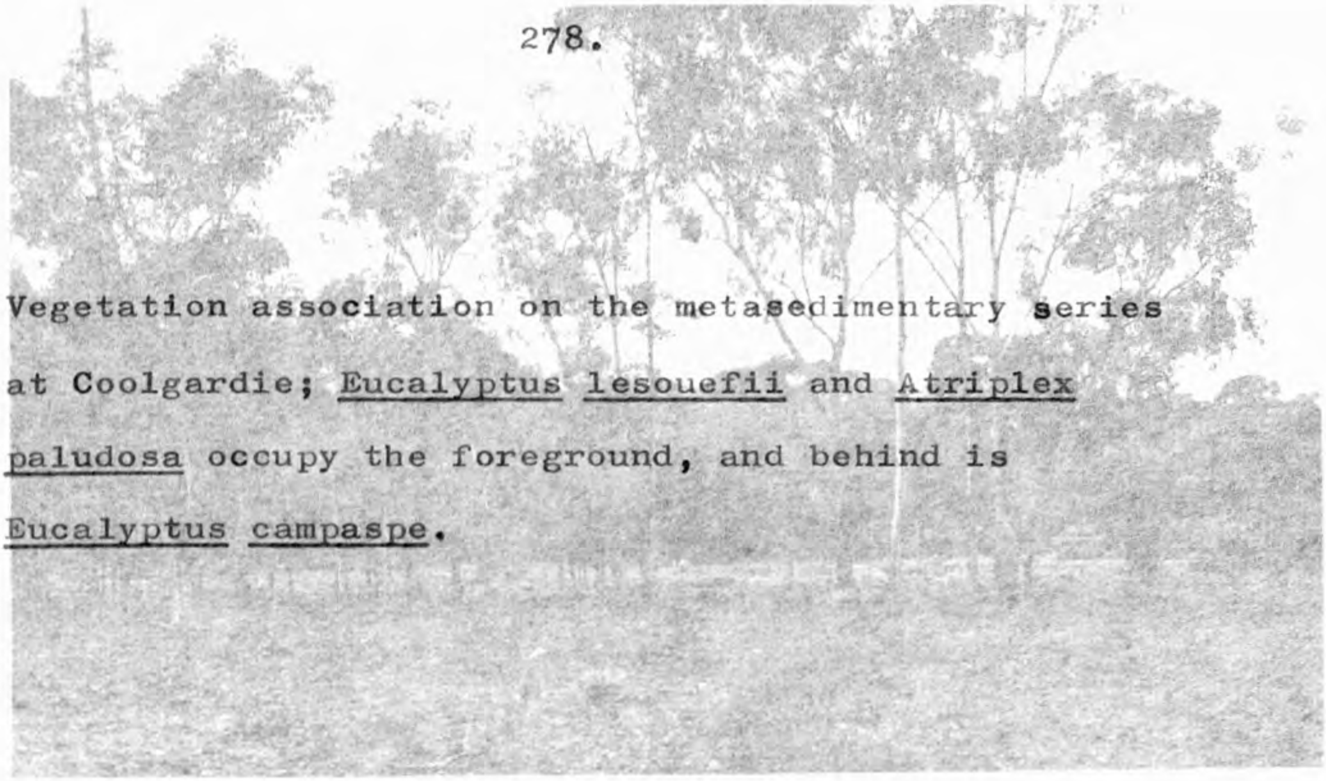
1. The Distribution of the vegetation assocations

The area studied covers a distance of almost four and a half miles, extending from the Three Mile Hill, three miles north-east of Coolgardie, to the Mungari granite, lying in the vicinity of Mungari railway station which is situated further north-east in the direction of Kalgoorlie. This area was the largest examined in detail during the field work, yet the number of different vegetation associations here is fewer than in other smaller localities.

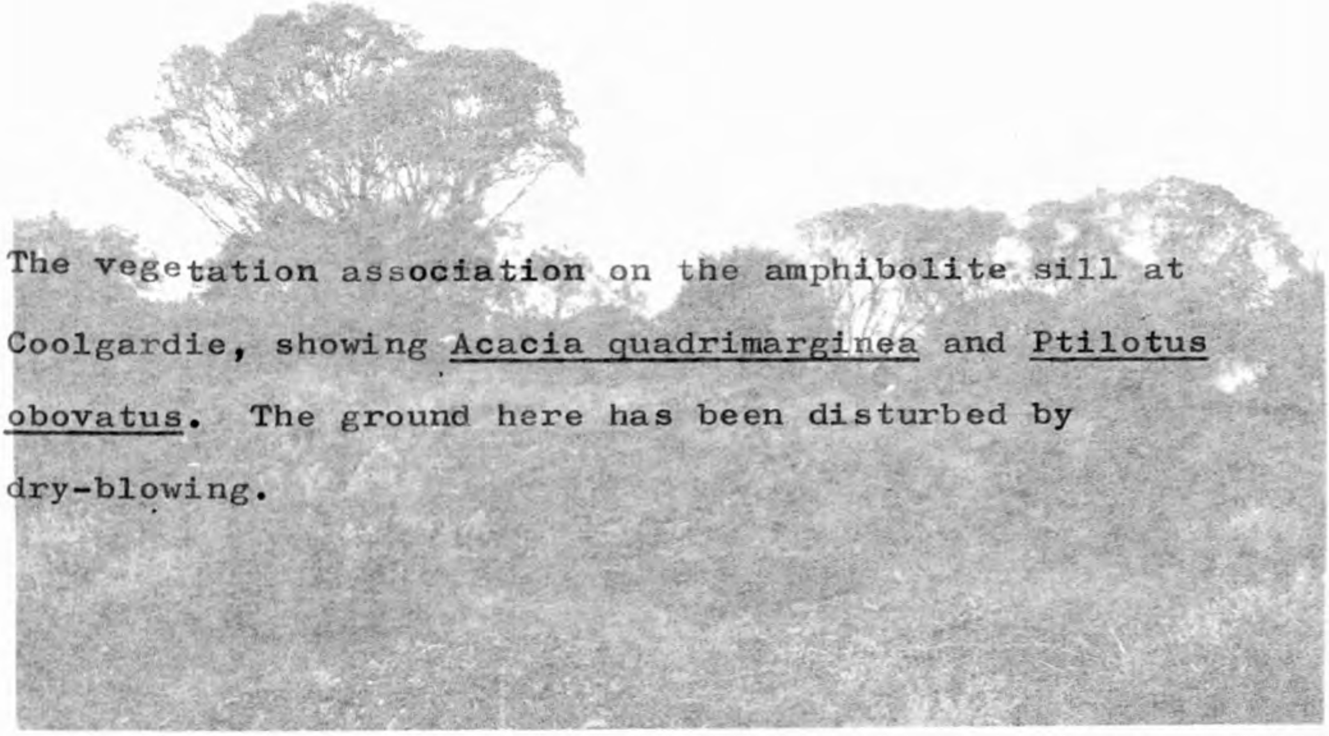
On the west side of Three Mile Hill is an association dominated by Acacia quadrimarginea, Dodonaea lobulata, Eremophila duttoni and Ptilotus obovatus. Other shrubs, including Eremophila interstans, Cassia eremophila, Scaevola spinescens and Rhagodia gaudichaudiana, occur in low numbers (Plate 7). This association extends beyond the Hill in a north-west south-east direction to follow the line of the amphibolite sill here, remaining constant except where crossed by the Dunallen axis where a porphyry sill is exposed. During the late winter and early spring ephemerals grow profusely within the association. Helipterum chlorocephalum and Cephalipterum drummondii cover areas of ground with carpets of white flowers, while the small red everlasting daisy, H. rubellum, also occurs.

The association on the north-east slopes of Three Mile Hill contrasts with the adjacent association considered above in its poor diversity and in the presence of Eucalypts. It is dominated by Eucalyptus campaspe, while E. celastroides and E. lesouefii occur occasionally (Plate 8). (E. lesouefii enters the association as a co-dominant species further north from the Three Mile Hill). Tree density is not especially high and the tree layer does not possess great height, E. campaspe averaging about twenty five feet. Atriplex paludosa is the most important shrub, usually attaining a high density, while Bassia patenticuspis is also very common. The ground flora, observed during late winter, was composed of Erodium circutarium, E. cygnorum, Plantago varia, Helipterum rubellum and Cephalipterum drummondii, growing with a thick density in the clay loam. Hordeum leporinum was the only common grass species, occurring only in the more open areas where tree growth is sparser.

The association changes abruptly at the north-east side of the Three Mile Hill, where relief becomes flatter. Tree and shrub species grow in new and greater variety and with a high density. Eucalyptus foecunda, the dominant Eucalypt, forms an immediate contrast with E. campaspe, for it has a graceful mallee form, the pale coloured trunks crowned with bright green leaves. E. foecunda averages about thirty five feet in height, and in certain areas is joined by E. lesouefii, one of the Goldfield's blackbutts. Eremophila interstans, Cassia eremophila and Atriplex paludosa are the most common species in the shrub layer (Plate 9), and occurring with them are a number of species of lower frequency but wide distribution in this association. Such shrubs include Eremophila duttoni, Dodonaea lobulata, Lycium australe, Eremophila glabra, Scaevola spinescens, Acacia erinacea, Eremophila weldii and Olearia muelleri. The sandalwood, Santalum spicatum, occurs as isolated specimens scattered throughout the association. It is a root parasite and its frequency is limited by the extent to which other plants can support it; hence its scattered occurrence (Brockway 1949). The ephemeral species of the ground flora are not well represented in this association, possibly owing to the greater competition from trees and shrubs, which grow in greater densities here than in the

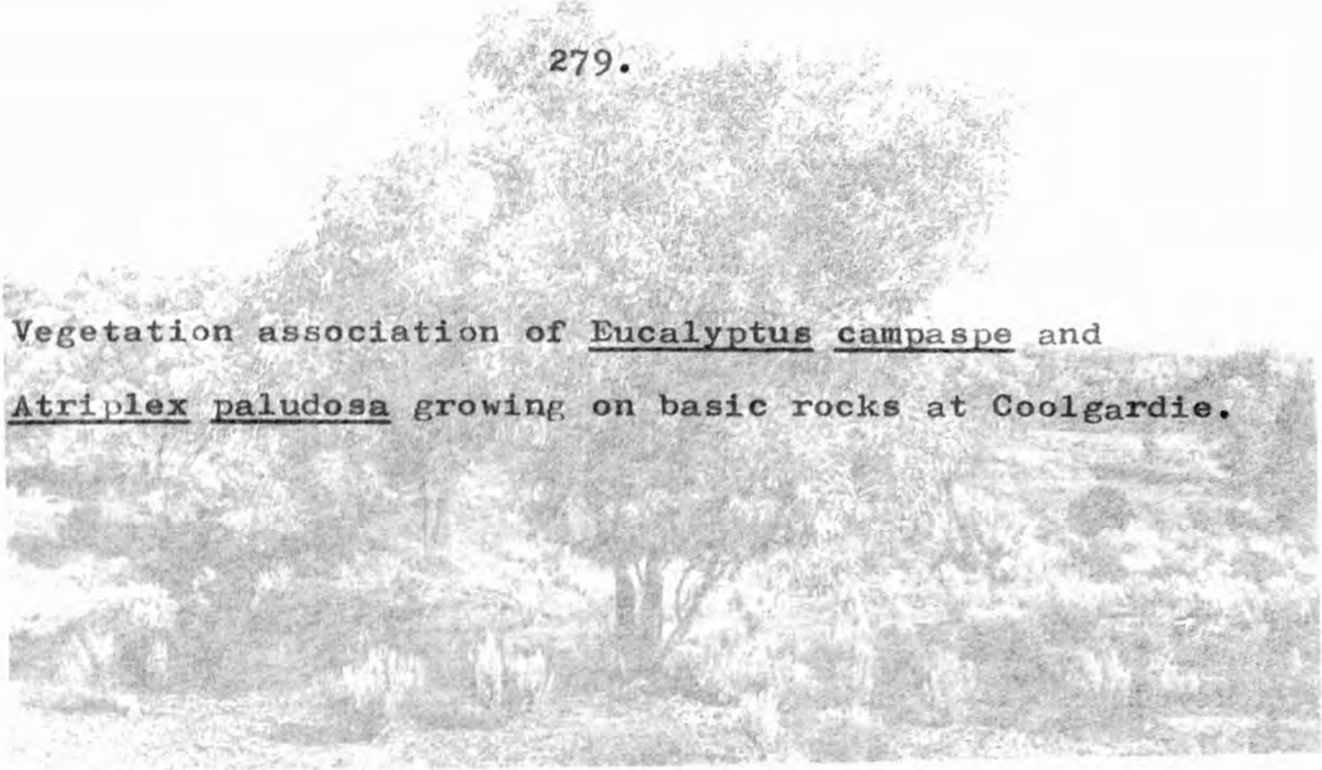


Vegetation association on the metasedimentary series at Coolgardie; Eucalyptus lesouefii and Atriplex paludosa occupy the foreground, and behind is Eucalyptus campaspe.

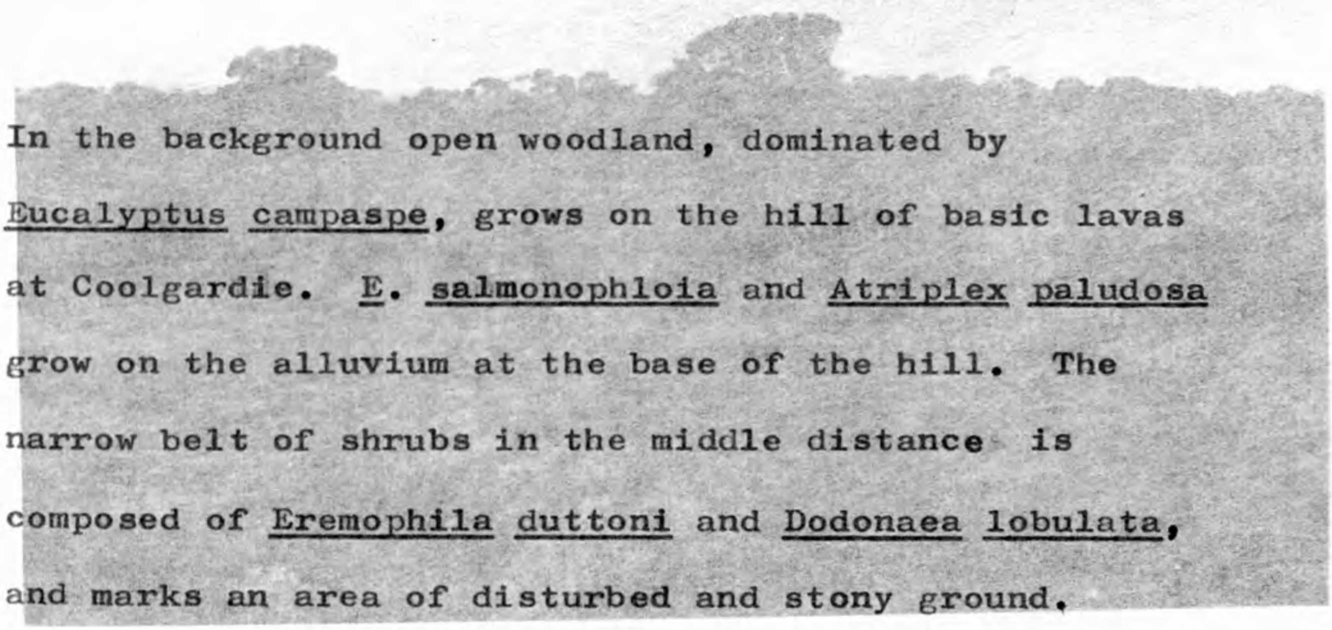


The vegetation association on the amphibolite sill at Coolgardie, showing Acacia quadrimarginea and Ptilotus obovatus. The ground here has been disturbed by dry-blowing.

Plate 7

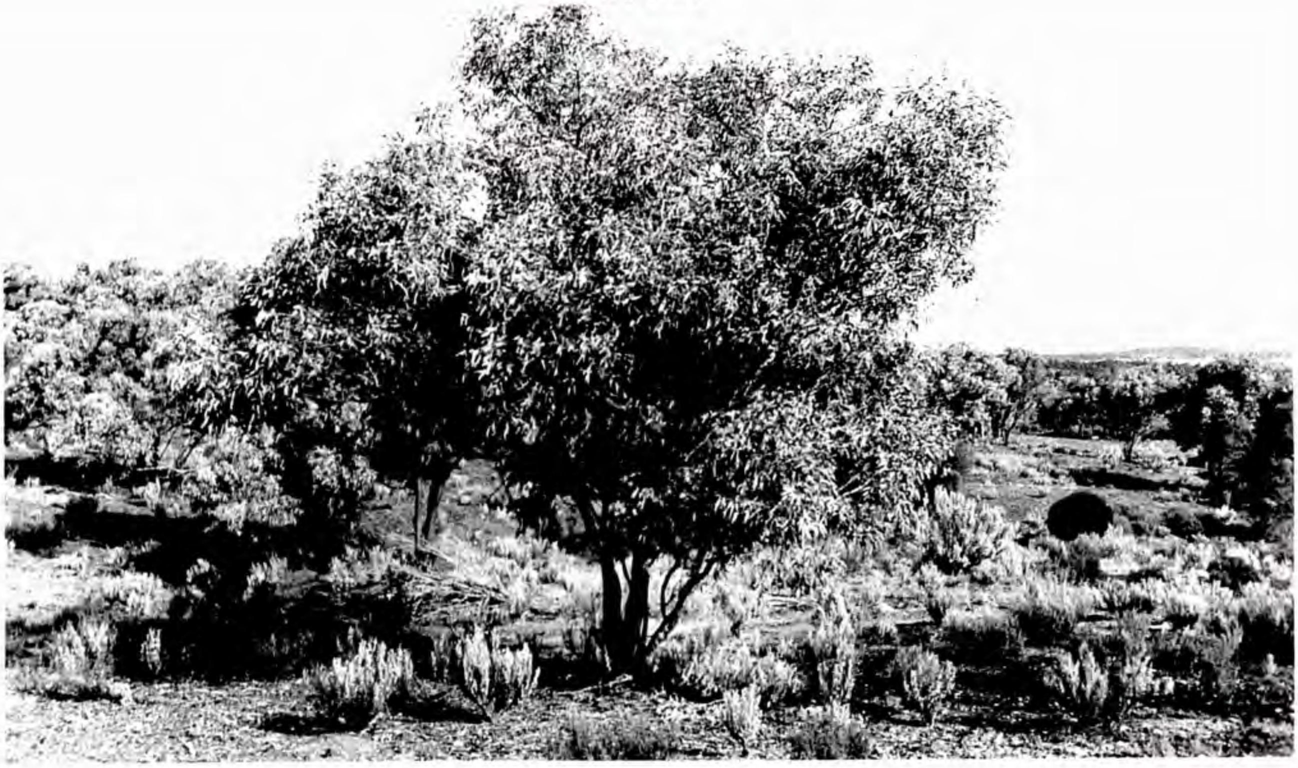


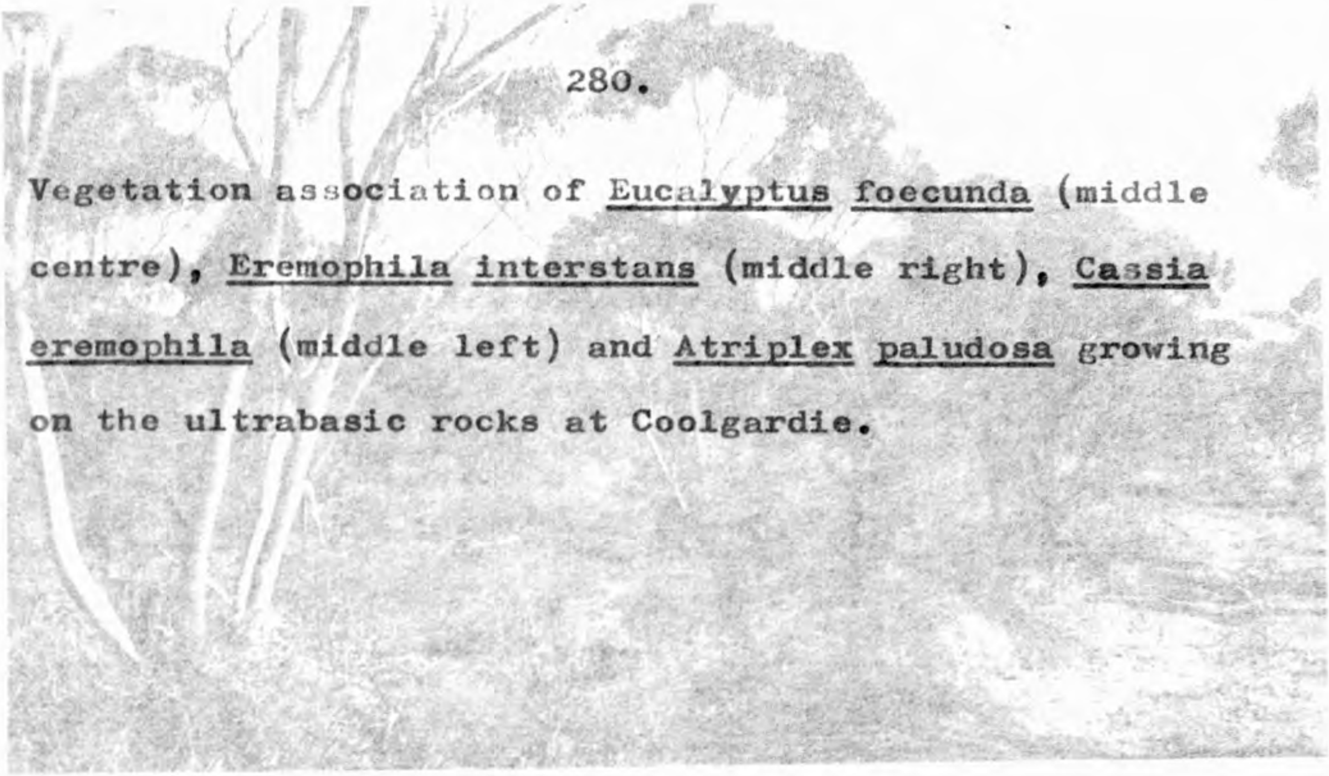
Vegetation association of Eucalyptus campaspe and Atriplex paludosa growing on basic rocks at Coolgardie.



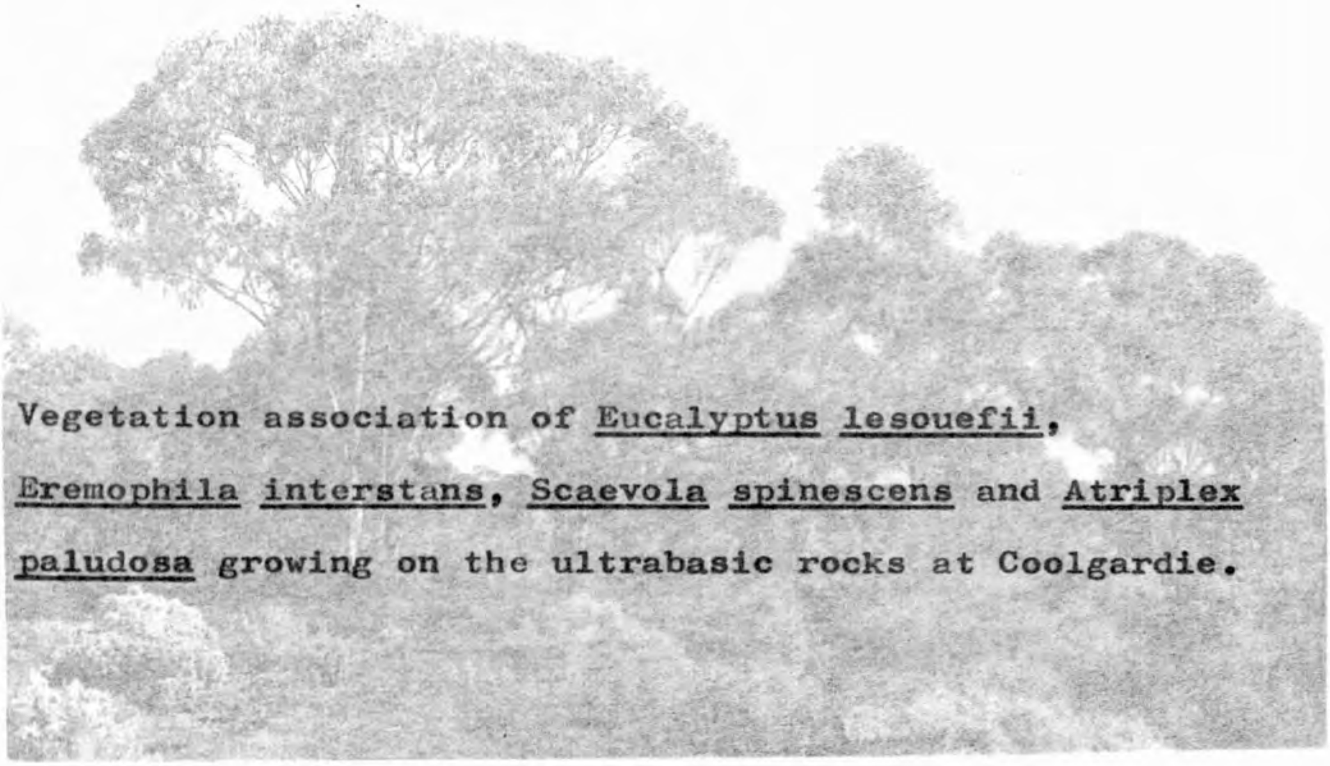
In the background open woodland, dominated by Eucalyptus campaspe, grows on the hill of basic lavas at Coolgardie. E. salmonophloia and Atriplex paludosa grow on the alluvium at the base of the hill. The narrow belt of shrubs in the middle distance is composed of Eremophila duttoni and Dodonaea lobulata, and marks an area of disturbed and stony ground.

Plate 8



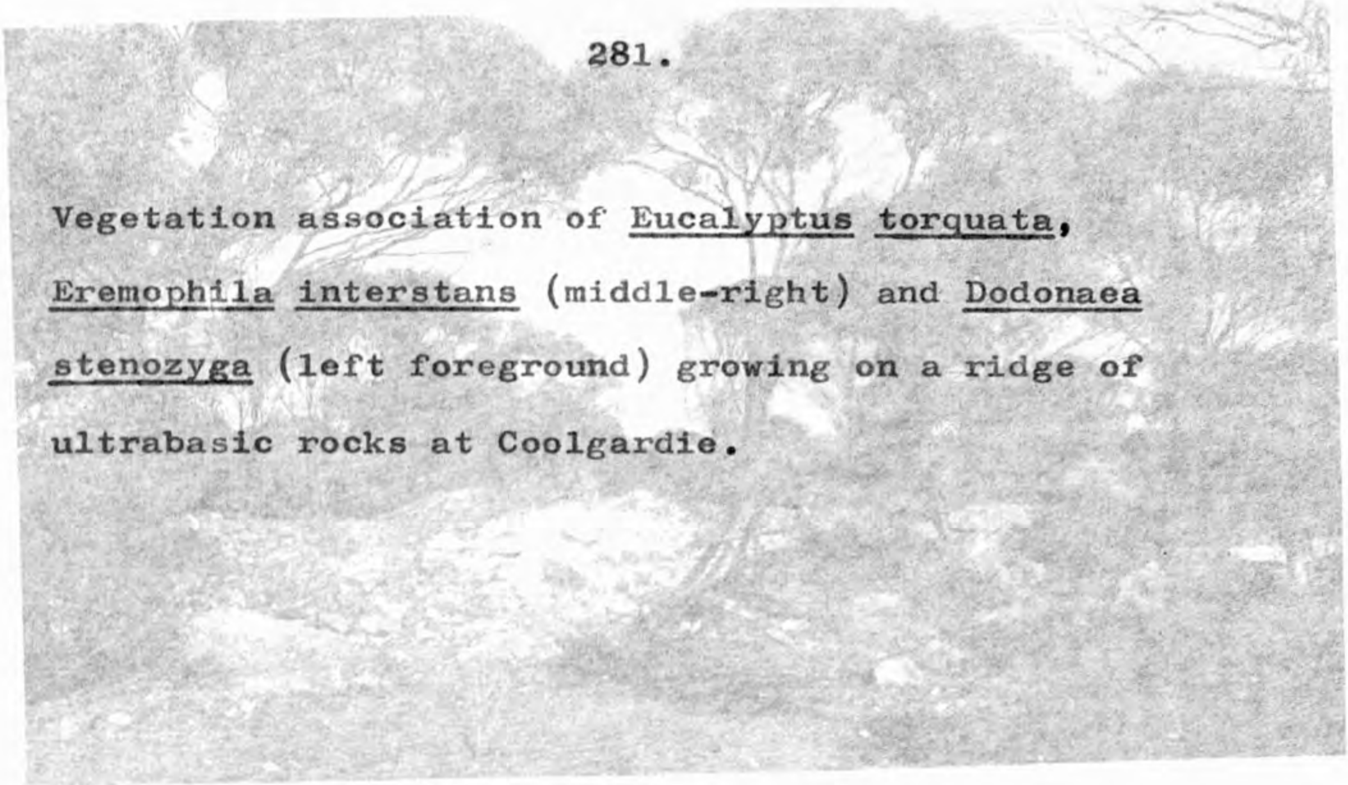


Vegetation association of Eucalyptus foecunda (middle centre), Eremophila interstans (middle right), Cassia eremophila (middle left) and Atriplex paludosa growing on the ultrabasic rocks at Coolgardie.

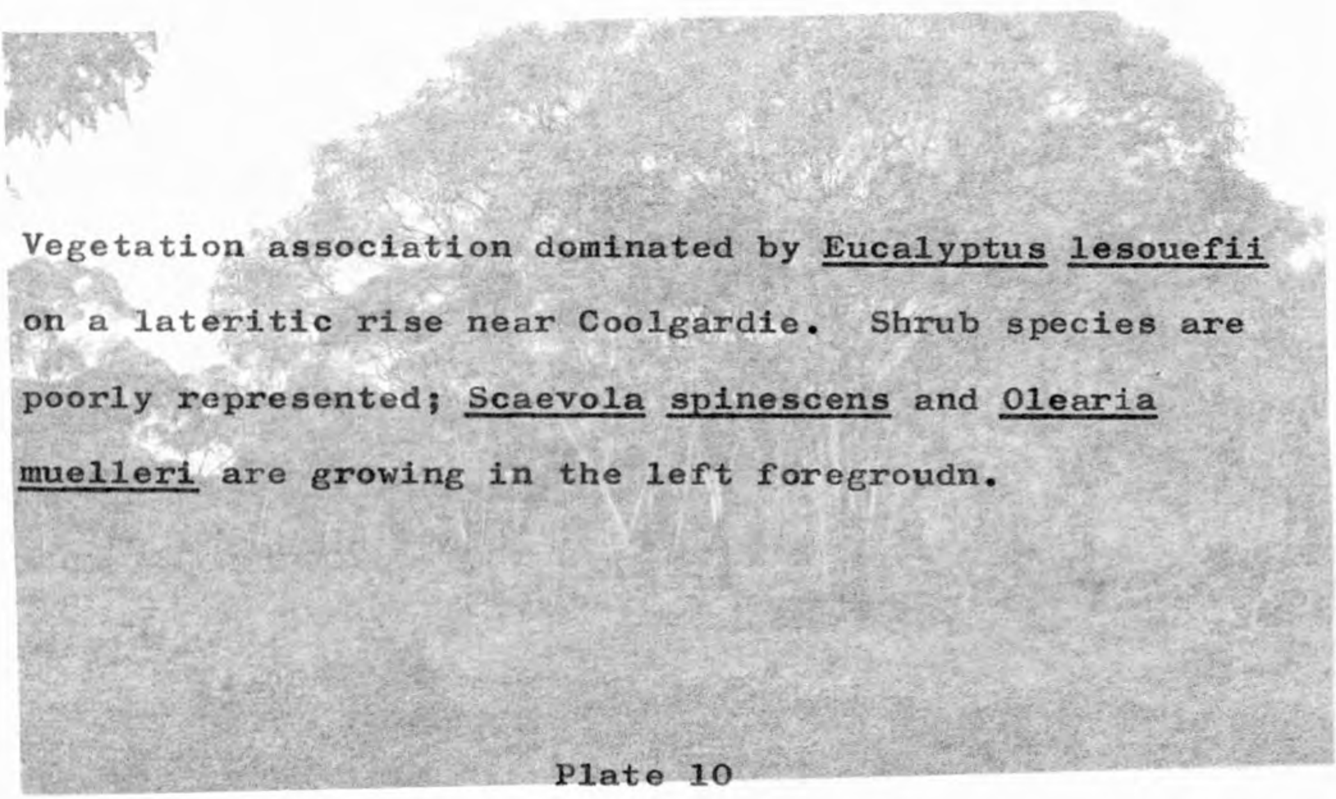


Vegetation association of Eucalyptus lesouefii, Eremophila interstans, Scaevola spinescens and Atriplex paludosa growing on the ultrabasic rocks at Coolgardie.

Plate 9

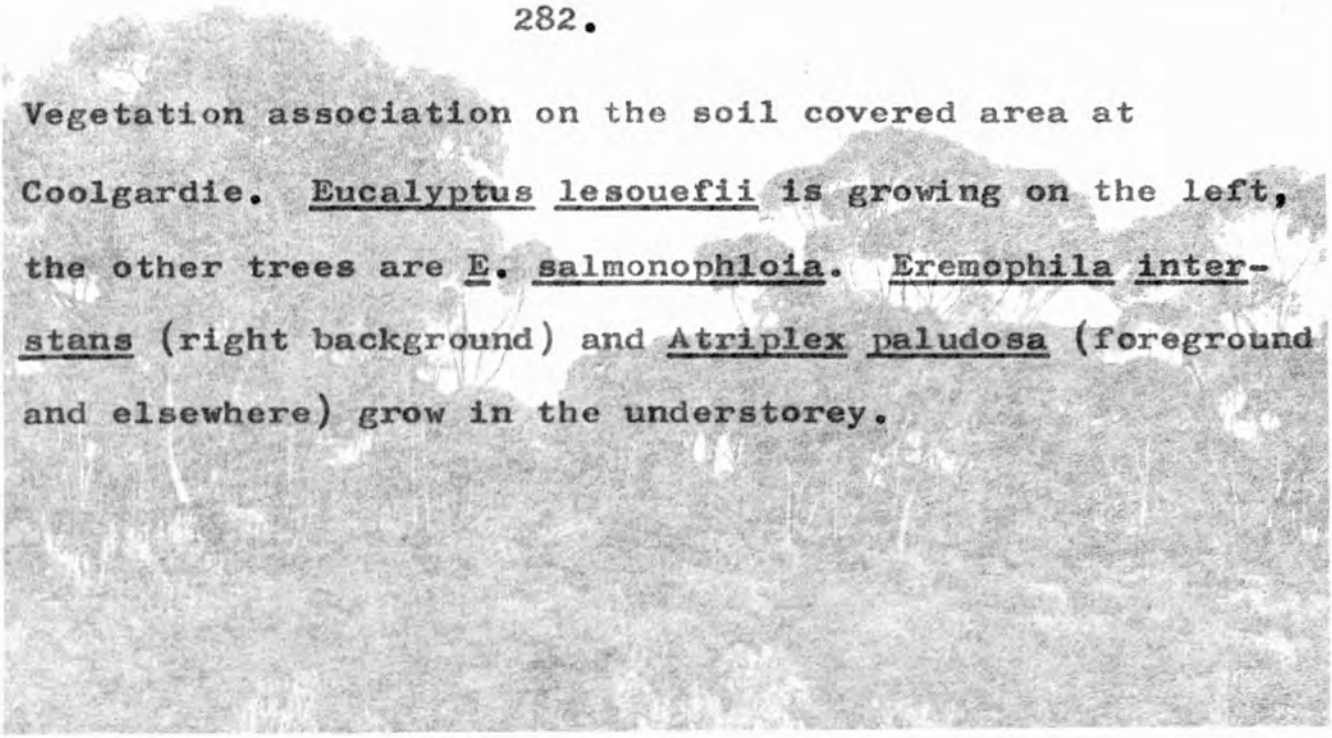


Vegetation association of Eucalyptus torquata, Eremophila interstans (middle-right) and Dodonaea stenozyga (left foreground) growing on a ridge of ultrabasic rocks at Coolgardie.

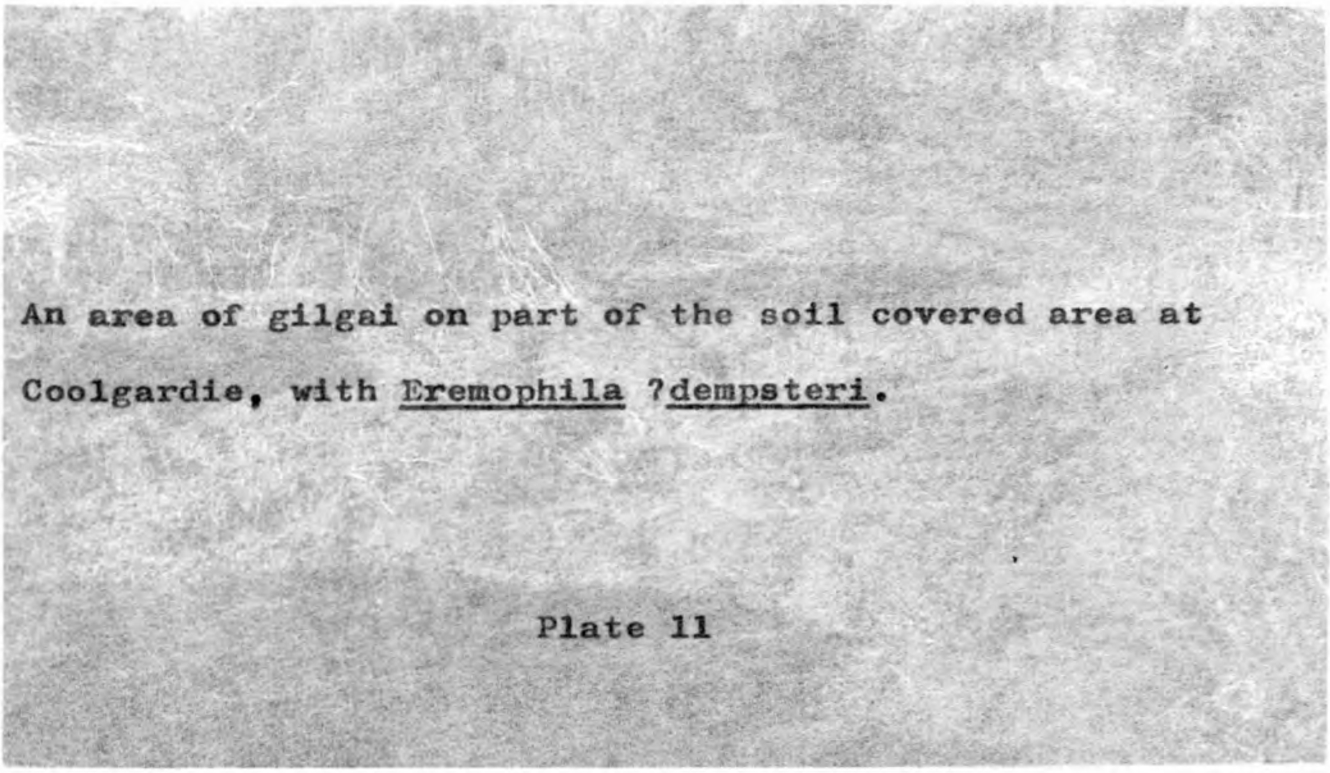


Vegetation association dominated by Eucalyptus lesouefii on a lateritic rise near Coolgardie. Shrub species are poorly represented; Scaevola spinescens and Olearia muelleri are growing in the left foregroudn.

Plate 10



Vegetation association on the soil covered area at Coolgardie. *Eucalyptus lesouefii* is growing on the left, the other trees are *E. salmonophloia*. *Eremophila interstans* (right background) and *Atriplex paludosa* (foreground and elsewhere) grow in the understorey.



An area of gilgai on part of the soil covered area at Coolgardie, with *Eremophila ?dempsteri*.

Plate 11

adjacent associations. It is noticeable that when clearing has taken place, as in the Camel Paddock, four miles north-east of Coolgardie, annuals become much more frequent.

Low ridges occur occasionally within this area, and here Eucalyptus torquata, the coral-flowered gum, is the only important Eucalypt, associated mainly with Eremophila interstans and Dodonaea stenozyga (Plate 10); other species growing in low frequencies include Scaevola spinescens, Eremophila weldii, Westringia rigida and Olearia muelleri. Where these ridges show signs of lateritisation, their surfaces covered with lateritic rubble and ironstone nodules, E. torquata is absent. E. lesouefii dominates the tree layer in an association which includes Eremophila duttoni, E. oppositifolia, Acacia tetragonophylla and Ptilotus obovatus (Plate 10).

The country becomes extensively flat further to the north-east, the soil surface differing from that in adjacent areas by the presence of a veneer of dark haematite gravel. This area is marked by a different association, consisting of varied Eucalyptus species (Plate 11). These include E. salmonophloia, E. lesouefii, E. transcontinentalis, E. salubris and E. oleosa, and the shrub layer is poorly varied and of low density: Eremophila interstans Exocarpus aphylla, Atriplex paludosa, Kochia georgei, K. radiata and Bassia patenticuspis occur more or less throughout, and the quondong, Santalum acuminatum, in small scattered groups or as individuals. Patches of gilgai are found in this area (Plate 11) and are generally characterised by a community of Eucalyptus salubris and Eremophila ?dempsteri, the latter species having a very characteristic bushy habit and a brighter green foliage than in habitats elsewhere. S. acuminatum also grows occasionally on the gilgai. The ground layer throughout this association is generally poorly represented, excepting where the surface is freer from the veneer of haematite gravel. In such localities Erodium cygnorum, E. circutarium and Cephalipterum drummondii occur.

About seven miles north-east of Coolgardie the surface of the Old Plateau terminates abruptly in a breakaway. The top of the breakaway face is marked by a dense, spindly growth of Eucalyptus clelandi, forming a low monospecific community over much of this area, although in other localities along the top of the scarp this species is joined by an occasional Atriplex paludosa. Other shrubs growing here, such as Cassia eremophila, Eremophila glabra and Acacia erinacea are stunted and grow with a very low frequency. E. clelandi does not grow on the breakaway face itself but various shrub species occur, concentrated particularly at the top of the scarp, their numbers decreasing towards the bottom. Dodonaea lobulata, Acacia erinacea and Olearia muelleri are the shrubs most commonly encountered, and the small cushiony plant Ptilotus helichrysoides is characteristic of this habitat. It was observed only on the scarp face of breakaways in various parts of the Goldfields.

From the base of the breakaway to the Mungari granite area the surface of the New Plateau supports a vegetation association in which the dominant tree species are Eucalyptus campaspe, E. salubris and E. lesouefii (Plate 7). Although these three species may grow together, each tends to form its own small dense copse, these copses separated from each other by more or less treeless areas. The shrub understorey is of low density, with Atriplex paludosa the only ubiquitous species. Eremophila interstans, Cassia eremophila, Acacia erinacea and Olearia muelleri occur occasionally, but all these are absent over part of this area where Arthrocnemum halocnemoides becomes co-dominant with Atriplex paludosa. In such areas the trees are less densely distributed and are mainly confined to the slightly higher ground around these saline areas. E. salubris and E. lesouefii still maintain their dominance in the tree stratum and E. salmonophloia forms a subdominant species. Nowhere does the ground flora assume prominence. Erodium cygnorum, E. circutarium and Helipterum variable occur occasionally.

The area of the Mungari granite is typically characterised by an open shrub association where the granite outcrops or has a shallow soil cover of a few inches only. Acacia acuminata is the most important species, occurring with Eremophila ?gibsoni and Ptilotus obovatus. Eucalypts are usually rare. The ground flora of ephemerals is well developed during the end of July and beginning of August. Such species include Podolepis capillaris, Cephalipterum drummondii, Senecio glossanthus, Helipterum variable and Erodium cygnorum. After rain pools of water often remain on areas of outcropping granite and where these overflow or there are damp hollows grass is found growing.

Where the granite is masked by a deeper soil cover, in excess of approximately 15 inches, the association is modified, as along the easterly end of transect 1. Eucalyptus foecunda and E. oleosa dominate the tree stratum here, and Eremophila duttoni, Dodonaea lobulata, *Cassia eremophila* and *Ptilotus obovatus* are important in the shrub layer. *Acacia acuminata* and *Eremophila ?gibsoni* assume dominance as the granite approaches the surface at the end of the transect and Eucalypts become infrequent.

2. The factors governing the distribution of the vegetation associations

(a) Relief and drainage

Most of the area is gently undulating. The Three Mile Hill is one of the higher prominences, and elsewhere the subdued relief is occasionally interrupted by low lateritic rises. Seven miles north-east of Coolgardie stands a series of breakaways. The steep scarp face varies in height along its length, but is over thirty feet high in places.

A number of small creeks occurs in the area. The creeks are most pronounced where relief is more marked. They debouch into wider drainage valleys which are less pronounced topographically, lying where the relief is subdued. They may carry large volumes of water after very heavy rain but generally rainwash does not scour so deeply here and often small patches of low shrubs are left standing on islands of soil one to three inches above the drainage level. These valleys trend towards local base levels comprising salinas, which only contain water when rainfall has been particularly heavy. There are no salinas within the immediate area under consideration.

Run-off in the areas of exposed granite outcrops tends to be fairly rapid and the water often lies around or within hollows on the granite so that such areas are important for water catchment.

Relief does not appear to play an important part in influencing the development and distribution of the vegetation associations here. The greater part of the area is flat to undulating and different associations succeed each other within the area in spite of little or no variation in topography. Part of the Three Mile Hill is characterised by its own particular association of Acacia quadrimarginea, Eremophila duttoni, Dodonaea lobulata and Ptilotus obovatus, and although this may be partly influenced in its development by relief and drainage, other factors are also indicated to be influential here: these are considered later.

Drainage is important in plant distribution in restricted localities. About seven miles north-east of Coolgardie the introduction of saline water into shallow drainage basins builds up the concentration of various salts in the soil and prohibits the growth of certain species such as Scaevola spinescens and Olearia muelleri, which could normally be expected to grow in this area. Trees may be rare and grow only around the limits of the basin or in stands on any slight rise of the ground. The dominant plants are halophytic species such as *Atriplex paludosa*, *Arthrocnemum halocnemoides* and *Kochia glomerifolia*.

Drainage factors are also influential around the granite outcrop near Mungari. Water tends to lie on or around the outcrops after rainfall and in such areas a specific vegetation association grows, comprising *Acacia acuminata*, *Eremophila ?gibsoni* and *Ptilotus obovatus*. Grasses and annuals, such as *Podolepis capillaris*, grow prolifically in the springtime. Drainage factors here, however, are linked to the geology which is considered below.

(b) Geology and soils

Most of the area is underlain by rocks comprising the older greenstones series, together with ancient metasediments. Granite occurs in the Mungari locality and there are areas of lateritic material (Figure 26).

The greenstones consist of igneous rocks ranging from basic to ultrabasic in composition. The basic lavas are defined as igneous or metamorphic rocks containing between 45% and 55% of combined silica. The ultrabasic rocks are igneous or metamorphic rocks containing less than 45% of combined silica (McMath 1953). The basic lavas occur on Three Mile Hill. They are relatively resistant to erosion and are made up of fine to coarse grained basic igneous rocks. They have undergone a low grade regional metamorphism and may possibly contain pillow structures, but the outcrops are too highly jointed and fractured to allow the recognition of such.

The ultrabasic rocks of the study area fall into the southern part of the Bonnie Vale Belt. They stretch for a distance of about two miles along the transect, and as they are less resistant to weathering than the basic rocks tend to occupy the lower ground. Exposures are not common, but weathered fragments and pieces of float which were observed comprised serpentinite and actinolite.

Metasedimentary rocks occur between the lateritic breakaways and the granite which lies at the north-east end of the area studied. In the geological sequence they overlie the older greenstones, but outcrop is limited and no good exposures were found in the transect area. The Mungari metasedimentary series comprise a variety of rock types including mica, quartz-feldspar, schists, slates, feldspathic grits, gneiss and migmatitic rocks (McMath 1953).

A sill of amphibolite or metagabbro is an example of a later basic intrusive which occurs in the Three Mile Hill area. This may belong to the younger greenstones of the Kalgoorlie Series. It forms a ridge lying in a north-west to south-east direction, following the regional strike, and abuts onto basic lavas on both sides. The northern boundary of the amphibolite is fairly well defined and is separated from the lavas by a graphitic schist band. The southern boundary tends to be obscured by alluvial soils. At the Three Mile Hill this rock type has undergone a certain degree of sulphide mineralisation. The belt of sulphides follows the sill and geophysical studies indicate that it extends for fifty to ninety feet on either side.

The Mungari granite forms one of the major granite intrusives of the Coolgardie area. It has a magmatic origin and is intrusive into the metasediments. The outcrops have been rounded by weathering and form pavements and low whalebacks.

The laterites will be treated in the following account of the soils of the Three Mile Hill - Mungari area.

The soils developing over the areas of basic lavas may be either skeletal or show the features of a solonised brown soil. The hardness and well-developed jointing of the lavas help to produce blocky scree, which is often stained with iron oxides. A thin loamy soil is present, yellowish red in colour (5YR 4/6) with a high pH approximating to 9.0. A deeper, solonised brown soil occurs where relief allows the soil to build up. The A horizon extends from the surface to about four inches depth, and is yellowish red in colour (5YR 4/6). The texture is that of a sandy-clay loam, and pH recordings were consistently high, from 8.8 to 9.7. The B horizon extends from approximately four inches downwards. The greater proportion of powdery calcium carbonate here imparts a paler colour to the soil, and there is an increase in the amount of clay. Fragments of soft magnesite may occasionally be present. The pH remains high.

The area underlain by the ultrabasic rocks occupies the lower, flatter ground and this has led to the development of deeper solonised soils. The A horizon, extending from the surface to three to ten inches depth, is a yellowish red (5YR 4/6) sandy-clay loam with alkaline reaction. The B horizon extends to eighteen inches and deeper; in a costean the weathered bedrock was seen at a depth of thirty five inches. The soil is paler in colour (5YR 5/6) and has a looser, more powdery texture, with a greater proportion of clay. Rounded nodules of travertine are generally present, and the pH range recorded in this lower horizon was 7.7 to 8.2.

Solonised brown soils have developed over the area underlain by metasediments. By comparison with the soils over the ultrabasic rocks, the A horizon tends to be a darker reddish brown (2.5YR 3/6) grading to a yellowish red (5YR 4/6), and there is very little or no free lime present. pH ranges from 7.0 to 7.9. The B horizon is a paler brown, with powdery calcium carbonate present.

The Mungari granite has undergone weathering along joint planes and by exfoliation to produce kaolinitic grits. The weathering products are removed and sandy soils are built up around the granite outcrops. No profile differentiation was observed in these soils, which reached a depth of about twelve inches above bed-rock in one area examined. The sandy texture persists down to bedrock and the soil is generally dark red (2.5YR 3/6). The pH recordings were from 5.2 to 5.6.

Lateritic soils have developed on the occasional low rises along the transect area. The surface here is covered with weathered nodules from the lateritic B horizon, prohibiting augering, and varying amounts of quartz pebbles are present. The best example of a lateritic soil here occurs along the breakaways a quarter of a mile south of the seven mile peg along the Kalgoorlie road. The A horizon has been removed and the surface is characterised by weathered lateritic material from the B horizon. The profile has been exposed on the breakaway scarp face, revealing an indurated B horizon approximately eight inches thick, overlying the kaolinitic C horizon. The C horizon is partly covered by a certain amount of float from the overlying horizon, and its exposed surface shows yellow iron staining. Below this yellow veneer the clay becomes characteristically white, with blue-grey and red mottles. The pH recorded on the lower part of the scarp face was 3.7.

The vegetation supported over large lateritic areas usually differs from that on adjacent non-lateritised areas. Parts of transect 1 and transect 4 cover the large area of laterite which was examined in this field area. Eucalyptus foecunda is the dominant tree species, and Casuarina cristata is important in this stratum. The most important shrubs in the association are _Acacia acuminata_, _Eremophila duttoni_, _Acacia tetragonophylla_, _Dodonaea lobulata_ and _Ptilotus obovatus_. The variety of species in such areas is striking and contrasts noticeably with the less varied association on the abutting metasediments and soil covered area. The environmental conditions prevailing over the laterite here appear favourable to a large number of different plants. It is only on the edge of the breakaway scarp that conditions appear to be less favourable and the plants present become stunted.

The underlying rock type is obscured by soil cover for a distance of over two miles along transect 1. The area is shown on the geological map as occurring to the south-west of the breakaways. Parts of this area are occupied by dark red to yellowish red clay soils exhibiting gilgai microrelief (Plate 11). These soils are markedly alkaline, the highest pH recorded being 8.7. The gilgai is of limited occurrence, however, and more commonly the soil surface is covered with haematite gravel, which is often characteristic of soils above sediments. In one pit examined the A horizon extended to a depth of four inches. It was dark reddish brown to yellowish red in colour (2.5YR 3/6 to 5YR 4/6) and in texture was a sandy-clay loam, containing fragments of fine haematite gravel. The pH recorded was 7.8. The B horizon extended from four to twelve inches and deeper. It contained a much greater proportion of clay which tended to adhere in hard nodules. The pH recorded in this horizon was 8.0.

Soils from transects 1, 4 and 5 were analysed for trace elements copper, zinc, lead, nickel and chromium (see Figures 27-33, 39 and 40). The content of copper, zinc and lead in the soil tends to remain within the same range throughout, never exceeding 200 ppm and generally occurring in concentrations below 100 ppm. There is no striking concentration difference between soils from differing bedrocks, so that it seems unlikely that the correspondence between vegetation associations and the underlying geology can be attributed primarily to differences in the concentration of these trace elements.

Nickel and chromium show greater variation in their soil concentration along transect 1, with nickel exceeding 400 ppm in some localities. The soil content of these two elements appears to be much more erratic than for copper, zinc and lead, so that it is more difficult to make tentative observations between their concentration in the soil and the underlying bedrock. The greater part of the soil covered area tends to be characterised by a higher soil content of these two elements than are the adjacent basic rocks and lateritic area, but elsewhere along the transect values rise and fall with little regard to variations in bedrock. The soil concentration of these elements does not appear to be of prime importance in the distribution of the vegetation associations. Many of the same species occur where nickel and chromium are at the higher and lower limits of their ranges, so that the actual soil content here does not seem to be important in the presence or absence of species. No soil samples were analysed along transect 2; geobotanical relationships here are similar to those observed along transect 1 (Figures 34-38).

A limited number of plant samples was analysed for trace elements. The results are shown in Table VIII.

The distribution of the associations in the Coolgardie area cannot be specifically related to the soil concentration of the elements for which analysis was undertaken. However, there is a close correspondence

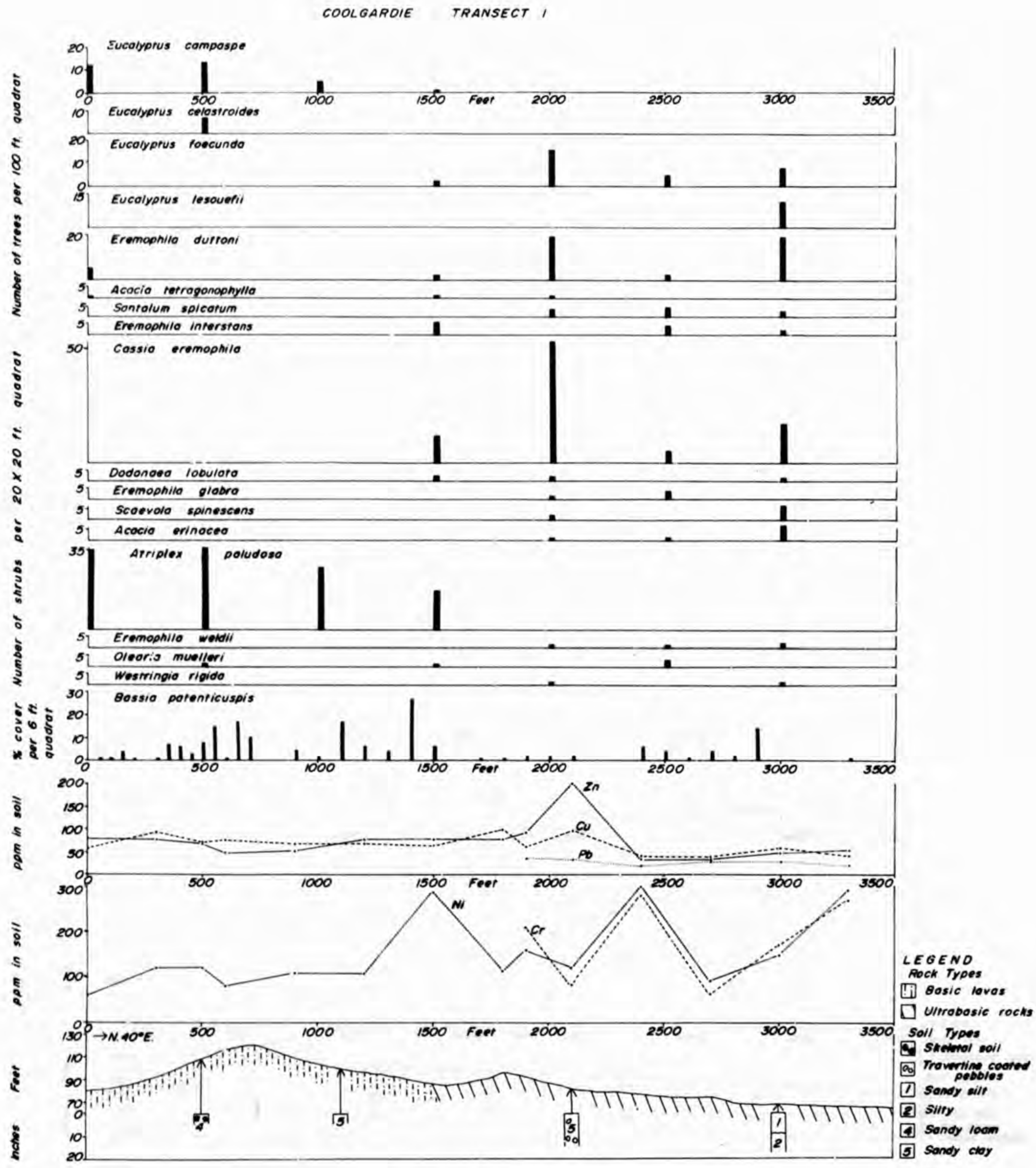

COOLGARDIE TRANSECT I
Eucalyptus campaspe
Eucalyptus celastroides
Eucalyptus foecunda
Eucalyptus lesouefii
Eremophila duttoni
Acacia tetragonophylla
Santalum spicatum
Eremophila interstans
Cassia eremophila
Dodonaea lobulata
Eremophila glabra
Scaevola spinescens
Acacia erinacea
Atriplex paludosa
Eremophila weldii
Olearia muelleri
Westringia rigida
Bassia patenticuspis
Number of trees per 100 ft. quadrat
Number of shrubs per 20 X 20 ft. quadrat
% cover per 6 ft. quadrat
ppm in soil
Feet
Inches
Zn
Cu
Pb
Ni
Cr
→N. 40°E.
LEGEND
Rock Types
Basic lavas
Ultrabasic rocks
Soil Types
Skeletal soil
Travertine coated pebbles
Sandy silt
Silty
Sandy loam
Sandy clay

Figure 27

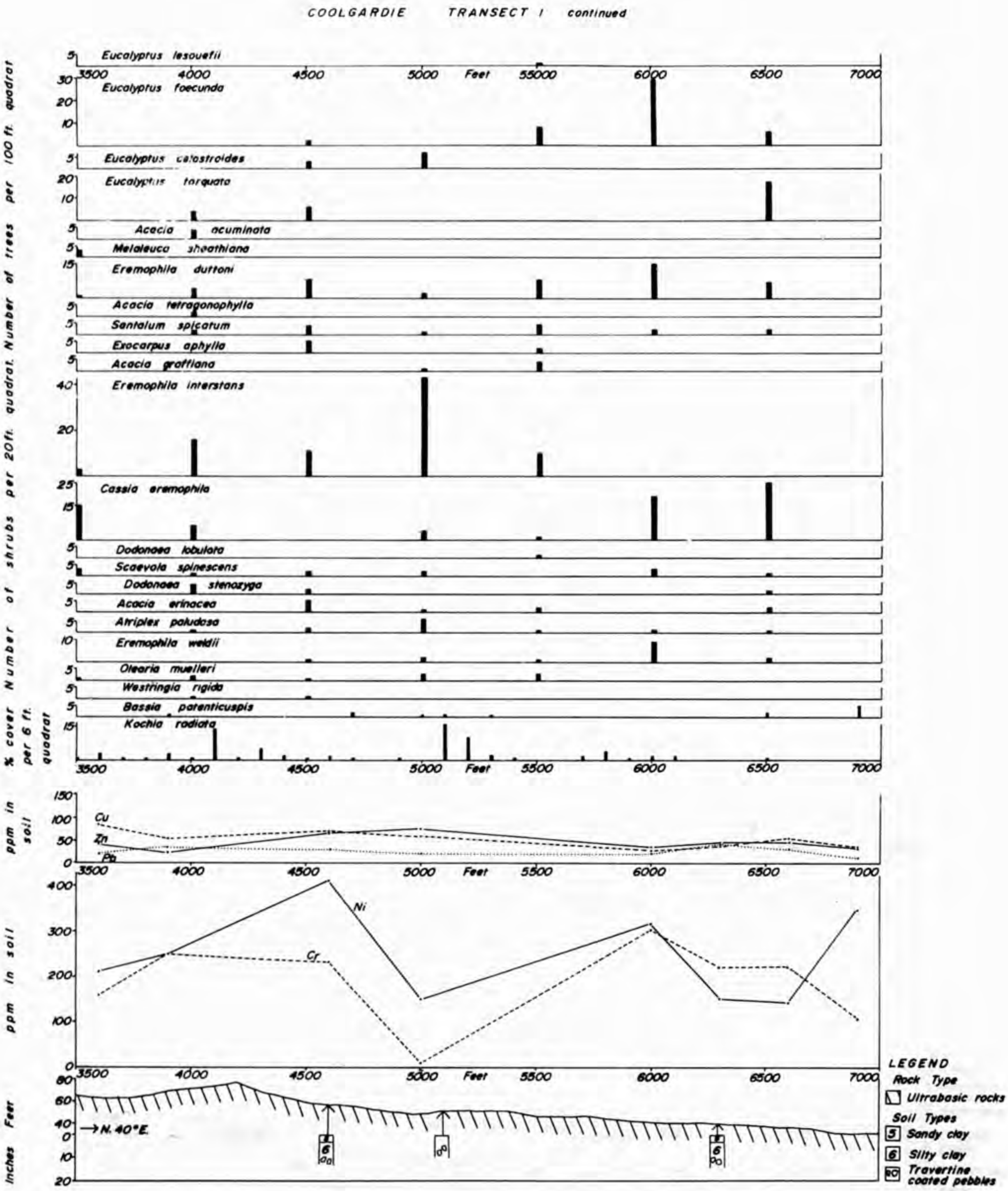

COOLGARDIE TRANSECT I continued
Eucalyptus lesouefii
Eucalyptus foecunda
Eucalyptus calostroides
Eucalyptus torquata
Acacia acuminata
Melaleuca sheathiana
Eremophila duttoni
Acacia tetragonophylla
Santalum spicatum
Exocarpus aphylla
Acacia graffiana
Eremophila interstans
Cassia eremophila
Dodonaea lobulata
Scaevola spinescens
Dodonaea stenozyga
Acacia erinacea
Atriplex paludosa
Eremophila weldii
Olearia muelleri
Westringia rigida
Bassia parenticuspis
Kochia radiata
Number of trees per 100 ft. quadrat
Number of shrubs per 20 ft. quadrat
% cover per 6 ft. quadrat
Feet
ppm in soil
Cu
Zn
Pb
Ni
Cr
Feet
Inches
→ N. 40° E.
LEGEND
Rock Type
Ultrabasic rocks
Soil Types
Sandy clay
Silty clay
Travertine coated pebbles

Figure 28

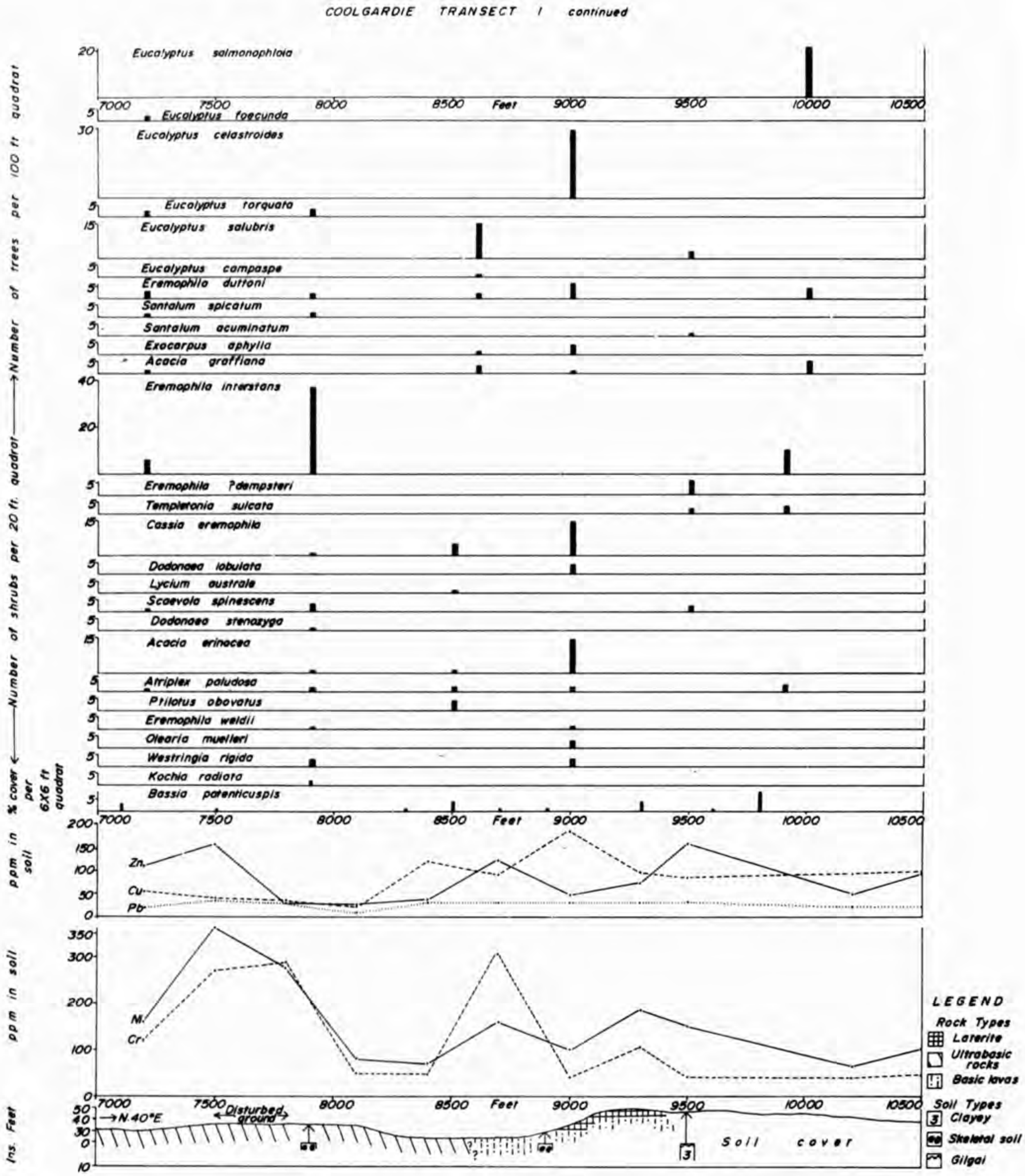

COOLGARDIE TRANSECT I continued
Eucalyptus salmonophloia
Eucalyptus foecunda
Eucalyptus celastroides
Eucalyptus torquata
Eucalyptus salubris
Eucalyptus campaspe
Eremophila duttoni
Santalum spicatum
Santalum acuminatum
Exocarpus aphylla
Acacia graffiana
Eremophila interstans
Eremophila ?dempsteri
Templetonia sulcata
Cassia eremophila
Dodonaea lobulata
Lycium australe
Scaevola spinescens
Dodonaea stenozyga
Acacia erinacea
Atriplex paludosa
Ptilotus obovatus
Eremophila weldii
Olearia muelleri
Westringia rigida
Kochia radiata
Bassia patenticuspis
Number of shrubs per 20 ft. quadrat ← → Number of trees per 100 ft quadrat
% cover per 6X6 ft quadrat
ppm in soil
ppm in soil
Ins. Feet
Feet
Zn
Cu
Pb
Ni
Cr
→N.40°E
Disturbed ground
Soil cover
LEGEND
Rock Types
Laterite
Ultrabasic rocks
Basic lavas
Soil Types
Clayey
Skeletal soil
Gilgai

Figure 29

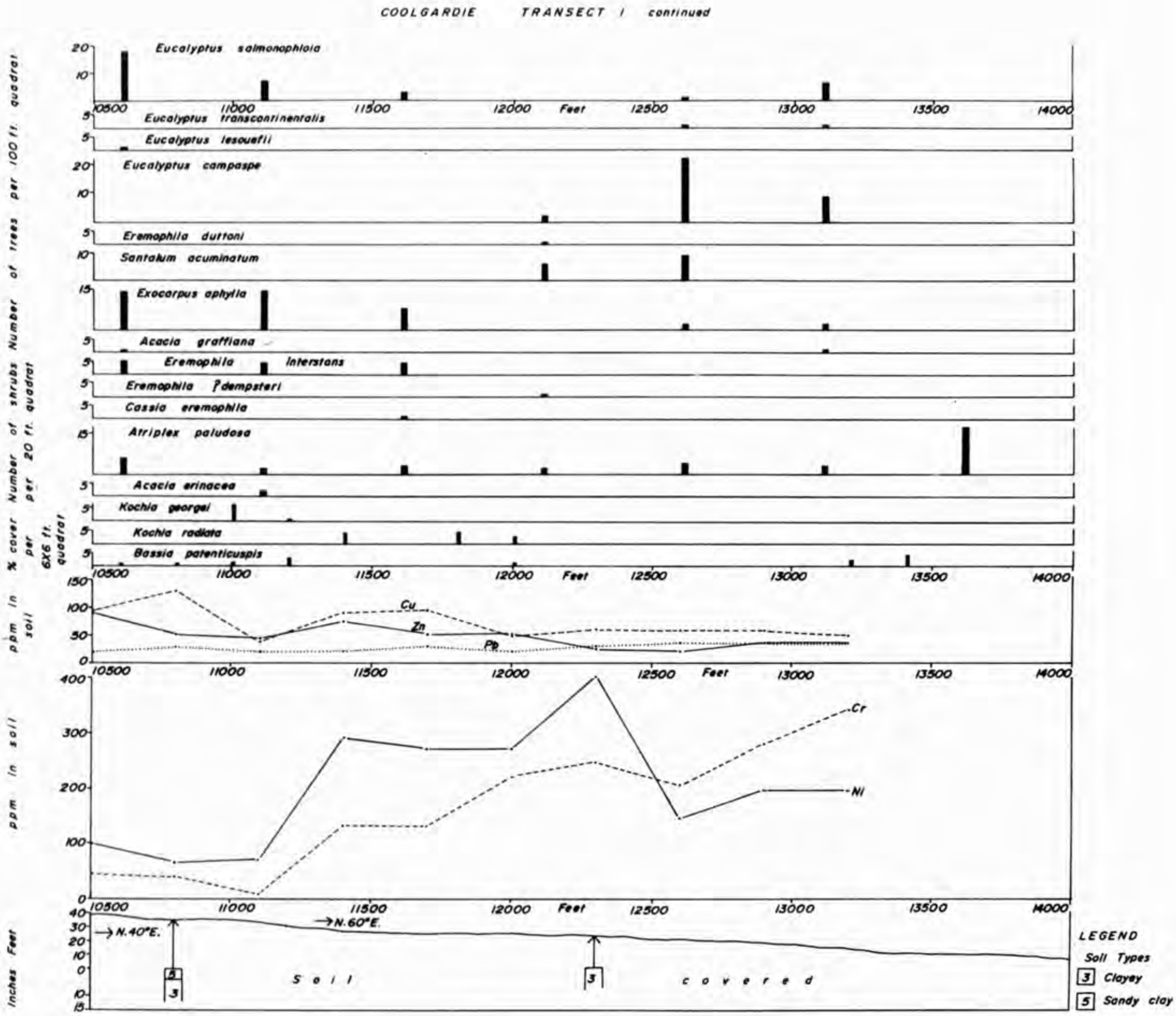

COOLGARDIE TRANSECT I continued
Number of trees per 100 ft. quadrat
Eucalyptus salmonophloia
Eucalyptus transcontinentalis
Eucalyptus lesouefii
Eucalyptus campaspe
Eremophila duttoni
Santalum acuminatum
Exocarpus aphylla
Acacia graffiana
Number of shrubs per 20 ft. quadrat
Eremophila interstans
Eremophila ?dempsteri
Cassia eremophila
Atriplex paludosa
Acacia erinacea
Kochia georgei
% cover per 6X6 ft. quadrat
Kochia radiata
Bassia patenticuspis
Feet
ppm in soil
Cu
Zn
Pb
Cr
Ni
Inches Feet
N.40°E.
N.60°E.
Soil covered
LEGEND
Soil Types
3 Clayey
5 Sandy clay

Figure 30

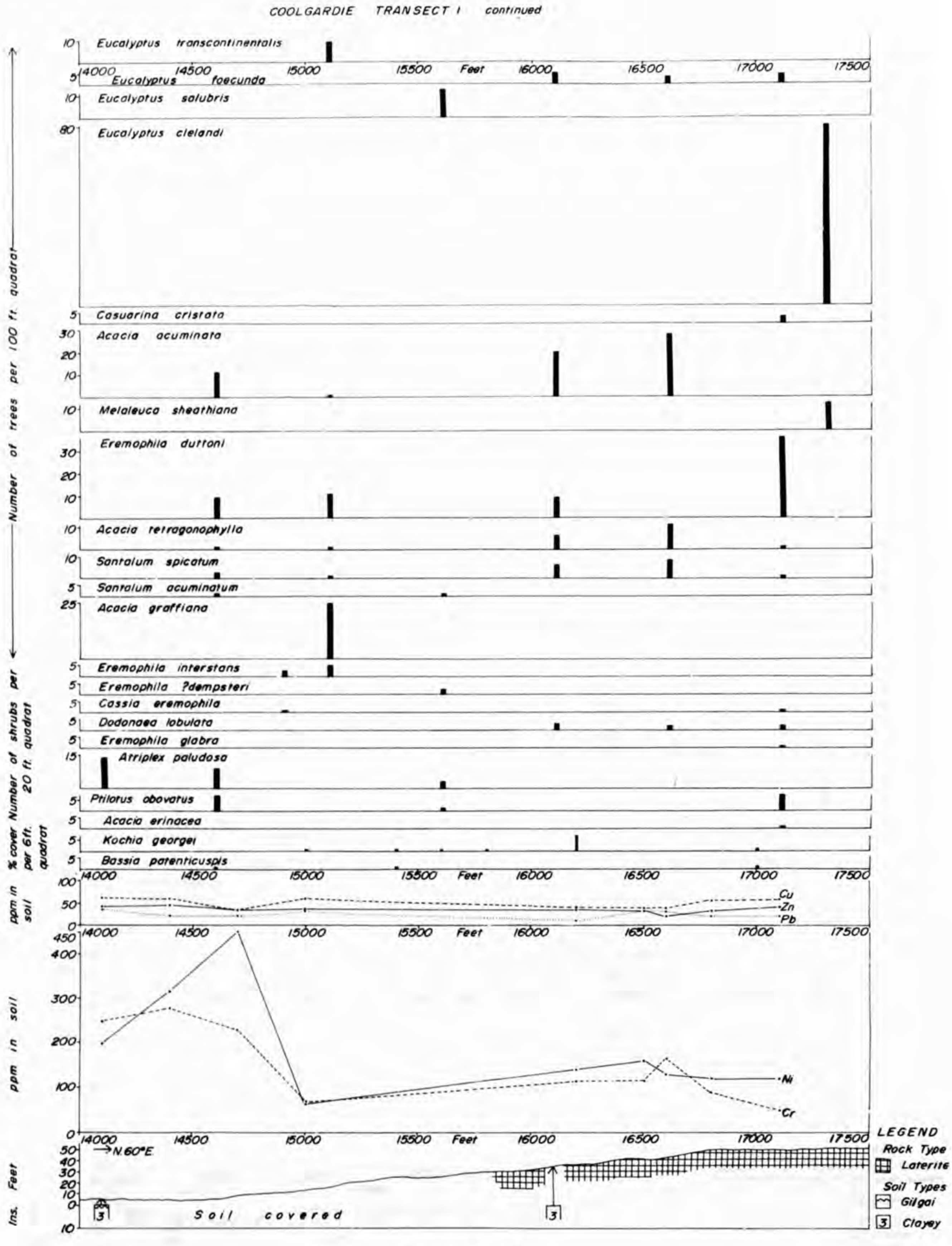

COOLGARDIE TRANSECT I continued
Eucalyptus transcontinentalis
Eucalyptus foecunda
Eucalyptus salubris
Eucalyptus clelandi
Casuarina cristata
Acacia acuminata
Melaleuca sheathiana
Eremophila duttoni
Acacia tetragonophylla
Santalum spicatum
Santalum acuminatum
Acacia graffiana
Eremophila interstans
Eremophila ?dempsteri
Cassia eremophila
Dodonaea lobulata
Eremophila glabra
Atriplex paludosa
Ptilotus obovatus
Acacia erinacea
Kochia georgei
Bassia patenticuspis
Number of trees per 100 ft. quadrat
Number of shrubs per 20 ft. quadrat
% cover per 6 ft. quadrat
ppm in soil
Feet
14000
14500
15000
15500
16000
16500
17000
17500
Cu
Zn
Pb
Ni
Cr
Ins. Feet
N.60°E.
Soil covered
LEGEND
Rock Type
Laterite
Soil Types
Gilgai
Clayey

Figure 31

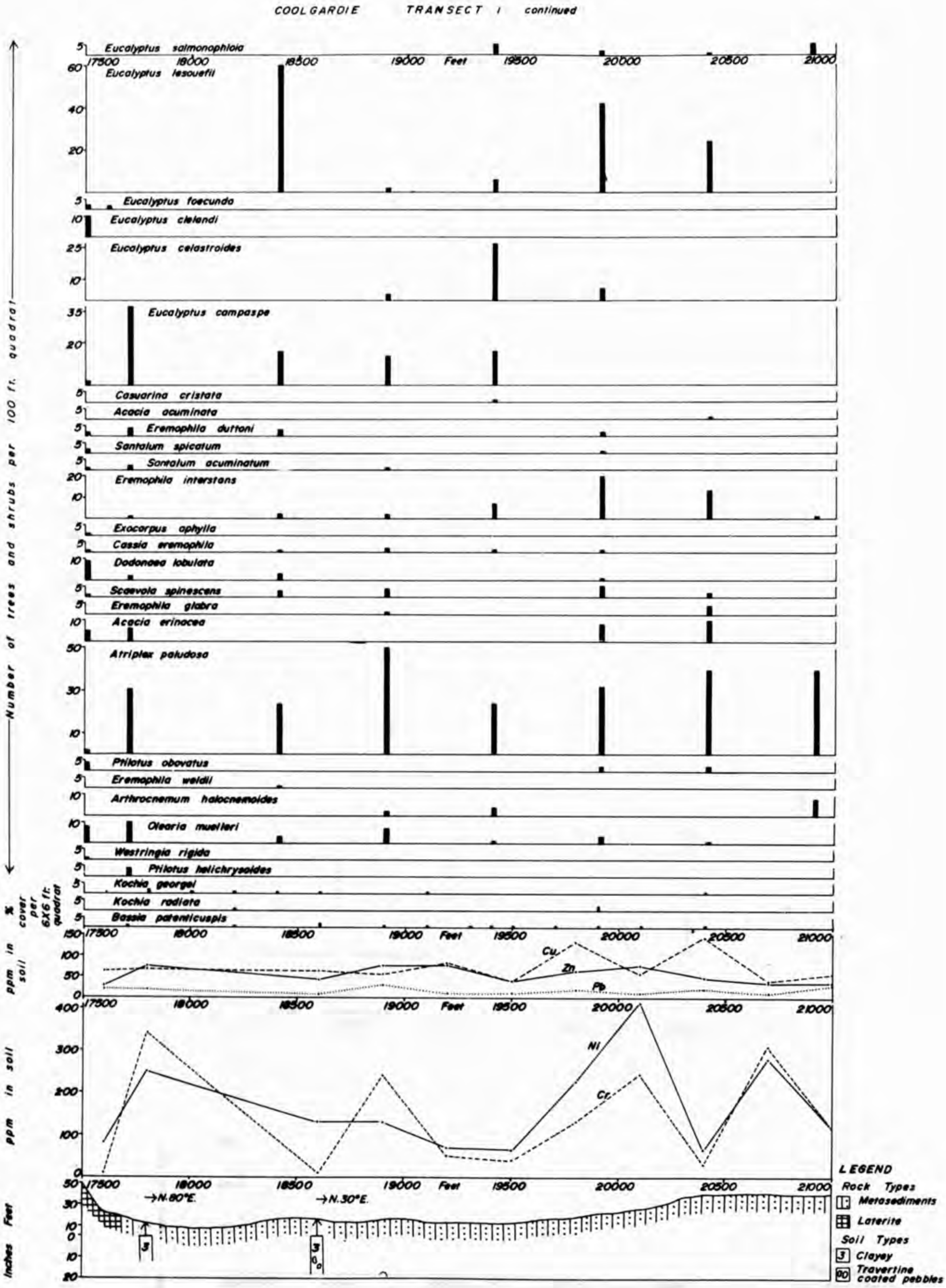

COOLGARDIE TRANSECT 1 continued
Number of trees and shrubs per 100 ft. quadrat
Eucalyptus salmonophloia
Eucalyptus lesouefii
Eucalyptus foecunda
Eucalyptus clelandi
Eucalyptus celastroides
Eucalyptus campaspe
Casuarina cristata
Acacia acuminata
Eremophila duttoni
Santalum spicatum
Santalum acuminatum
Eremophila interstans
Exocarpus aphylla
Cassia eremophila
Dodonaea lobulata
Scaevola spinescens
Eremophila glabra
Acacia erinacea
Atriplex paludosa
Ptilotus obovatus
Eremophila weldii
Arthrocnemum halocnemoides
Olearia muelleri
Westringia rigida
Ptilotus helichrysoides
% cover per 6X6 ft. quadrat
Kochia georgei
Kochia radiata
Bassia patenticuspis
17500
18000
18500
19000
Feet
19500
20000
20500
21000
ppm in soil
Cu
Zn
Pb
Ni
Cr
Feet
Inches
→N.80°E.
→N.30°E.
LEGEND
Rock Types
Metasediments
Laterite
Soil Types
3 Clayey
Travertine coated pebbles

Figure 32

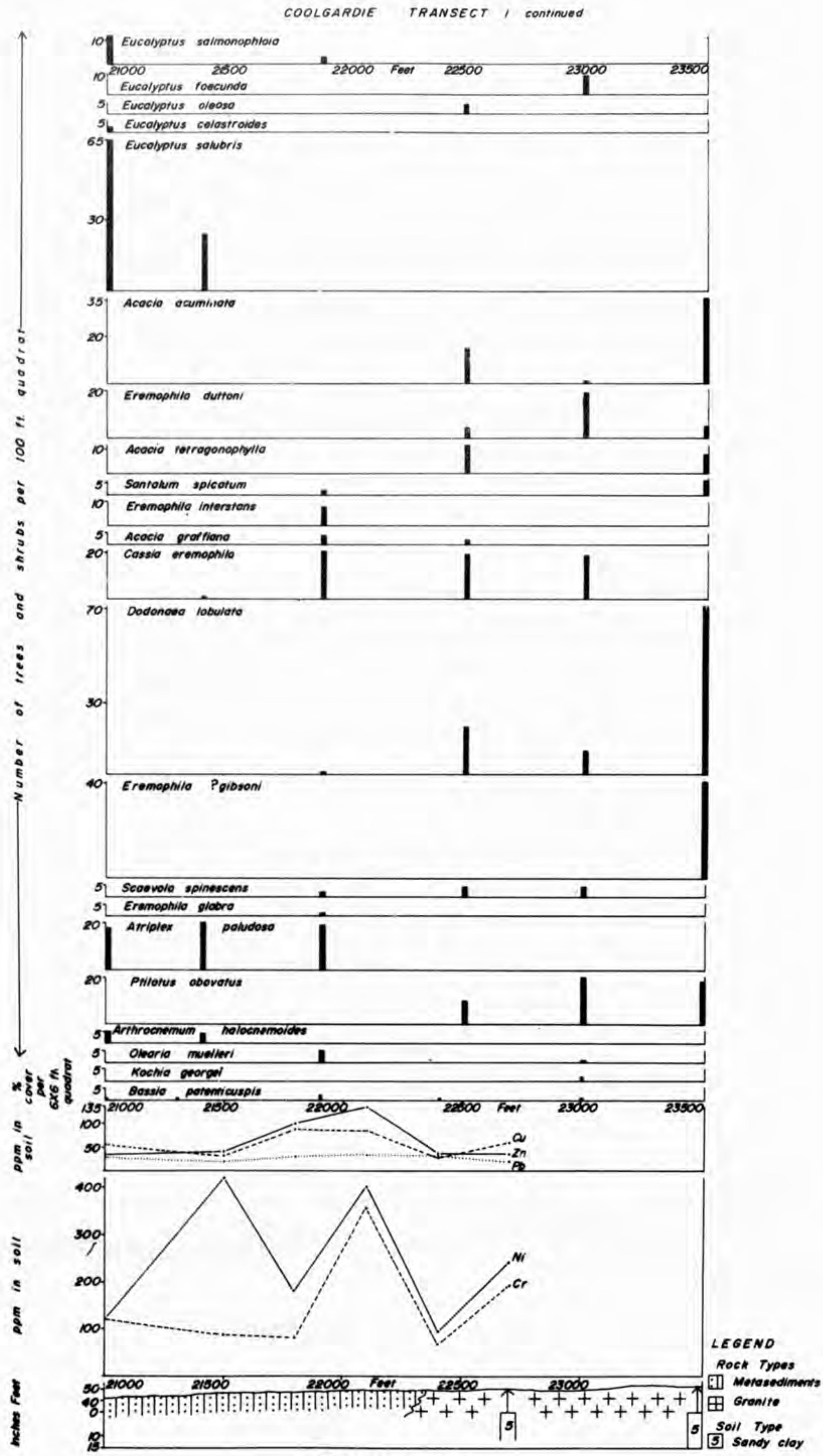

COOLGARDIE TRANSECT I continued
Eucalyptus salmonophloia
Eucalyptus foecunda
Eucalyptus oleosa
Eucalyptus celastroides
Eucalyptus salubris
Acacia acuminata
Eremophila duttoni
Acacia tetragonophylla
Santalum spicatum
Eremophila interstans
Acacia grafflana
Cassia eremophila
Dodonaea lobulata
Eremophila ?gibsoni
Scaevola spinescens
Eremophila glabra
Atriplex paludosa
Ptilotus obovatus
Arthrocnemum halocnemoides
Olearia muelleri
Kochia georgei
Bassia patenticuspis
Number of trees and shrubs per 100 ft. quadrat
% cover per 6X6 ft. quadrat
ppm in soil
Cu
Zn
Pb
Ni
Cr
Inches Feet
21000
21500
22000
Feet
22500
23000
23500
LEGEND
Rock Types
Metasediments
Granite
Soil Type
5 Sandy clay

Figure 33

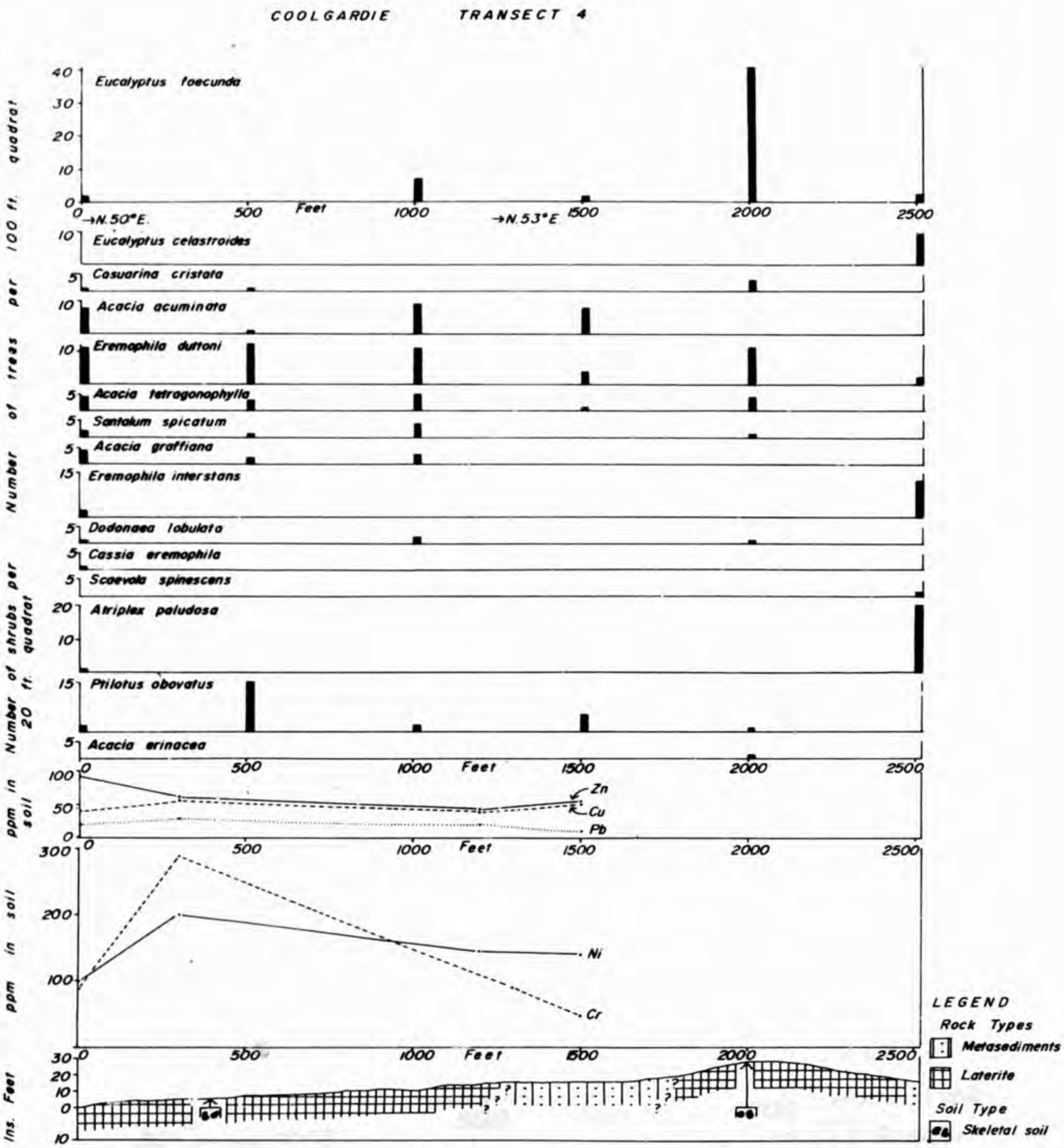

COOLGARDIE TRANSECT 4
Number of trees per 100 ft. quadrat
Eucalyptus foecunda
Feet
→N.50°E.
→N.53°E.
Eucalyptus celastroides
Casuarina cristata
Acacia acuminata
Eremophila duttoni
Acacia tetragonophylla
Santalum spicatum
Acacia graffiana
Eremophila interstans
Dodonaea lobulata
Cassia eremophila
Scaevola spinescens
Number of shrubs per 20 ft. quadrat
Atriplex paludosa
Ptilotus obovatus
Acacia erinacea
ppm in soil
Zn
Cu
Pb
Ni
Cr
Ins. Feet
LEGEND
Rock Types
Metasediments
Laterite
Soil Type
Skeletal soil

Figure 39

COOLGARDIE TRANSECT 5

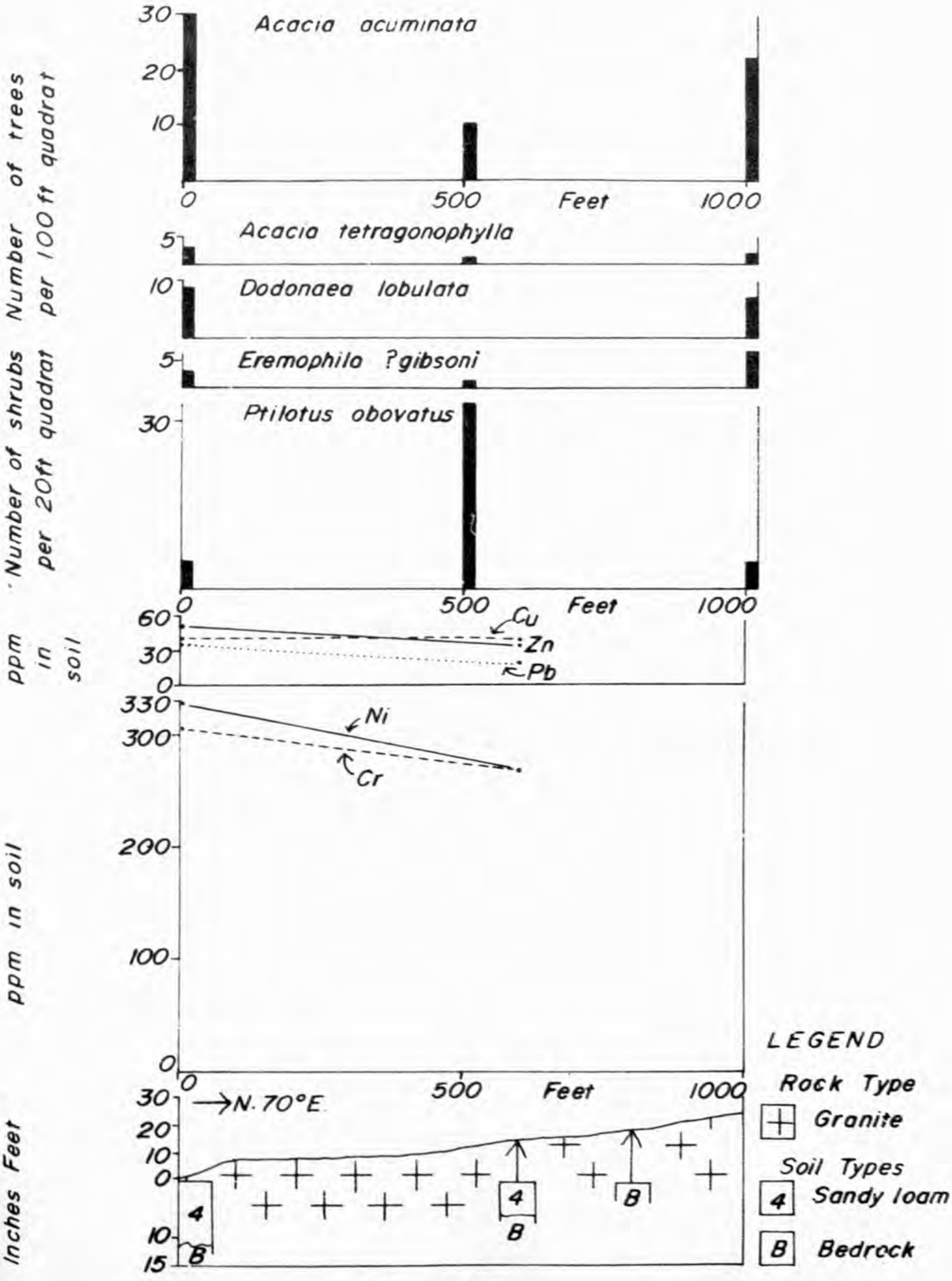
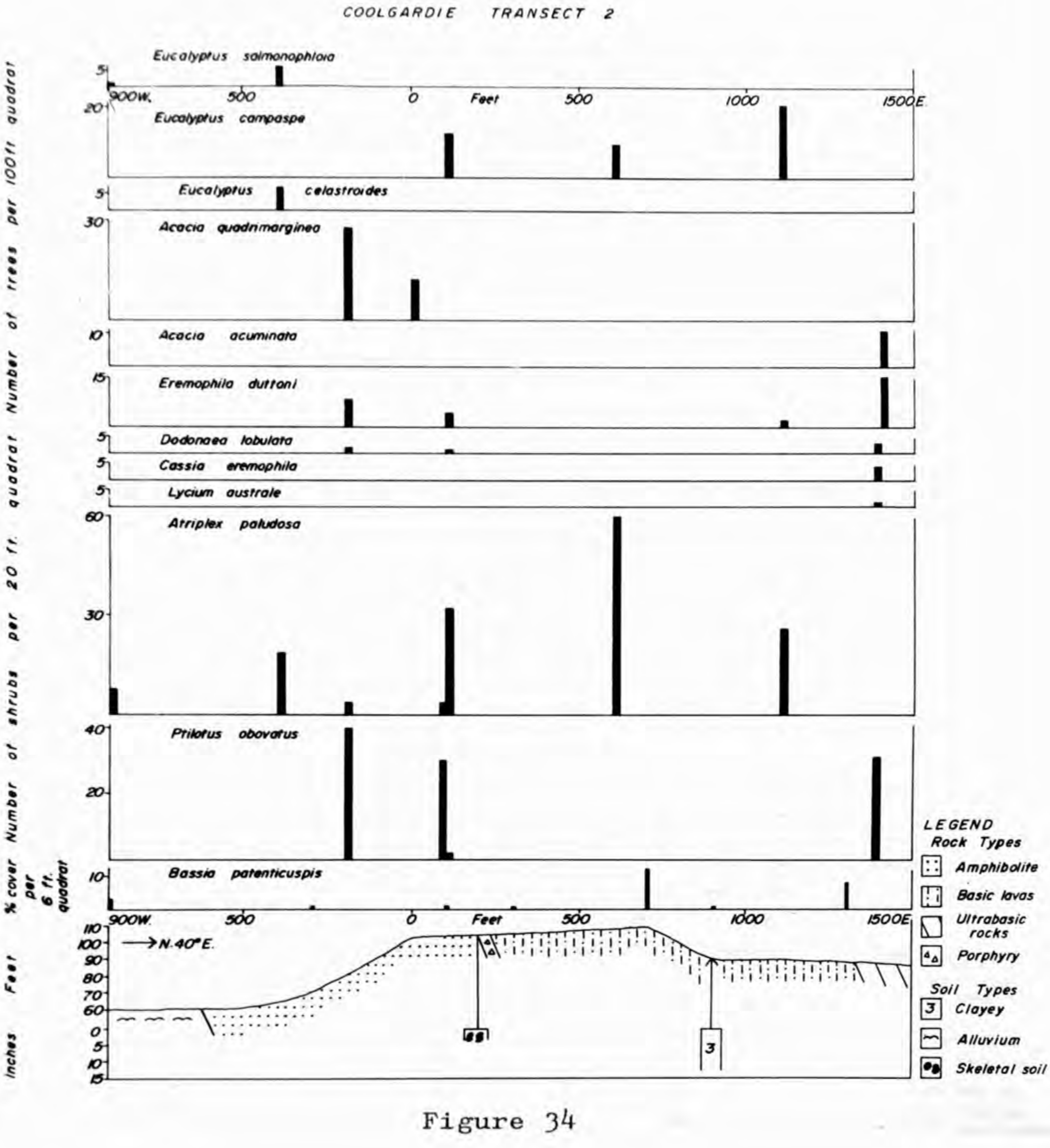


Figure 40

between the vegetation and the underlying rock type; associations are limited in their distributions by the extent of the supporting bedrock. The geology influences both the physical and chemical environment of the vegetation, and both environments must provide conditions which are satisfactory for normal growth and development. The range in the five trace elements as revealed by analysis appears to be a tolerable one for the species growing throughout this area. It is possible that within the plant environment other elements are more critical here and that these provide more precise limits of tolerance which differ between rock types. However, this could not be ascertained without many more soil analyses. The geological control of the vegetation is examined in more detail in the following section.



COOLGARDIE TRANSECT 2
Eucalyptus salmonophloia
Eucalyptus campaspe
Eucalyptus celastroides
Acacia quadrimarginea
Acacia acuminata
Eremophila duttoni
Dodonaea lobulata
Cassia eremophila
Lycium australe
Atriplex paludosa
Ptilotus obovatus
Bassia patenticuspis
900W. 500 0 Feet 500 1000 1500E.
Number of trees per 100 ft. quadrat
Number of shrubs per 20 ft. quadrat
Number of shrubs per 20 ft. quadrat
% cover per 6 ft. quadrat
Feet
Inches
→N.40°E.
LEGEND
Rock Types
Amphibolite
Basic lavas
Ultrabasic rocks
Porphyry
Soil Types
Clayey
Alluvium
Skeletal soil

Figure 34

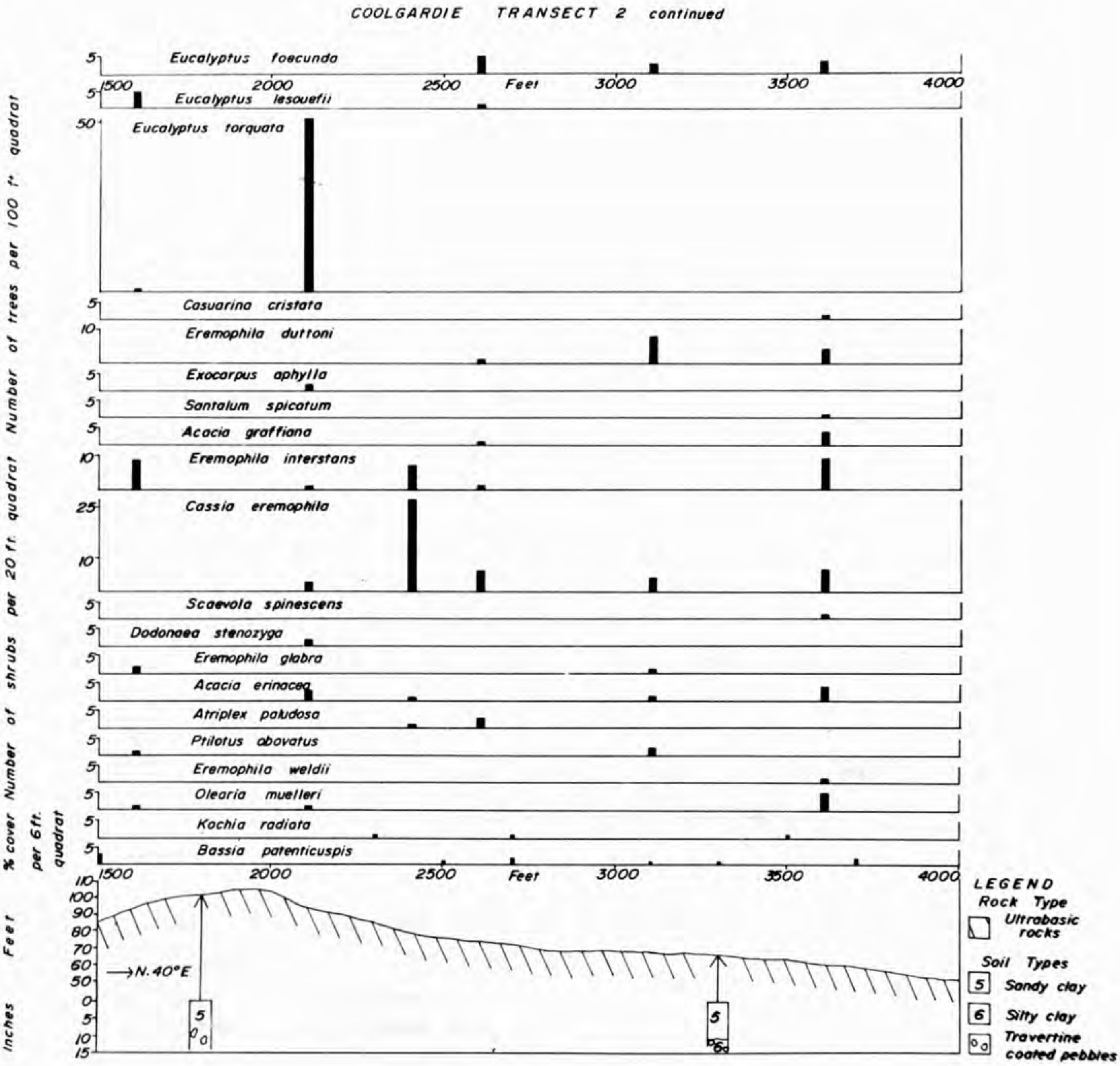

COOLGARDIE TRANSECT 2 continued
Eucalyptus foecunda
Eucalyptus lesouefii
Eucalyptus torquata
Casuarina cristata
Eremophila duttoni
Exocarpus aphylla
Santalum spicatum
Acacia graffiana
Eremophila interstans
Cassia eremophila
Scaevola spinescens
Dodonaea stenozyga
Eremophila glabra
Acacia erinacea
Atriplex paludosa
Ptilotus obovatus
Eremophila weldii
Olearia muelleri
Kochia radiata
Bassia patenticuspis
Number of trees per 100 ft. quadrat
Number of shrubs per 20 ft. quadrat
% cover per 6 ft. quadrat
Feet
Inches
1500
2000
2500
3000
3500
4000
→N. 40°E
LEGEND
Rock Type
Ultrabasic rocks
Soil Types
5 Sandy clay
6 Silty clay
Travertine coated pebbles

Figure 35

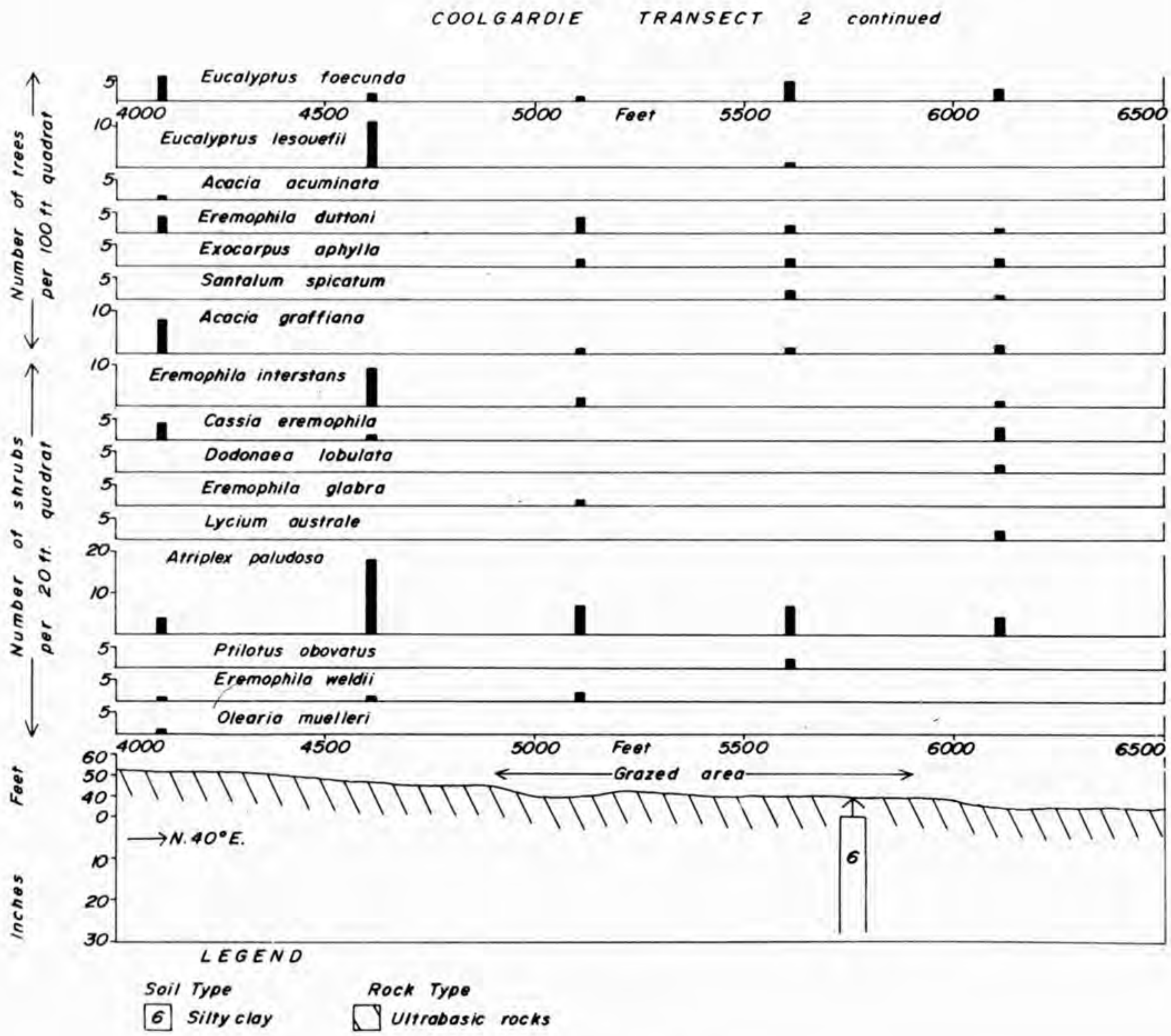

COOLGARDIE TRANSECT 2 continued
Number of trees per 100 ft. quadrat
Number of shrubs per 20 ft. quadrat
Eucalyptus foecunda
Eucalyptus lesouefii
Acacia acuminata
Eremophila duttoni
Exocarpus aphylla
Santalum spicatum
Acacia graffiana
Eremophila interstans
Cassia eremophila
Dodonaea lobulata
Eremophila glabra
Lycium australe
Atriplex paludosa
Ptilotus obovatus
Eremophila weldii
Olearia muelleri
4000
4500
5000
Feet
5500
6000
6500
Grazed area
N. 40° E.
Feet
Inches
6
LEGEND
Soil Type
6 Silty clay
Rock Type
Ultrabasic rocks

Figure 36

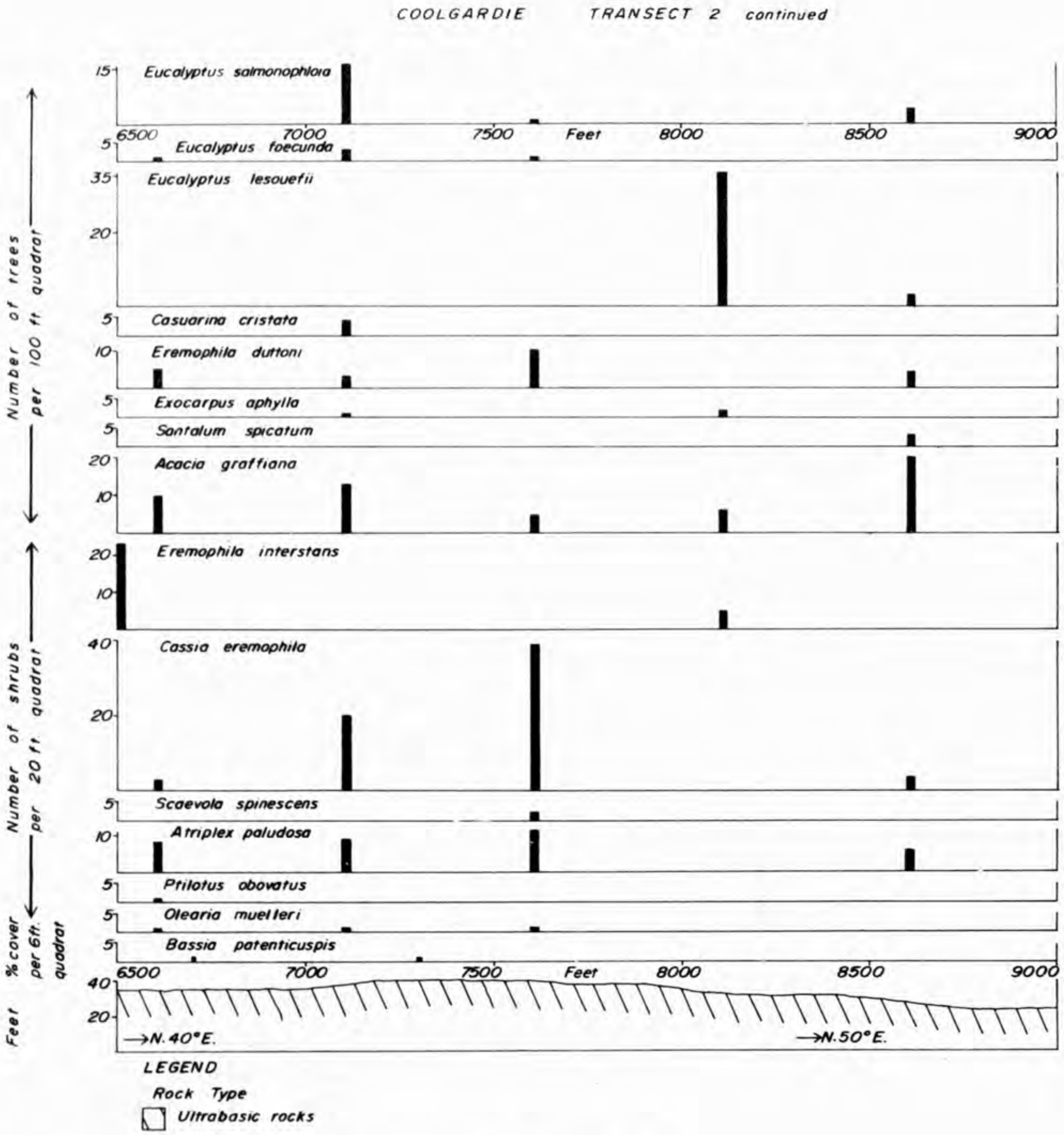

COOLGARDIE TRANSECT 2 continued
Eucalyptus salmonophloia
Eucalyptus foecunda
Eucalyptus lesouefii
Casuarina cristata
Eremophila duttoni
Exocarpus aphylla
Santalum spicatum
Acacia graffiana
Eremophila interstans
Cassia eremophila
Scaevola spinescens
Atriplex paludosa
Ptilotus obovatus
Olearia muelleri
Bassia patenticuspis
6500
7000
7500
Feet
8000
8500
9000
Number of trees per 100 ft. quadrat
Number of shrubs per 20 ft. quadrat
% cover per 6 ft. quadrat
Feet
→N. 40°E.
→N. 50°E.
LEGEND
Rock Type
Ultrabasic rocks

Figure 37

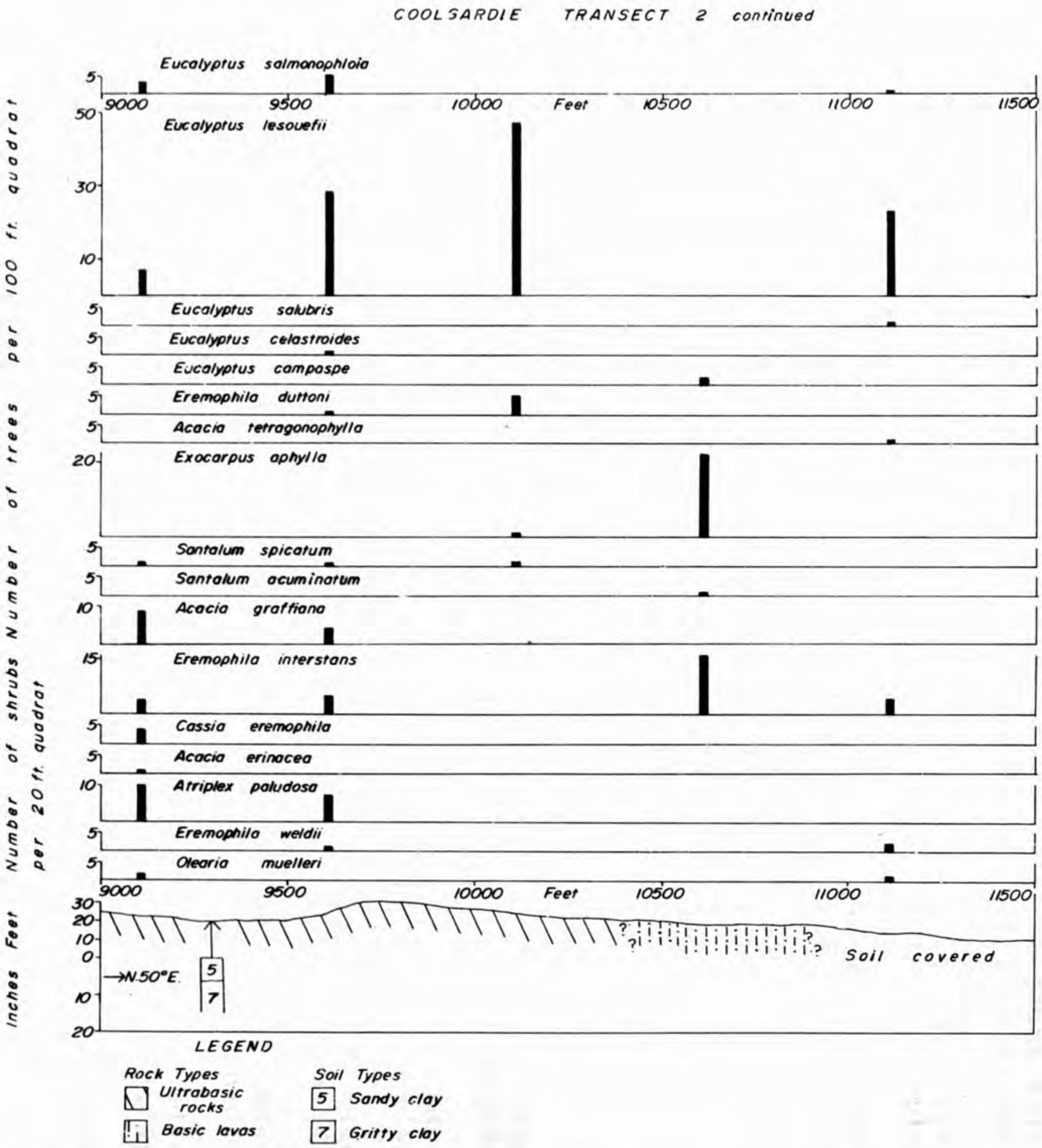

COOLGARDIE TRANSECT 2 continued
Eucalyptus salmonophloia
Eucalyptus lesouefii
Eucalyptus salubris
Eucalyptus celastroides
Eucalyptus campaspe
Eremophila duttoni
Acacia tetragonophylla
Exocarpus aphylla
Santalum spicatum
Santalum acuminatum
Acacia graffiana
Eremophila interstans
Cassia eremophila
Acacia erinacea
Atriplex paludosa
Eremophila weldii
Olearia muelleri
Number of trees per 100 ft. quadrat
Number of shrubs per 20 ft. quadrat
Feet
9000
9500
10000
10500
11000
11500
Feet
Inches
N.50°E.
Soil covered
LEGEND
Rock Types
Ultrabasic rocks
Basic lavas
Soil Types
5 Sandy clay
7 Gritty clay

Figure 38

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	ppm, Ashed Zn	ppm, Ashed Cu	ppm, Oven-dried Ni	ppm, Oven-dried Zn	ppm, Oven-dried Cu	ppm, Soil Ni	ppm, Soil Zn	ppm, Soil Cu	Rock Type
6	Eucalyptus campaspe	T 1 00	Leaves	5.0	82	800	85	4.1	40.0	4.3	60	78	56	Basic lavas
7	Eucalyptus campaspe	T 1 00	Buds	3.8	82	650	140	3.1	29.6	5.3				"
8	Eucalyptus campaspe	T 1 00	Young twigs	4.6	70	840	115	3.2	38.6	5.3				"
12	Eucalyptus campaspe	T 1 500	Leaves	4.5	57	390	85	2.5	17.5	3.8	120	68	72	"
13	Eucalyptus campaspe	T 1 500	Buds	4.1	70	240	115	2.8	9.8	4.7				"
14	Eucalyptus campaspe	T 1 500	Young twigs	4.3	45	440	120	1.9	18.9	5.2				"
2	Eucalyptus foecunda	T 1 2000	Leaves	4.9	237	210	62	11.6	10.3	3.0				Ultrabasic rocks
1	Eucalyptus foecunda	T 1 2000	Fruit	3.5	168	440	100	5.8	15.4	3.5				"
3	Eucalyptus foecunda	T 1 2000	Young twigs	6.0	105	180	95	6.3	10.8	5.7				"
10	Eucalyptus torquata	T 1 4500	Leaves	4.2	165	200	75	6.9	8.4	3.1				"
9	Eucalyptus torquata	T 1 4500	Fruit	4.4	67	200	115	2.9	8.8	5.1				"

Analyses of unmilled, dry-ashed plant material.
CV series samples.

TABLE VIII

COOLGARDIE

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Zn	Cu	ppm, Oven-dried Ni	Zn	Cu	ppm, Soil Ni	Zn	Cu	Rock Type
11	Eucalyptus torquata	T 1 4500	Young twigs	4.6	75	390	130	3.4	17.9	6.0				Ultrabasic rocks
4	Eucalyptus foecunda	T 1 6000	Leaves	4.1	57	350	85	2.3	14.3	3.5	315	35	28	"
5	Eucalyptus foecunda	T 1 6000	Young twigs	5.1	57	420	160	2.9	21.4	8.2				"
17	Eucalyptus torquata	T 1 6500	Leaves	3.7	112	152	56	4.1	5.6	2.1				"
18	Eucalyptus torquata	T 1 6500	Fruit	4.1	95	260	68	3.8	10.7	2.8				"
19	Eucalyptus torquata	T 1 6500	Young twigs	4.5	82	252	154	3.6	11.4	6.9				"
31	Eucalyptus torquata	T 1 7900	Leaves	4.2	123	148	76	5.1	6.2	3.2				"
32	Eucalyptus torquata	T 1 7900	Young twigs	0.5	105	132	88	0.5	0.7	0.4				"
33	Eucalyptus campaspe	T 1 12600	Leaves	4.2	70	320	52	2.9	13.4	2.2	145	20	58	Soil covered
34	Eucalyptus campaspe	T 1 12600	Young twigs	5.1	70	296	48	3.5	15.1	2.4				"
15	Eucalyptus campaspe	T 1 13100	Leaves	4.9	62	390	230	3.0	19.1	11.2				"

Analyses of unmilled, dry-ashed plant material.
CV series samples.

TABLE VIII cont. COOLGARDIE

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Zn	Cu	ppm, Oven-dried Ni	Zn	Cu	ppm, Soil Ni	Zn	Cu	Rock Type
16	Eucalyptus campaspe	T 1 13100	Young twigs	5.4	43	390	95	2.3	21.1	5.1				Soil covered
25	Eucalyptus campaspe	T 1 18900	Leaves	4.9	50	380	52	2.4	18.6	2.5	130	75	55	Meta-sediments
27	Eucalyptus campaspe	T 1 18900	Buds	4.3	70	388	84	3.0	16.7	3.6				"
28	Eucalyptus campaspe	T 1 18900	Fruit	4.3	70	380	100	3.0	16.3	4.3				"
26	Eucalyptus campaspe	T 1 18900	Young twigs	5.1	50	264	88	2.5	13.4	4.5				"
22	Eucalyptus campaspe	T 1 19400	Leaves	5.1	70	532	88	3.5	27.2	4.5				"
24	Eucalyptus campaspe	T 1 19400	Buds	3.5	165	440	80	5.7	15.4	2.8				"
23	Eucalyptus campaspe	T 1 19400	Young twigs	4.6	95	532	104	4.3	24.5	4.8				"
29	Eucalyptus lesouefii	T 1 19900	Leaves	5.2	268	132	48	13.9	6.9	2.5				"
30	Eucalyptus lesouefii	T 1 19900	Young twigs	6.4	165	200	64	10.5	12.8	4.1				"
20	Eucalyptus lesouefii	T 1 20400	Leaves	4.9	35	140	170	1.7	6.9	8.3				"

Analyses of unmilled, dry-ashed plant material.
CV series samples.

TABLE VIII cont. COOLGARDIE

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Zn	Cu	ppm, Oven-dried Ni	Zn	Cu	ppm, Soil Ni	Zn	Cu	Rock Type
21	Eucalyptus lesouefii	T 1 20400	Young twigs	6.3	28	176	64	1.7	11.1	4.0	65	48	140	Meta-sediments
35	Eucalyptus foecunda	T 3 3100	Leaves	4.5	165	252	44	7.4	11.3	2.0				Ultrabasics
36	Eucalyptus foecunda	T 3 3100	Buds	3.2	105	252	42	3.3	8.0	1.3				"
37	Eucalyptus foecunda	T 3 3100	Young twigs	0.5	123	244	44	0.6	1.2	0.2				"

Analyses of unmilled, dry-ashed plant material.
CV series samples.

TABLE VIII cont. COOLGARDIE

3. The importance of geological control over vegetation distributions

The distribution of the vegetation associations in the Coolgardie area coincides with the underlying geology to a marked extent. This factor of the environment is obviously of prime importance in influencing the growth and distribution of the vegetation associations here. The geology influences the relief and drainage of an area, and also operates through the provision of a soil environment which is physically and chemically satisfactory for the plants supported.

At the Three Mile Hill the basic lavas support a relatively simple association composed predominantly of Eucalyptus campaspe, Atriplex paludosa and Bassia patenticuspis (Plate 8). Other species, such as E. lesouefii and E. celastroides, grow occasionally, but it is the small silver gimlet trees and the low, relatively unbroken cover of saltbush that serves to differentiate the outcrop of this rock type.

The extent of the second area underlain by basic lavas, to the north-east of the ultrabasic rocks, is not precisely known. The area differs from that at the Three Mile Hill in that outcrop is uncommon and there is much soil cover over the lower-lying ground. A low lateritic rise is the only relief feature here, with abundant lateritic scree and quartz float covering the ground surface. Nevertheless, there is an observable change in vegetation associations at approximately point 8574 feet east along transect 1, this apparently corresponding with the junction of the ultrabasic and basic rocks. Whereas the ultrabasic rocks, lying to the south-west of this contact, can be distinguished by their varied association of Eucalyptus foecunda, E. torquata (occupying the higher ground), Eremophila duttoni, E. interstans, Cassia eremophila, Acacia graffiana, Dodonaea lobulata, Eremophila glabra, Scaevola spinescens, Atriplex paludosa and Olearia muelleri, the association on the basics is less varied. Eucalyptus campaspe is present in the area but not frequent, and the tree layer is dominated by E. salubris. A. paludosa becomes abundant, and, by contrast with the Three Mile Hill, Eremophila interstans is also common. Shrubs, such as E. glabra and Acacia graffiana, appear infrequently. The association growing over the basic lavas in this locality is therefore somewhat modified from that characterising the basic rocks at the Three Mile Hill. This modification, exemplified by the dominance of Eucalyptus salubris over E. campaspe, and the frequency of Eremophila interstans in the shrub layer, may be due to the physical nature of the environment here. Instead of the scree covered and skeletal soil, as occurs on the outcrop at the Three Mile Hill, the basic lavas here are masked by a deeper soil cover and the ground is much flatter. Thus conditions may be more acceptable for such species as Eucalyptus salubris and Eremophila interstans, which can successfully compete for places in the association. Eucalyptus campaspe may prefer a stonier terrain over basic rocks or may not be able to compete very successfully with E. salubris where basic lavas are soil covered. The laterite in the low rise to the north-east overlies the basic rocks and is marked by a different association which tends to be more diversified. Eucalyptus celastroides dominates the tree layer and Cassia eremophila and Acacia erinacea are common in the shrub layer.

The amphibolite sill in the vicinity of the Three Mile Hill can be traced by the growth of a particular association as well as by its pronounced topography. The association is composed predominently of Acacia quadrimarginea, Eremophila duttoni, Dodonaea lobulata and

Ptilotus obovatus (Plate 7). This association is confined to the amphibolite sill within this area and indicates the importance of the geological control in its distribution. Although relief and drainage may play some part in this distribution these factors are considered to be of secondary importance only, as similar physical factors operate over part of the adjacent basic lavas, yet do not support this particular association.

The boundary between the basic lavas and the ultrabasic rocks can be picked out by the change in associations. The open Eucalyptus woodland of the ultrabasic rocks is dominated by E. foecunda. E. lesouefii becomes a co-dominant species in certain localities (Plate 9) and E. torquata assumes importance on ridges of higher ground (Plate 10). The shrub layer is both denser and the variety of species composing it much greater. While Eremophila interstans, Cassia eremophila and Atriplex paludosa are the most ubiquitous shrubs growing over this rock type, other shrubs frequently encountered include Eremophila duttoni, Dodonaea lobulata, Acacia graffiana, Scaevola spinescens, Lycium australe, Eremophila glabra, E. weldii, Acacia erinacea and Olearia muelleri.

The underlying geology is masked by soil cover to the north-east of the area of ultrabasic rocks. The extent of this area can be seen by its predominant growth of Eucalypts (Plate 11). Several species are represented here, including E. salmonophloia, E. lesouefii, E. transcontinentalis, E. salubris and E. ?oleosa. The shrub layer, by comparison, is of low density and has little species variety. Exocarpus aphylla, Eremophila interstans and Atriplex paludosa are the larger shrub species represented, and together with the smaller perennials Kochia georgei, K. radiata and Bassia patenticuspis, grow throughout the area. As judged by the consistency of the vegetation association here, the soil covered area appears to be of one lithological unit.

Rocks belonging to the metasedimentary series occur between the breakaways and the Mungari granite. The vegetation association here is again one that is unique to these rocks as they occur within the Coolgardie area, serving to distinguish them from other abutting rock types. Eucalyptus lesouefii, E. salubris and E. campaspe dominate the tree stratum, while Atriplex paludosa is the only shrub species which is widely spread (Plate 7). The drainage pattern plays a primary role in the control of the distribution of the vegetation over part of the metasediments where the ground has become saline. In this small local drainage area, stretching along transect 1 from approximately 20700 feet east to 21900 feet east, the concentration of salts in the soil has been built up, thus affecting the vegetation supported. The halophytic species, Arthrocnemum halocnemoides, assumes importance with Atriplex paludosa, while other shrubs are absent. Trees tend to be confined to the higher patches of ground and are less densely distributed where the soil is saline.

The Mungari granite at the north-east end of the field area (Figure 40) supports an association which is very typical of outcropping areas of this rock type within the Eastern Goldfields region. Eucalypts are generally rare, and Acacia acuminata dominates the vegetation with Eremophila ?gibsoni and Ptilotus obovatus. It appears that, where the granite does not outcrop so readily and is masked by a soil cover in excess of approximately fifteen inches depth, a modified vegetation association occurs. The north-eastern end of transect 1 extended over such an area (Figure 33). A. acuminata, E. ?gibsoni and P. obovatus occur frequently over part of this area, but the tree stratum is dominated by

E. oleosa and E. foecunda. The shrub layer is much diversified; Eremophila duttoni, Dodonaea lobulata, Cassia eremophila, Scaevola spinescens and other species grow here, and the association is more varied than that occupying the outcropping areas of this rock type.

Thus within the Three Mile Hill-Mungari area the distribution of the vegetation associations is controlled by the underlying geology. This control may be operating in a number of ways. The relative hardness of the rocks may be important in that their rate of weathering influences, among other things, the topographical features of the land and the degree of soil development. For example, the basic lavas are generally more resistant to erosion than are the adjacent ultrabasic rocks, and are consequently encountered as areas of relief where soil is skeletal and outcrop common. The association growing here is therefore one which either prefers or can tolerate such a physical environment. As has been noted above in this section, modification may occur in the vegetation association when such rocks do not outcrop so readily. Similarly, the association characteristic of the area underlain by ultrabasic rocks is apparently one which is best fitted to grow where soils are deeper and better developed.

If the physical environment over these rock types was different it is highly probable that the association would be consequently modified.

The geology also affects the drainage features of an area and this may play an important part in influencing the particular vegetation association which develops. The introduction of salts into the soil in drainage basins has already been mentioned. Attention may also be drawn to the granite area at Mungari. Outcrops of granite and gneiss are important throughout the region as water catchments. Hollows in the rocks may hold water after rain and many of the outcrops provide soaks and gnamma holes. Thus the plants growing around such localities may require more water than do species growing elsewhere, or may be more successful in competing for it. These areas may consequently be marked by a thick growth of annuals in late winter and spring. However, this is only one aspect of a granite environment; plants must also be able to tolerate other features, such as the slightly acid sandy soils.

The geology also influences the chemical nature of the soil environment. This must be satisfactory for normal plant growth. There is little variation in the soil concentration of the five trace elements overlying different rock types here. However, it is possible that other elements are more critical, varying with the type of bedrock and providing concentrations in the soil environment which are more favourable for some plants than for others. The cation exchange capacity will vary between skeletal and mature soils. This may be an influential factor in plant distributions and should repay investigation.

(B) THE MOUNT HUNT AREA, BOULDER

1. The distribution of the vegetation associations

A remarkably large number of vegetation associations is encountered within the relatively small field area of Mt. Hunt. Most of the associations succeed each other in rapid succession and the same association may recur in several localities as environmental conditions which are favourable to them are repeated. Most of the trees grow on the higher ground on rises and on the slopes of Mt. Hunt where they attain a moderate density, forming areas of open woodland (Plate 12). *Eucalyptus foecunda* is the most widespread tree species (Figure 41). It is associated with a variety of different plants and forms the dominant tree in associations which are quite distinct from each other. For example, it occurs where *Acacia leptoneura* and *Triodia irritans* are the most important species in the understorey (Figures 41 and 42), while elsewhere it grows with *Eucalyptus lesouefii*, *Eremophila interstans*, *Atriplex paludosa* and other shrub species. Where *E. foecunda* becomes the sub-dominant tree in an association *E. lesouefii* assumes the position of the dominant Eucalypt.

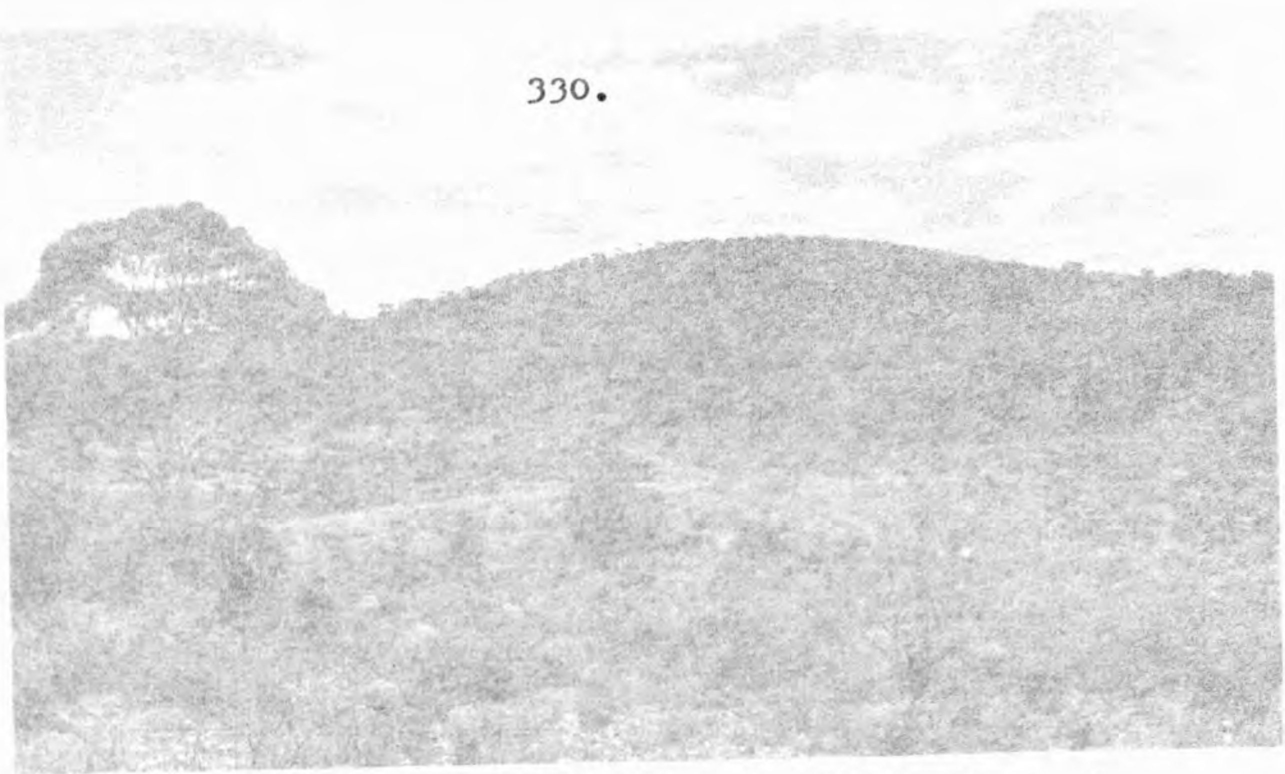
These two species may be found together as co-dominants, as is the case to the east of Mt. Hunt.

Trees are generally absent from lower ground around Hannan's Lake and the saltpans and saline areas, although a few scattered Eucalypts of the species lesouefii grow where the association is composed largely of halophytic plants (Plate 13). In these lower-lying saline localities the dominant species are Atriplex paludosa and other Chenopodiaceae including Arthrocnemum halocnemoides and Kochia glomerifolia; Disphyma australe (Ficoidiaceae) also assumes importance, and Eremophila interstans and Cratystylis subspinescens may occur occasionally. The ground flora beneath these shrubs is well developed during late winter and spring. Erodium circutarium, E. cygnorum, Helipterum demissum and Senecio glossanthus grow with the grasses Hordeum leporinum, Trisetum pumilum and Serrafalcus arrenanius.

Acacia quadrimarginea is dominant over large parts of the area, including the highest parts of Mt. Hunt. It forms areas of low scrub and only rarely grows with Eucalypts. It is a characteristic species in several different associations. It may occur together with Eremophila duttoni, Dodonaea lobulata and Ptilotus obovatus, or in other localities with Eremophila sp. J.B./W.A. III, Dodonaea boroniaefolia, Prostanthera wilkieana, Ptilotus obovatus and/or Helipterum adpressum. H. adpressum, a small cushiony Composite, and P. obovatus vary in distributional density, sometimes forming their own dense communities in limited patches. The ephemeral ground flora in these two associations is composed of many species. Helipterum polygalifolium, H. battii, another unidentified Composite No. J.B./W.A. 119, and Athrixia athrixioides are all common, and other ephemerals which grow here include Erodium cygnorum, E. circutarium, Calotis hispidula, Calandrinia pusilla, Trachymene ornata, Trisetum pumilum, Helipterum demissium and H. humboldtianum.

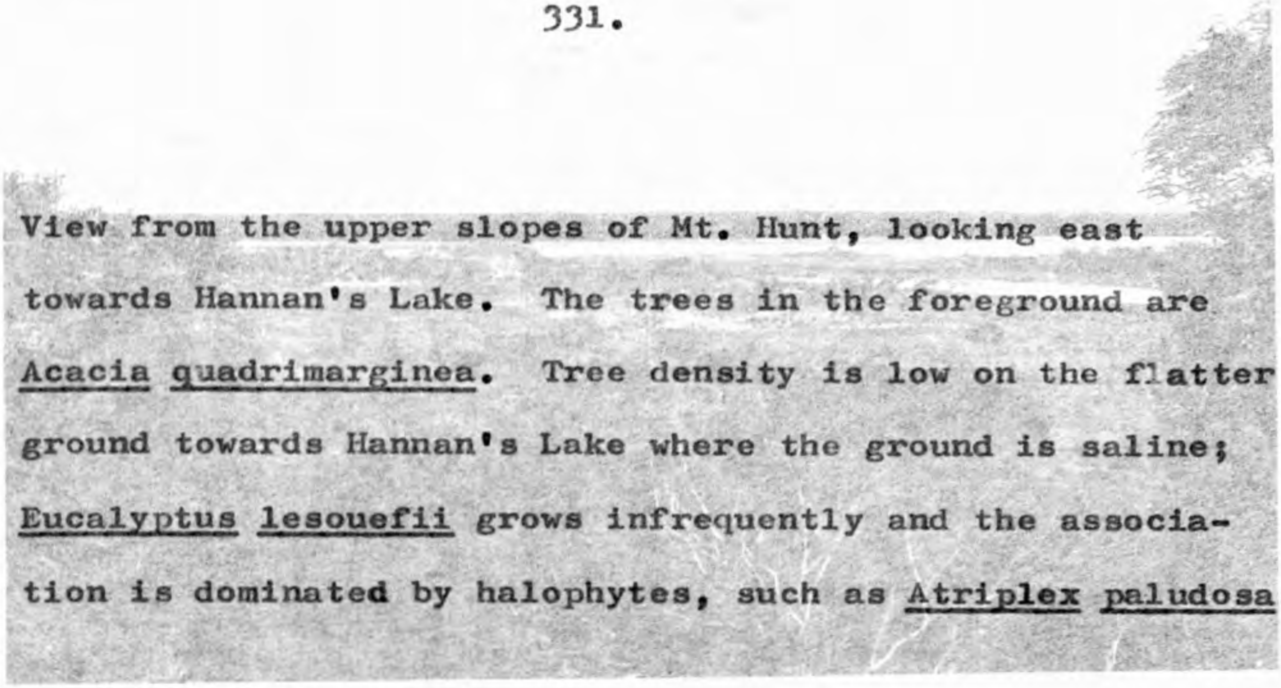
In another area Acacia quadrimarginea dominates an association where other shrubs present are Eremophila decipiens, Dodonaea lobulata and Ptilotus obovatus. The ground flora includes many of the species found elsewhere with A. quadrimarginea.

It is noticeable in many of these areas that as environmental conditions alter and associations are consequently modified the genus Eremophila persists although the species will change. This is also true of

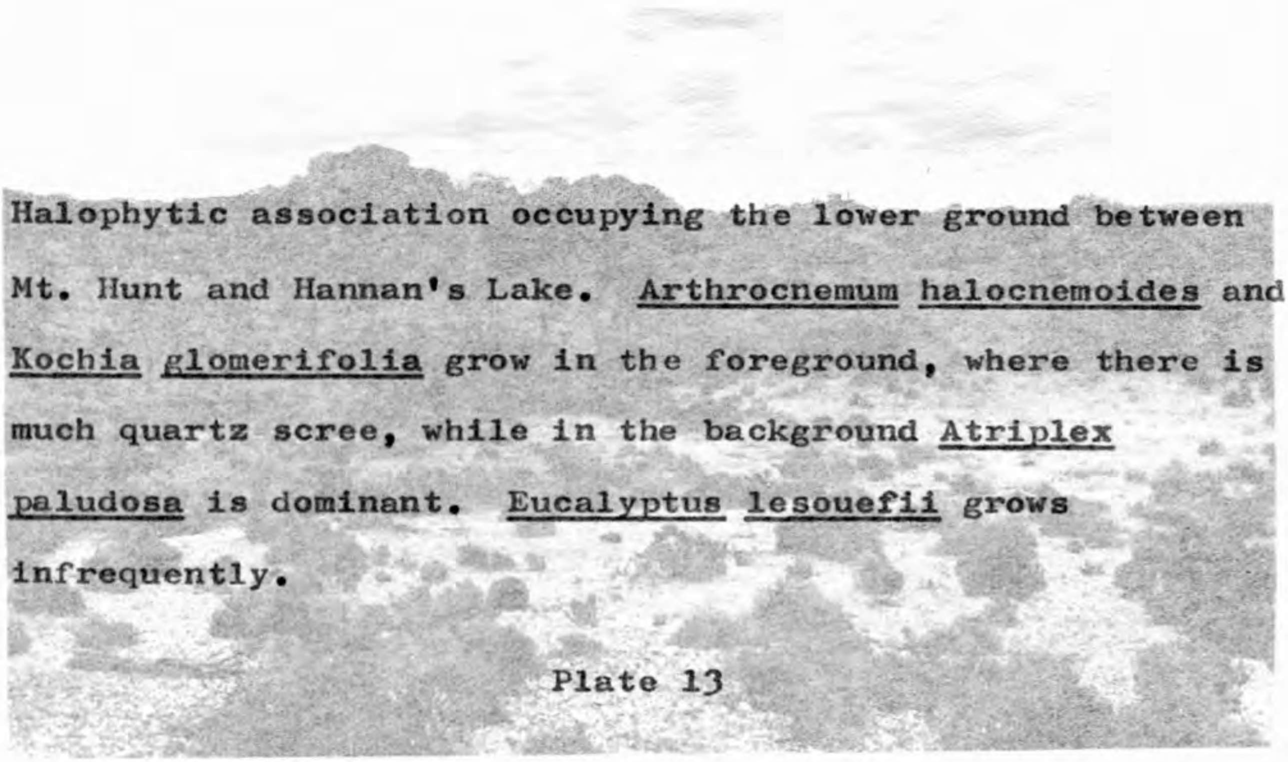


The Mt. Hunt area, with Mt. Hunt in the background. The middle distance is an area of soil covered terrain, and tends to be saline, hence the low frequency of trees and the dominance of Atriplex paludosa. Eucalyptus foecunda enters the association as the ground rises towards the lower slopes of the hill. The upper slopes are dominated by Acacia quadrimarginea.

Plate 12



View from the upper slopes of Mt. Hunt, looking east towards Hannan's Lake. The trees in the foreground are <u>Acacia quadrimarginea</u>. Tree density is low on the flatter ground towards Hannan's Lake where the ground is saline; <u>Eucalyptus lesouefii</u> grows infrequently and the association is dominated by halophytes, such as <u>Atriplex paludosa</u>.



Halophytic association occupying the lower ground between Mt. Hunt and Hannan's Lake. <u>Arthrocnemum halocnemoides</u> and <u>Kochia glomerifolia</u> grow in the foreground, where there is much quartz scree, while in the background <u>Atriplex paludosa</u> is dominant. <u>Eucalyptus lesouefii</u> grows infrequently.

Plate 13

VEGETATION MAP TO SHOW THE DISTRIBUTION OF FOUR SPECIES IN THE MT. HUNT AREA, BOULDER

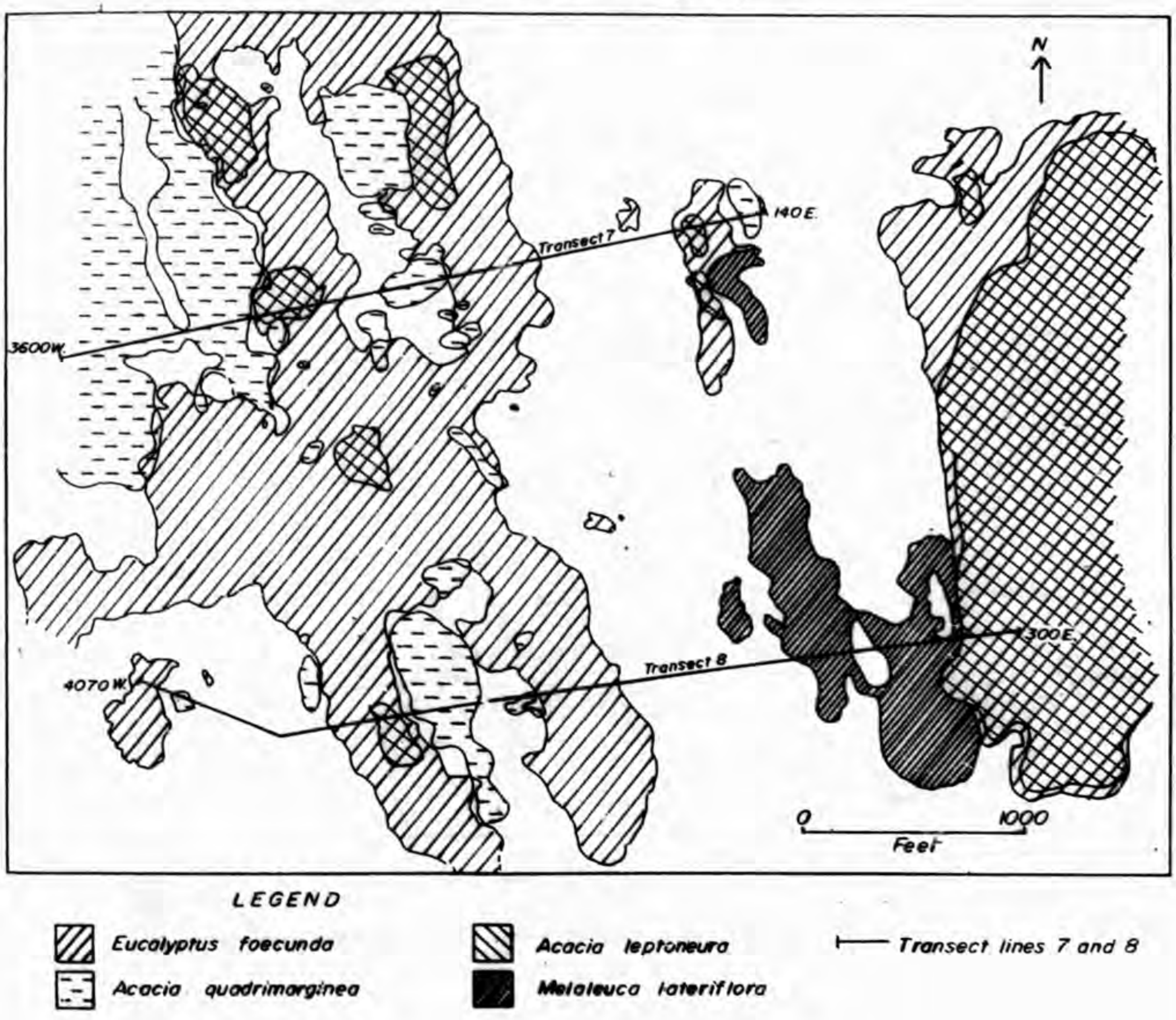


Figure 41

VEGETATION MAP TO SHOW THE DISTRIBUTION OF THREE SPECIES
IN THE MT. HUNT AREA, BOULDER

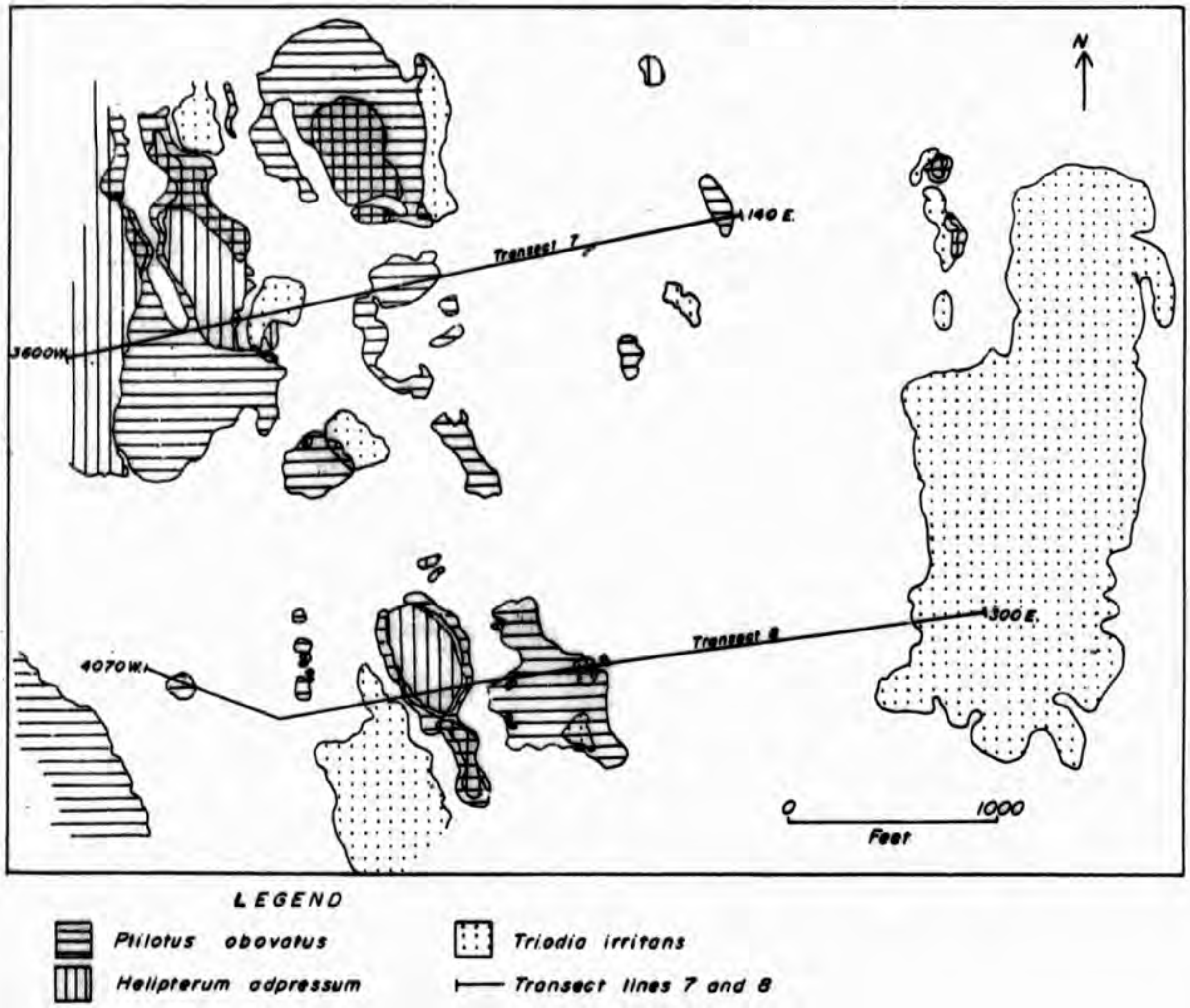


Figure 42

the genus Dodonaea.

In certain localities in the area Cassia eremophila and Acacia graffiana commonly occur together as the most prominent members of an association. E. foecunda is present in the low density tree layer, while other occasional small shrubs are Eremophila weldii, Acacia erinacea, Westringia rigida and Olearia muelleri. Calotis hispidula and Athrixia athrixioides are the commonest of the spring ephemerals, and Helipterum polygalifolium, Calandrinia pusilla, Trisetum pumilum and Gnephosis ?skirrophora may also grow.

The spinifex grass, Triodia irritans, grows in considerable density over limited areas where Eucalyptus foecunda is either absent or less prominent in the association. It occurs with Acacia leptoneura and Westringia rigida; Casuarina helmsii and Melaleuca lateriflora may also be present. The ground flora is sparse, with Calotis hispidula, Athrixia athrixioides and Gnephosis ?skirrophora growing in low frequency.

2. The factors governing the distribution of the vegetation associations

(a) Relief and drainage

Mt. Hunt is one of the few hills in the Boulder area, and reaches to a height of over 1350 feet above sea level. It stands in marked contrast with the greater part of the surrounding area which is more or less flat and undulating. Smaller knolls and prominences are evident in the immediate vicinity, such as those on the western shores of Hannan's Lake, and are formed by outcrops of serpentinite and porphyry. The metajaspilite bands form narrow upstanding ridges in some localities and small knolls are sometimes formed where metadolerite and metabasalt outcrop on the sides of the hill. Hannan's Lake lies to the east of Mt. Hunt. Its surface is flat and stands at 1170 feet above sea level. It is dry for the greater part of the year, its surface occasionally broken with small islands of carbonated serpentinite upstanding from its floor.

Drainage from Mt. Hunt is radial. A number of dry creeks runs down the slopes of the hill to the flats below. The creeks remain dry for most of the year, forming water courses only after thunder storms or rainy spells. Most of the water eventually finds its way into the flats and salt pans in the area or into Hannan's Lake.

Field observation indicates that relief and topographic position do not play a major role in determining the distribution of associations in the Mt. Hunt area. Different associations succeed one another over the sides of the hill where factors of slope and aspect are similar. The association of Acacia quadrimarginea, Eremophila sp. J.B./W.A. III, Dodonaea boroniaefolia, Ptilotus obovatus and Helipterum adpressum, growing on the top and upper slopes also grows at lower elevations where exposure is not so great and relief is more abundant.

Drainage and the introduction of salts into the soil markedly affect the development of the association growing in the lower, flatter parts of the locality. Where the creeks open out into the flats and pans at the base of Mt. Hunt salt concentration tends to build up in the soil and many trees and shrubs are prohibited from developing (Plate 13). With the exception of the highly saline pans, which are devoid of vegetation, a halophytic association is characteristic of such areas. Eucalyptus lesouefii and Eremophila interstans grow occasionally but the dominant members of the association are shrubs which can tolerate the higher salt concentrations. Atriplex paludosa and Arthrocnemum halocnemoides occur most commonly, but Cratystylis subspinescens, Kochia pyramidata, K. glomerifolia and Disphyma australe also occur quite frequently. Elsewhere drainage appears to have less effect on the development of associations. The water holding capacity of the soil varies between localities. Some areas of outcrop carry large amounts of scree with small pockets of soil, with a consequently low water retention, while other flatter areas have deeper soils and are able to retain water to a greater extent. This may have some effect on the development of particular species which are found in these localities, and may partly account for their presence. However, some species which are dominant members in some associations here, such as Cassia eremophila and Triodia irritans, grow equally well on skeletal and on deeper soils on Mt. Hunt.

(b) Geology and soils

The Mt. Hunt area has been mapped in detail by Western Mining Corporation (Figure 43). It is one of the few areas of undisturbed outcrop in the locality, and consists of a tightly folded anticlinal structure with a steep pitch to the north. Evidence from pillow lavas and from the trend of the beds indicates that the anticlines and synclines have been overturned, the anticline lying vertically.

All the rocks in the Kalgoorlie region have suffered greenschist facies metamorphism. As a result of this the basic and ultrabasic rocks are extensively chloritized and carbonatised; minerals present are albite, zoisite, serpentinite, talc, epidote, actinolite/tremolite, quartz, carbonates, sericite, chlorite and possibly biotite. Most of the rock types found at Kalgoorlie occur at Mt. Hunt, the important exception being the auriferous Golden Mile Dolerite. A summary of the main rock types at Mt. Hunt follows (G. Bartram, personal communication).

Serpentinite:

This consists of 90% to 95% serpentinite, showing pseudomorphs after olivine. The largest outcrop in the Mt. Hunt area lies to the east of the hill on the western shores of Hannan's Lake. Smaller outcrops lie on the eastern hillslopes and further to the south.

GEOLOGICAL MAP OF THE MT. HUNT AREA, BOULDER

(After G. Bartram)

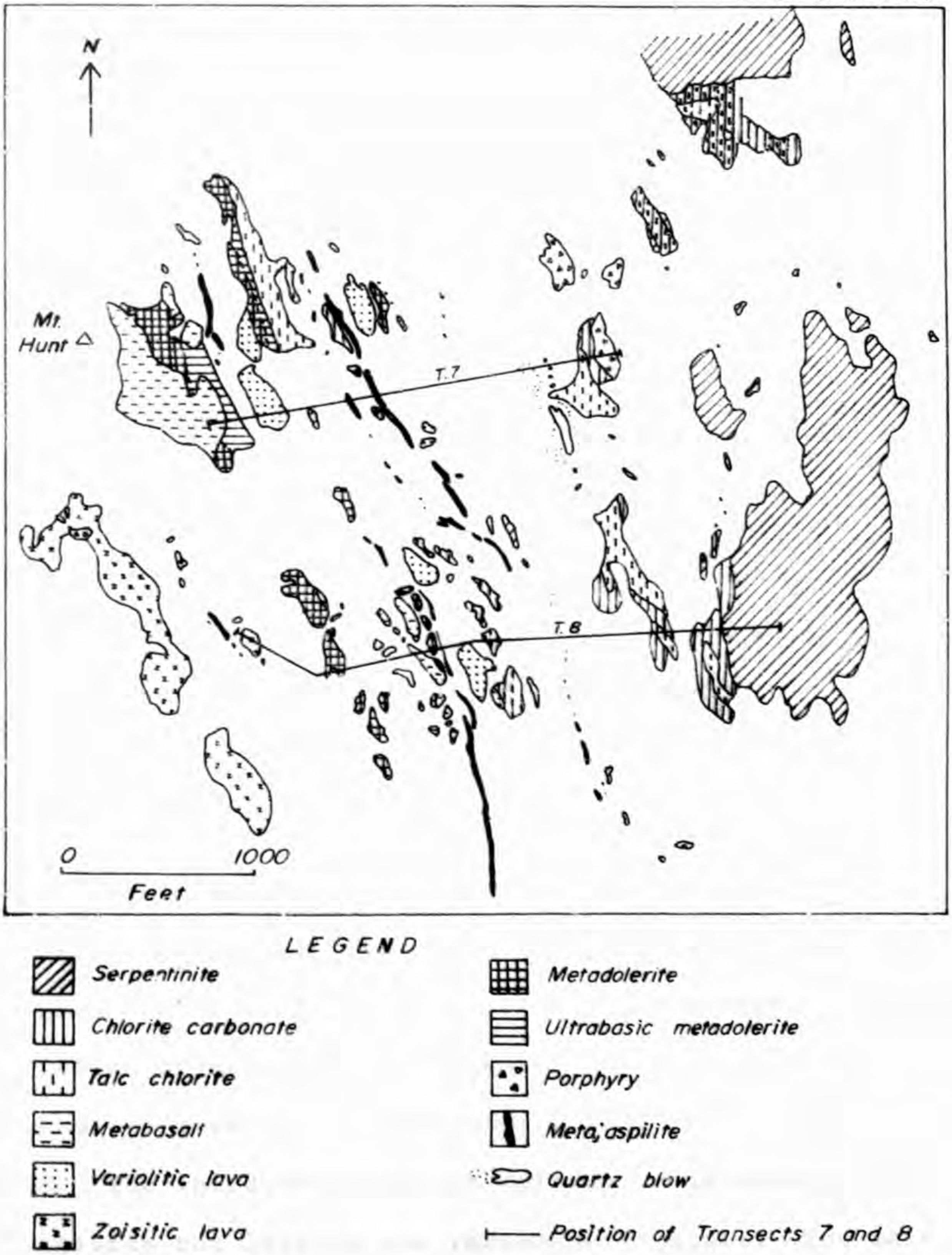


Figure 43

Serpentinite alteration products:

These consist of chlorite talc rock, and carbonated serpentinite. The most important outcrops of carbonated serpentinite occur on the west of the large south-east outcrop of serpentinite. It is highly weathered and friable.

Metadolerite:

This is typically differentiated into actinolite/tremolite-albite rock, and rock which is dominantly actinolite/tremolite, tending towards ultrabasic in composition. Outcrops of metadolerite lie on the east slopes of Mt. Hunt with other exposures to the south-east of the hill.

Metabasalt:

There are three variations of this rock type. Variolitic metabasalt contains varioles consisting of zoisite or epidote. Typically it contains pillows, the margins of the pillows being marked by varioles. A second variation of metabasalt contains megascopic acicular actinolite/tremolite. This forms the summit of Mt. Hunt. The third variation is zoisitic metabasalt, rich in zoisite but lacking the variolitic texture. The main outcrops occur to the south of the hill.

Banded Iron Formation or metajaspilite:

This is typically highly siliceous and at depth consists of carbonaceous shales. The metajaspilite forms the main beds for mapping the area, forming resistant bands which withstand erosion.

Porphyry:

There are three main outcrops to the east of Mt. Hunt near Hannan's Lake, smaller pods occurring further south. The porphyry is typically albite. Additional information on the three main outcrops has been provided by W. O'Beirne (personal communication). The most northerly outcrop and the one to the east of it are both heavily cut by late quartz veining. This quartz veining is one of the last phases of igneous activity in the Archaean in the Kalgoorlie area. These two outcrops contain more pyrite and other sulphide minerals associated with the quartz veining in much greater abundance than the outcrop to the south. In this southerly outcrop, by comparison, there is greater evidence of assimilation of country material.

Quartz reef:

There is a small quartz blow to the east of Mt. Hunt.

Over much of Mt. Hunt soils are shallow and skeletal. Each outcrop marked on the geological map of this area is characterised by immature soils, which are often extremely stony and covered with scree. They attain a depth of only a few inches and show no development into horizons. In colour they are dark reddish brown (2.5YR 3/6 to 5YR 3/4), and in texture are usually a sandy-clay loam. They are mainly acidic in reaction, although a slightly alkaline reaction may be obtained infrequently, pH ranging from 4.8 to 7.4.

Soils are better developed in the soil covered areas shown on the geological map. These soils are solonised, with the exception of the area on the lower ground lying between Hannan's Lake and the east slopes of the hill. One profile examined in a solonised brown soil reveals an A horizon extending to thirteen inches and brown in colour (7.5YR 5/4 to 7.5YR 5/6). The soil is loosely textured with some small travertine coated nodules present. Its reaction is alkaline, a pH of 8.0 being recorded. The B horizon extends from thirteen to eighteen inches and deeper, the soil becoming paler in colour with occasional white powdery patches. The proportion of clay present increases. The pH recorded here was 8.3.

The low-lying area between Hannan's Lake and the east slopes of Mt. Hunt has a soil consisting in part of transported material. As witnessed by the mixture of dissorted stone fragments in a creek profile here, the soil, at least in this immediate area, has not developed from weathering of the underlying bedrock. Four horizons are visible. From the surface to seven inches depth is a clay loam, with very few pebbles and a pH of 8.3. From seven to nine inches is a gravelly, stony horizon with a coarse sandy texture. The pH recorded was 8.8, and there were many more plant roots present. From nine to sixteen inches is a horizon of sandy-clay loam, containing some fine gravel. At sixteen inches a hard consolidated soil is encountered, with some small pieces of gravel.

Soils in the salt pans and lake are very saline, the salts left after evaporation forming a white encrustation on the surface. A profile examined on the western side of Hannan's Lake showed an upper horizon extending to four inches depth with a silt-clay texture and platy structure. There were no stones or plant roots present. From four to twelve inches the soil texture changes to a sandy-clay loam with a crumb structure. Stones and plant roots were absent. At twelve inches the weathered serpentinite bedrock was struck.

Soils were analysed for various trace and major elements (Figures 44 and 45 and Table XII). Of the five trace elements for which analysis was carried out chromium was generally present in the highest concentrations. The area of carbonated serpentinite at the eastern end of transect 7 reveals an increase in this element in the overlying soil, values rising from 325 ppm on the adjacent porphyry to 530 ppm on the carbonated serpentinite. Once this chromium-enriched rock is left soil concentration falls again. The highest concentration of this element in the soil occurs at 1900 feet west: from a value of 335 ppm at 1800 feet west, where there is an outcrop of metajaspilite, the soil chromium content at 1900 feet west rises to 1370 ppm. This may be accounted for by the presence of a creek at 1920 feet west and the point 1900 feet west occurs on the side of a narrow but moderately steepsided valley. Soil chromium values fall again to 220 ppm at 2100 feet west where soils are developed from ultrabasic rocks. The presence of a small serpentinite pod at 2300 feet west is marked by a slight peak of 395 ppm on the graph, and after falling to 200 ppm on the adjacent variolitic lavas, values creep up again and fall sporadically over the upper slopes of Mt. Hunt where the underlying rocks are metadolerite and metabasalt.

Soil nickel concentrations along transect 7 follow a somewhat similar pattern to that given by chromium, excepting that the values are generally lower. The soil does not exhibit the same peak in concentration over the eastern outcrop of carbonated serpentinite, but higher values exist at the base of this outcrop at the contact with the lower-lying soil covered area: the nickel concentration rises from 300 ppm on the carbonated serpentinite to 420 ppm where the underlying rock type is masked by soil. This could be accounted for by the fact that nickel is generally a more mobile element than is chromium. As with chromium, peaks in the soil nickel concentration also occur at 1900 feet west and at 2300 feet west, that at 2300 feet west reaching a value of 575 ppm and exceeding the soil chromium value at this point.

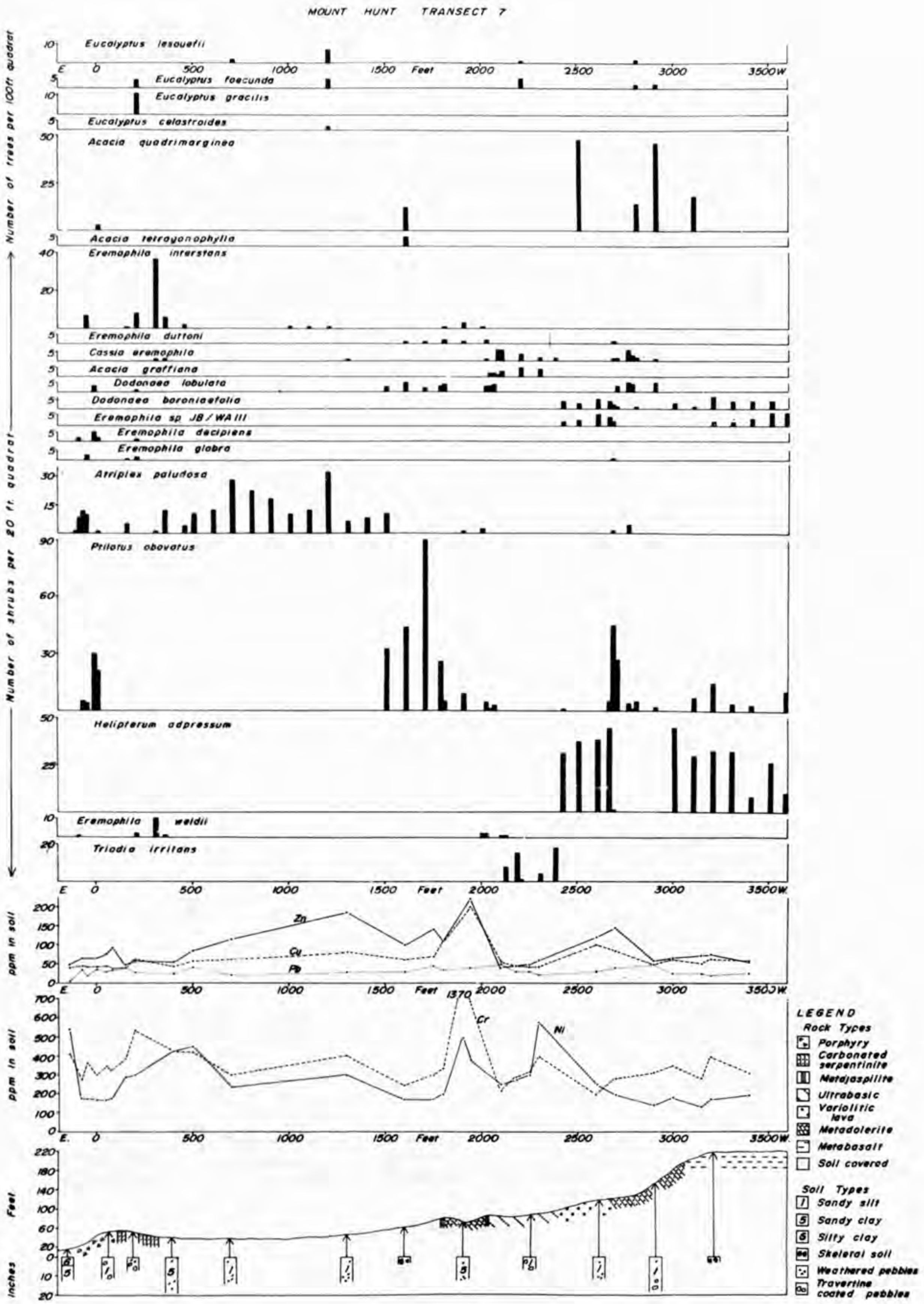
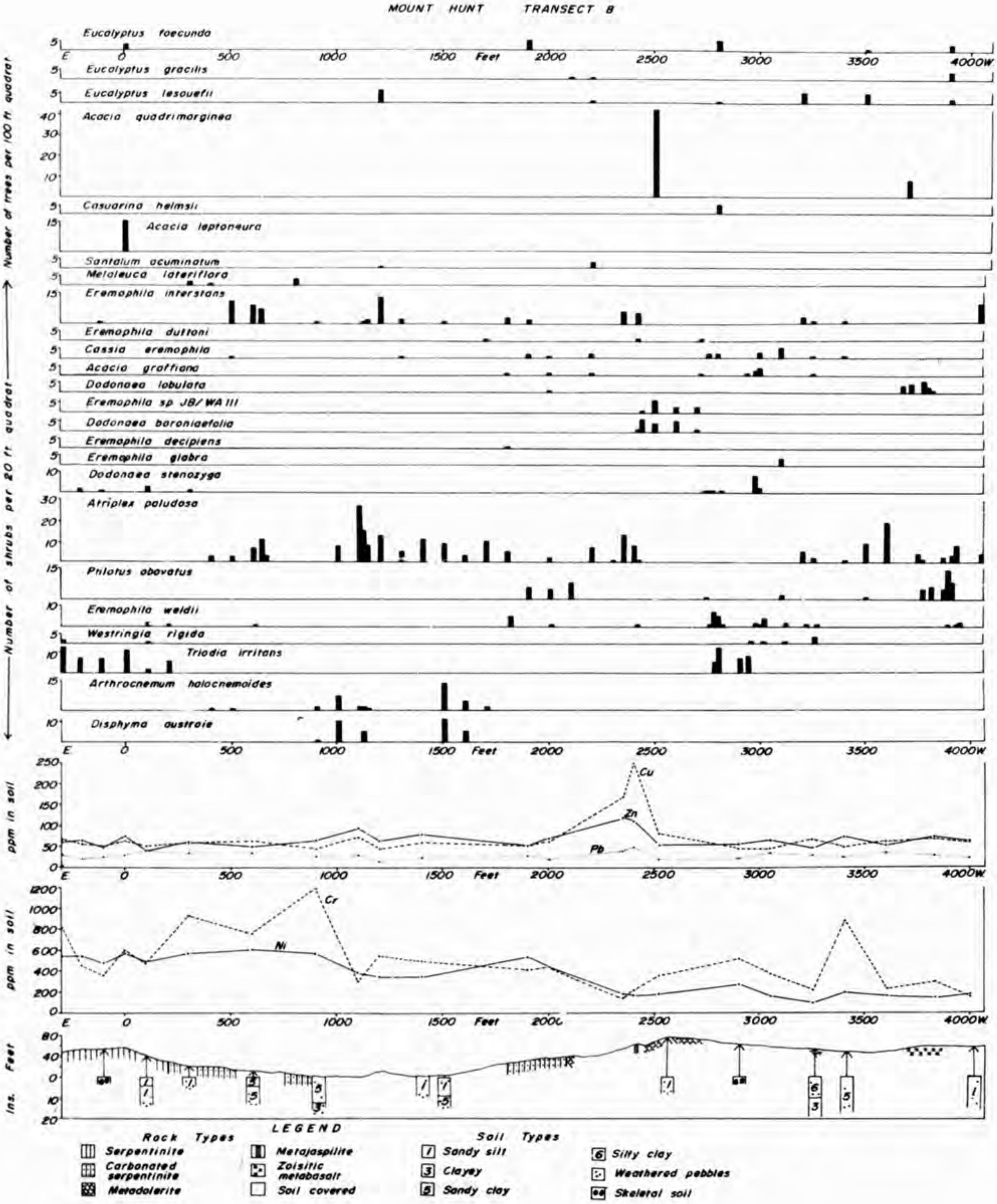

MOUNT HUNT TRANSECT 7
Number of trees per 100 ft. quadrat
Number of shrubs per 20 ft. quadrat
Eucalyptus lesouefii
Eucalyptus foecunda
Eucalyptus gracilis
Eucalyptus celastroides
Acacia quadrimarginea
Acacia tetragonophylla
Eremophila interstans
Eremophila duttoni
Cassia eremophila
Acacia graffiana
Dodonaea lobulata
Dodonaea boroniaefolia
Eremophila sp JB/WA111
Eremophila decipiens
Eremophila glabra
Atriplex paludosa
Ptilotus obovatus
Helipterum adpressum
Eremophila weldii
Triodia irritans
E 0 500 1000 1500 Feet 2000 2500 3000 3500W
ppm in soil
Zn
Cu
Pb
1370
Cr
Ni
Feet
inches
LEGEND
Rock Types
Porphyry
Carbonated serpentinite
Metajaspilite
Ultrabasic
Variolitic lava
Metadolerite
Metabasalt
Soil covered
Soil Types
Sandy silt
Sandy clay
Silty clay
Skeletal soil
Weathered pebbles
Travertine coated pebbles

Figure 44



MOUNT HUNT TRANSECT B
Eucalyptus foecunda
Eucalyptus gracilis
Eucalyptus lesouefii
Acacia quadrimarginea
Casuarina helmsii
Acacia leptoneura
Santalum acuminatum
Melaleuca lateriflora
Eremophila interstans
Eremophila duttoni
Cassia eremophila
Acacia graffiana
Dodonaea lobulata
Eremophila sp JB/WA III
Dodonaea boroniaefolia
Eremophila decipiens
Eremophila glabra
Dodonaea stenozyga
Atriplex paludosa
Ptilotus obovatus
Eremophila weldii
Westringia rigida
Triodia irritans
Arthrocnemum halocnemoides
Disphyma australe
Number of trees per 100 ft quadrat
Number of shrubs per 20 ft quadrat
E 0 500 1000 1500 Feet 2000 2500 3000 3500 4000W
ppm in soil
Cu
Zn
Pb
Cr
Ni
Feet
Ins.
LEGEND
Rock Types
Serpentinite
Carbonated serpentinite
Metadolerite
Metajaspilite
Zoisitic metabasalt
Soil covered
Soil Types
Sandy silt
Clayey
Sandy clay
Silty clay
Weathered pebbles
Skeletal soil

Figure 45

The carbonated serpentinite at the eastern end of transect 8 is marked by a high soil chromium content, peak values occurring at 900 feet west where the soil chromium concentration is 1200 ppm. The other noticeable peaks in the graph of soil metal concentrations occur at 2900 feet west where there is an outcrop of weathered metadolerite, and at 3400 feet west, which point occurs at the edge of a further outcrop of metadolerite.

The soil nickel content along transect 8 does not reveal striking peaks to the same degree as does chromium. At the eastern end of the transect, where outcrops of serpentinite and carbonated serpentinite occur, values in the soil remain fairly uniformly around 575 ppm. Westwards from these rock types the values fall to 350 ppm, rising to 540 ppm at 1950 feet west where soil masks the underlying bedrock. The concentration then falls again and remains at a fairly even level over the remainder of the transect.

The geochemical results for copper, zinc and lead are shown on the same graph for each separate transect. Values remain at a fairly uniform level in all three elements over the eastern end of transect 7. Zinc is the only element to rise slightly in value over the soil covered area; concentrations in the soil increase from 85 ppm at 500 feet west to 185 ppm at 1300 feet west. Both zinc and copper show peaks at 1940 feet west, which point lies on the valley side near the base of a creek. Lead remains at a moderately uniform concentration throughout, never exceeding 50 ppm.

The graph of the concentration of these three metals in the soil along transect 8 is very uniform. The only peak of any note oocurs at 2350 feet west, located below and on the outcrop of metajaspilite. Copper rises from 63 ppm at 2000 feet west to 250 ppm at 2400 feet west. Similarly, zinc rises from 70 ppm to 120 ppm, and lead shows a very small increase in value from 20 ppm to 50 ppm. Throughout the area lead remains lowest in concentration in the soil.

A soil sample from each rock type was analysed for the major elements sodium, potassium, calcium and magnesium. These results can be seen in Table XII.

The amounts of nickel and chromium present in the ash of plant samples is less than the amount present in the soils here (Table IX). The amount of nickel is below 100 ppm in the majority of samples, and usually there is less chromium than nickel present in the aerial organs of the plants. The plants tend to concentrate the amount of zinc present in their tissues so that there may be considerably more of this metal in the plant than is revealed in the soil at the point of sampling. The amount of copper in the plant ash may exceed that in the soil but, compared with zinc, less of this metal is present in the plant aerial organs. The high nickel and chromium soil values from the outcrop of carbonated serpentinite at the east end of transect 8 are not reflected by correspondingly high amount in the plants here. It appears that the species can resist the uptake of large quantities of these metals from the soil. Alternatively, it is possible that a large amount of these elements are taken up but are precipitated in the roots; no root samples were collected. The generally low density and variety of the vegetation here seems to indicate that the metals are available for uptake; other species are prohibited from developing because of the high nickel and chromium soil content.

A consideration of the soil concentrations of these elements does not appear to indicate that the distribution of vegetation associations at Mt. Hunt is primarily determined by these metals. Besides the carbonated serpentinite no other rock type is consistently marked by particularly high soil concentrations of nickel and chromium. The high concentrations of these two elements in the soil overlying the carbonated serpentinite at the eastern end of transect 8 probably account for the low vegetation density in this area. The concentrations of nickel and chromium appear to be too high to allow the vegetation association to develop to any great extent, and those species which grow here may be more efficient in their resistance to the uptake of toxic metal amounts than are the other species. Analysis of the aerial organs of two samples of Melaleuca lateriflora from this rock type did not reveal abnormally high quantities of these metals (Table IX).

The concentration of nickel and chromium in the soil over the rest of Mt. Hunt falls within the same range of values, i.e. between approximately 200 and 600 ppm, which is lower than the values found in the area of carbonated serpentinite mentioned above. Within this range the vegetation associations are varied, but their distribution does not appear to be primarily influenced by these elements.

Similarly, the metals copper, zinc and lead do not vary in characteristic concentrations in the soils which are developed from the various rock types. Although the soil from the metajaspilite band along transect 8 shows a peak in these elements, another band at 1800 feet west along transect 7 is not similarly marked. The different vegetation associations encountered along the transects do not appear to be a direct response to differing concentrations of these elements.

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Zn	Cu	ppm, Oven-dried Ni	Cr	Zn	Cu	ppm, Soil Ni	Cr	Zn	Cu	Rock Type
249	Ptilotus obovatus	T 7 00	Leaves & stems	5.4	60	100	140	68	3.2	5.4	7.5	3.6	170	300	65	43	Porphyry
246	Eremophila decipiens	T 7 00	Leaves & stems	9.4	24	80	212	144	2.2	6.1	19.9	13.5					
248	Acacia quadrimarginea	T 7 00	Leaves	5.3	44	70	420	84	2.3	3.7	22.2	4.4					
247	Acacia quadrimarginea	T 7 00	Twigs	4.6	24	90	132	76	1.1	4.1	6.0	3.4					
181	Acacia quadrimarginea	T 7 50W	Leaves	5.2	20	30	328	26	1.0	1.5	17.0	1.3	170	345	75	44	
182	Acacia quadrimarginea	T 7 50W	Twigs	4.8	32	5	-	-	1.5	2.4	-	-					
233	Eremophila interstans	T 7 200W	Leaves & stems	2.4	36	190	432	88	0.8	4.5	10.3	2.1	300	530	60	63	Carbonated serpentinite
218	Acacia leptoneura	T 7 200W	Leaves	2.7	80	20	-	-	2.1	0.5	-	-					
219	Acacia leptoneura	T 7 200W	Twigs	0.3	65	-	-	-	0.1	-	-	-					
180	Eucalyptus foecunda	T 7 200W	Leaves	4.2	75	10	252	120	3.1	0.4	10.5	5.0					
216	Eucalyptus foecunda	T 7 200W	Young twigs	5.5	32	10	104	154	1.7	0.5	5.7	8.4					

Analyses of unmilled, dry-ashed plant material.
Mt.H. series samples.

TABLE IX MT. HUNT

Sample	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Zn	Cu	ppm, Oven-dried Ni	Cr	Zn	Cu	ppm, Soil Ni	Cr	Zn	Cu	Rock Type
177	Eucalyptus foecunda	T 7 200W	Old twigs	4.9	47	5	104	100	2.3	2.4	5.0	4.9	300	530	60	63	Soil covered
187	Atriplex paludosa	T 7 700W	Leaves & stems	19.9	32	15	80	76	6.3	2.9	15.9	15.1	235	300	115	63	
229	Atriplex paludosa	T 7 1200W	Leaves & stems	20.9	36	-	84	72	7.5	-	17.5	15.0	285	400	120	85	
172	Atriplex paludosa	T 7 1300W	Leaves & stems	14.3	64	60	104	64	9.1	8.5	14.8	9.1	302	400	185	82	
175	Eucalyptus foecunda	T 7 1400W	Leaves	4.4	204	5	372	56	8.9	2.2	16.3	2.4					
176	Eucalyptus foecunda	T 7 1400W	Young twigs	6.0	128	10	388	68	7.6	0.6	23.2	4.0					
174	Eucalyptus foecunda	T 7 1400W	Old twigs	4.2	140	10	-	-	5.8	0.4	-	-					
243	Dodonaea lobulata	T 7 1600W	Leaves & stems	4.2	48	-	640	150	2.0	-	26.8	6.3	170	245	100	63	
238	Ptilotus obovatus	T 7 1600W	Leaves & stems	4.5	100	-	464	26	4.5	-	20.8	1.1					
234	Acacia quadrimarginea	T 7 1600W	Leaves	4.0	76	-	1200	166	3.0	-	48.0	6.6					
237	Acacia quadrimarginea	T 7 1600W	Twigs	3.8	72	-	560	134	2.7	-	21.2	5.0					

Analyses of unmilled, dry-ashed plant material.
Mt.H. series samples.

TABLE IX cont. MT. HUNT

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed				ppm, Oven-dried				ppm, Soil				Rock Type
					Ni	Cr	Zn	Cu	Ni	Cr	Zn	Cu	Ni	Cr	Zn	Cu	
173	Ptilotus obovatus	T 7 1750W	Leaves & stems	0.4	65	20	-	-	0.2	0.08	-	-	175	300	140	70	
212	Acacia leptoneura	T 7 2120W	Leaves	3.2	20	10	-	-	0.6	0.3	-	-					Ultrabasic
213	Acacia leptoneura	T 7 2120W	Twigs	0.3	45	-	-	-	0.1	-	-	-					
230	Cassia eremophila	T 7 2200W	Leaves & stems	5.4	36	-	300	124	1.9	-	16.2	6.6					
241	Acacia quadrimarginea	T 7 2300W	Leaves	4.6	48	115	888	88	2.2	5.2	40.0	4.0	575	395	60	43	Serpentinite
240	Dodonaea boroniaefolia	T 7 2300W	Leaves & stems	3.9	52	105	420	108	2.0	3.8	16.3	4.2					
239	Helipterum adpressum	T 7 2300W	Leaves & stems	3.2	172	190	940	158	5.5	6.0	30.0	5.0					
227	Acacia quadrimarginea	T 7 2500W	Leaves	3.8	52	-	800	182	1.9	-	30.4	6.9					Variolitic lava
236	Acacia quadrimarginea	T 7 2500W	Twigs	4.1	60	-	290	146	2.4	-	11.8	5.9					
226	Dodonaea boroniaefolia	T 7 2500W	Leaves & stems	3.7	88	-	600	270	3.2	-	22.2	9.9					
245	Helipterum adpressum	T 7 2500W	Leaves & stems	2.9	32	-	910	194	0.9	-	26.3	5.6					

Analyses of unmilled, dry-ashed plant material.
Mt.H. series samples.

TABLE IX cont. MT. HUNT

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Zn	Cu	ppm, Oven-dried Ni	Cr	Zn	Cu	ppm, Soil Ni	Cr	Zn	Cu	Rock Type
228	Acacia quadrimarginea	T 7 3100W	Twigs	3.3	76	-	384	240	2.5	-	12.6	7.9					Metadolerite
235	Dodonaea boroniaefolia	T 7 3100W	Leaves & stems	4.0	72	-	656	72	2.8	-	26.2	2.8					Metadolerite
242	Helipterum adpressum	T 7 3100W	Leaves & stems	5.0	52	-	900	158	2.6	-	45.0	7.9					Metadolerite
188	Ptilotus obovatus	T 7 3200W	Leaves & stems	5.2	60	15	232	34	3.1	0.7	12.0	1.7	170	390	75	63	Meta-basalt
183	Eucalyptus foecunda	T 8 100W	Leaves	4.2	52	40	184	38	2.1	1.6	7.7	1.5	490	480	40	50	Serpentinite
185	Eucalyptus foecunda	T 8 100W	Fruit	4.4	45	5	-	-	1.9	0.2	-	-					Serpentinite
184	Eucalyptus foecunda	T 8 100W	Young twigs	4.2	52	15	168	30	2.1	0.6	7.0	1.2					Serpentinite
186	Eucalyptus foecunda	T 8 100W	Old twigs	2.9	47	5	-	-	1.3	1.4	-	-					Serpentinite
224	Acacia leptoneura	T 8 150W	Leaves	3.0	30	15	-	-	0.9	0.4	-	-					Serpentinite
225	Acacia leptoneura	T 8 150W	Twigs	0.3	82	-	-	-	0.2	-	-	-					Carbonated serpentinite
178	Melaleuca lateriflora	T 8 300W	Leaves & twigs	6.0	52	20	96	26	3.1	0.1	5.7	1.5	575	940	60	58	Carbonated serpentinite

Analyses of unmilled, dry-ashed plant material.
Mt.H. series samples.

TABLE IX cont. MT. HUNT

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Zn	Cu	ppm, Oven-dried Ni	Cr	Zn	Cu	ppm, Soil Ni	Cr	Zn	Cu	Rock Type
231	Eremophila interstans	T 8 600W	Leaves & stems	3.2	80	-	252	100	2.5	-	8.0	3.2	575	620	48	63	Soil cover
189	Melaleuca lateriflora	T 8 850W	Leaves & twigs	6.3	125	35	-	-	7.8	2.2	-	-					Carbonated serpentinite
232	Eremophila interstans	T 8 900W	Leaves & stems	3.1	116	95	290	146	3.5	2.9	8.9	4.5	580	1200	65	45	
205	Atriplex paludosa	T 8 1400W	Leaves & stems	16.7	20	40	72	38	3.3	6.6	12.0	6.3	350	500	75	60	
215	Eucalyptus foecunda	T 8 1900W	Leaves	4.4	287	15	-	-	12.6	0.6	-	-					Soil covered
217	Eucalyptus foecunda	T 8 1900W	Young twigs	6.4	100	10	-	-	6.4	0.6	-	-					
207	Eucalyptus foecunda	T 8 1900W	Old twigs	3.3	90	5	-	-	8.8	0.1	-	-					
209	Atriplex paludosa	T 8 1950W	Leaves & stems	18.7	10	15	72	92	1.8	2.8	13.4	17.2	540	420	45	55	
220	Acacia leptoneura	T 8 2800W	Leaves	4.5	17	10	-	-	0.7	0.4	-	-					
221	Acacia leptoneura	T 8 2800W	Twigs	5.5	32	45	-	-	1.7	2.4	-	-					
208	Atriplex paludosa	T 8 3400W	Leaves & stems	17.3	32	15	112	120	5.5	2.5	19.3	20.7	200	895	55	40	

Analyses of unmilled, dry-ashed plant material.
Mt.H. series samples.

TABLE IX cont. MT. HUNT

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Zn	Cu	ppm, Oven-dried Ni	Cr	Zn	Cu	ppm, Soil Ni	Cr	Zn	Cu	Rock Type
210	Ptilotus obovatus	T 8 3800W	Leaves & stems	5.3	36	35	176	116	1.9	1.8	9.3	6.1					Zoisitic lava
222	Acacia quadrimarginea	T 8 3800W	Leaves	4.9	64	20	532	38	3.1	0.9	26.0	1.8					Zoisitic lava
223	Acacia quadrimarginea	T 8 3800W	Twigs	4.8	44	15	148	96	2.1	0.7	7.1	4.6					Zoisitic lava
211	Atriplex paludosa	T 8 4000W	Leaves & stems	18.5	48	15	104	116	8.8	2.7	19.2	21.4	185	170	65	63	Soil cover

Analyses of unmilled, dry-ashed plant material.
Mt.H. series samples.

TABLE IX cont. MT. HUNT

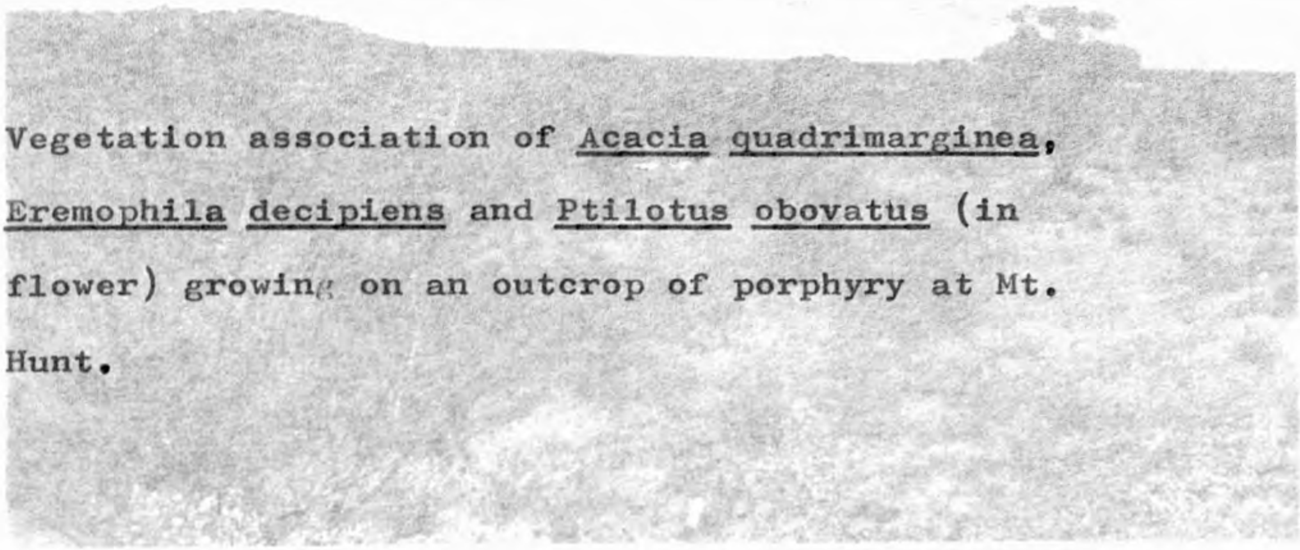
3. The importance of geological control over vegetation distribution

From a study of the distribution of the various associations found at Mt. Hunt it is noticeable that the vegetation boundaries coincide with the geological boundaries to a remarkable extent. These relationships will now be surveyed.

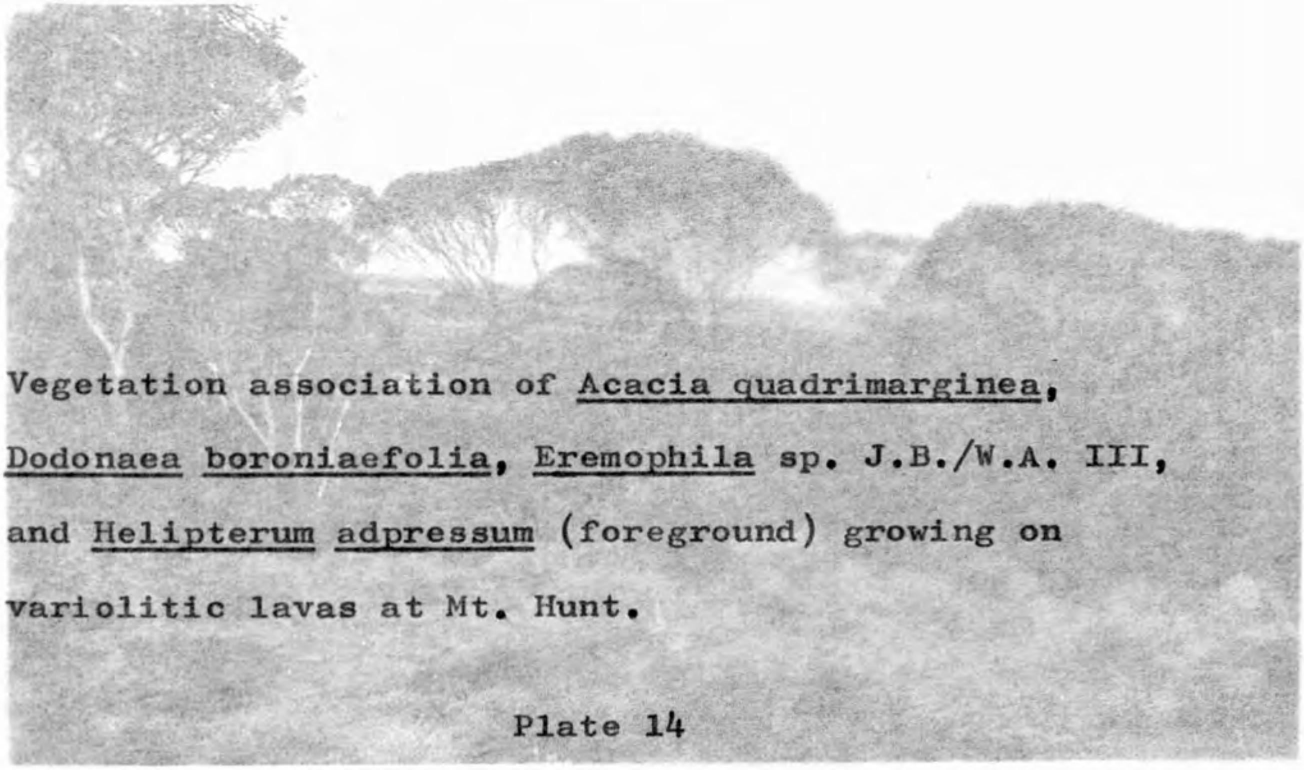
The outcrop of porphyry at the eastern end of transect 7 has its own distinctive association composed of Acacia quadrimarginea, Eremophila decipiens and Ptilotus obovatus (Plate 14). This assemblage of species occurs only over this porphyry outcrop, and at the junction with the adjacent area of carbonated serpentinite gives way to another association which is completely different, dominated by Eucalyptus foecunda, E. gracilis, Eremophila interstans, and E. weldii. Other rock types have their distinctive associations. The areas of metadolerite can be distinguished by their association of Acacia quadrimarginea, Eremophila duttoni, Dodonaea lobulata, and Ptilotus obovatus (Plate 15), while the outcrops of variolitic lava and metabasalt are characterised by A.

quadrimarginea, Eremophila sp. J.B./W.A. III, Dodonaea boroniaefolia, Prostanthera wilkieana, P. obovatus and Helipterum adpressum (Plate 14). The area underlain by ultrabasic rocks is distinguished by its association of Eucalyptus foecunda, Acacia leptoneura, Acacia graffiana, Cassia eremophila and Triodia irritans.

It is interesting to note that the western section of the soil covered area, from 1500 feet west to 1800 feet west, supports the association which is typical of metadolerite. In spite of absence of outcrop, the vegetation indicates the underlying rock type, and from an examination of the geological map it is evident that metadolerite could well form the bedrock here. The large expanse of soil covered area to the east is mainly characterised by an assemblage of halophytic species. The salt content of the soil appears to be the controlling factor here; trees are not common but Eucalyptus lesouefii grows occasionally (Plate 13). The association comprises Atriplex paludosa, Frankenia interioris, Arthrocnemum halocnemoides and Disphyma australe. Lycium australe and Kochia glomerifolia grow more infrequently. As the ground rises slightly to the west Eucalyptus foecunda and Eremophila interstans become important, and most of

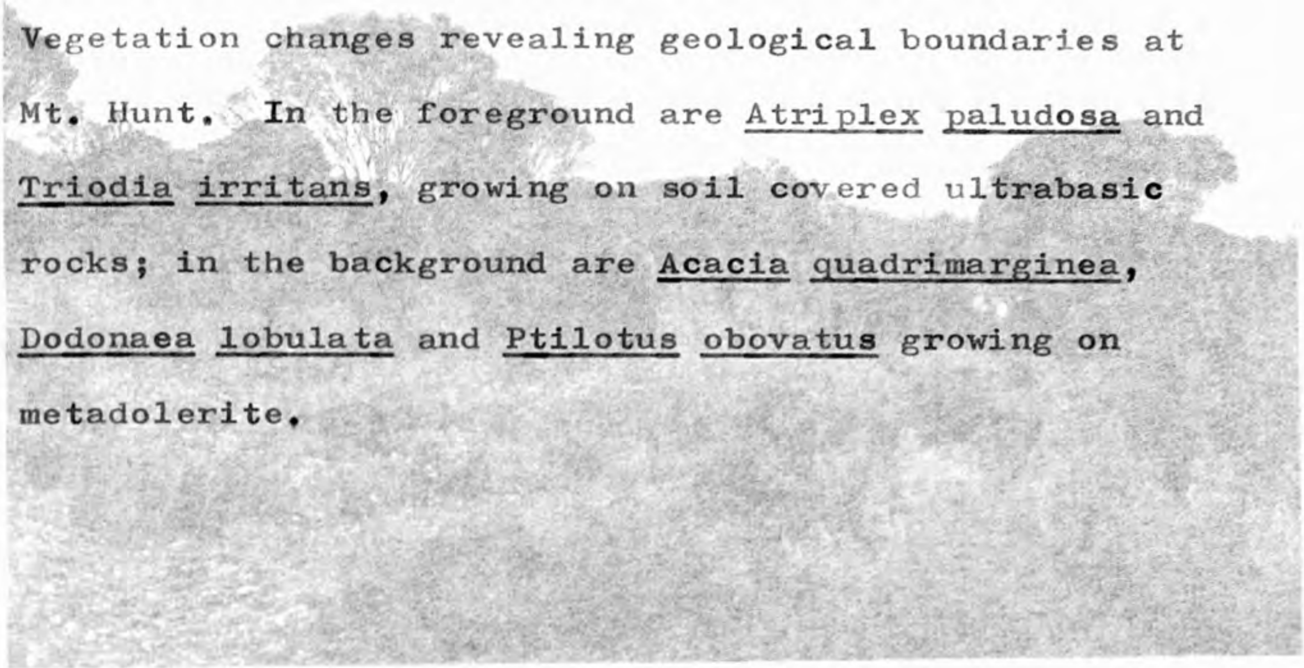


Vegetation association of Acacia quadrimarginea, Eremophila decipiens and Ptilotus obovatus (in flower) growing on an outcrop of porphyry at Mt. Hunt.

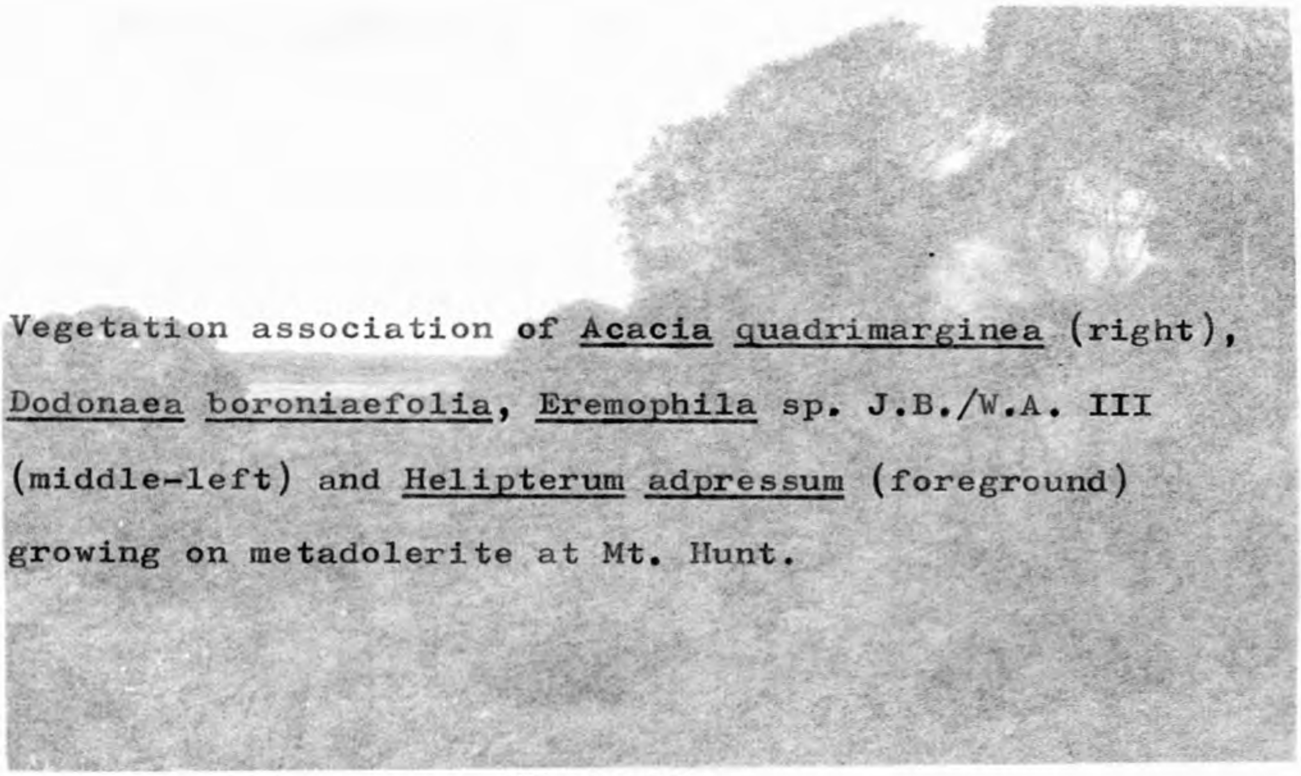


Vegetation association of Acacia quadrimarginea, Dodonaea boroniaefolia, Eremophila sp. J.B./W.A. III, and Helipterum adpressum (foreground) growing on variolitic lavas at Mt. Hunt.

Plate 14

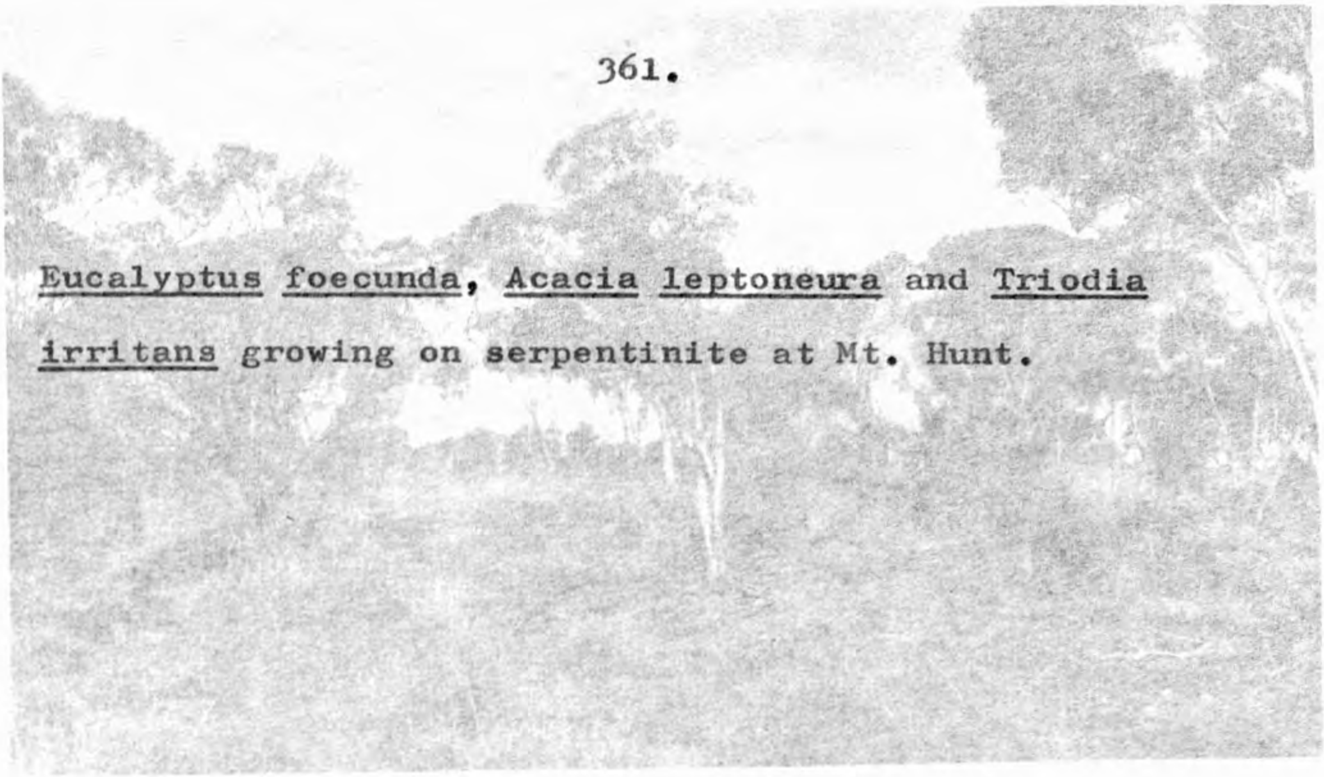


Vegetation changes revealing geological boundaries at Mt. Hunt. In the foreground are Atriplex paludosa and Triodia irritans, growing on soil covered ultrabasic rocks; in the background are Acacia quadrimarginea, Dodonaea lobulata and Ptilotus obovatus growing on metadolerite.

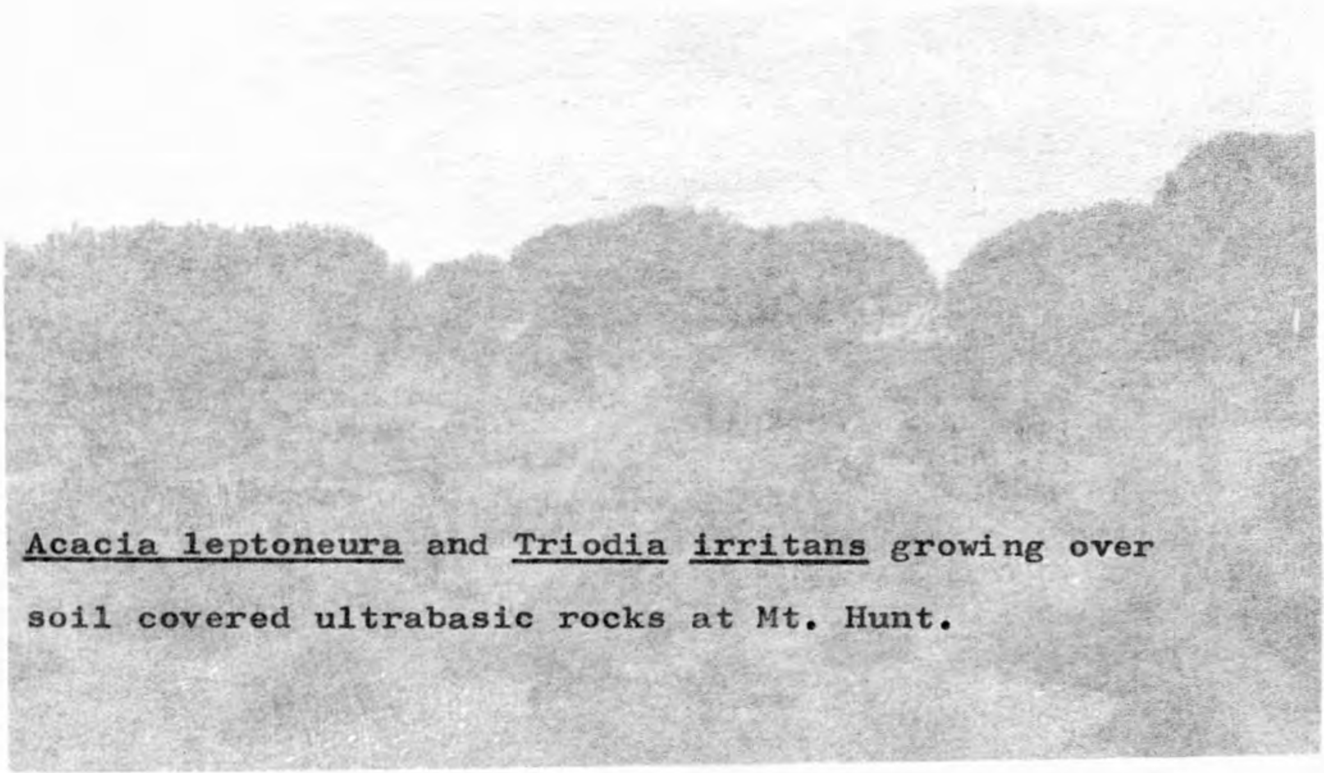


Vegetation association of Acacia quadrimarginea (right), Dodonaea boroniaefolia, Eremophila sp. J.B./W.A. III (middle-left) and Helipterum adpressum (foreground) growing on metadolerite at Mt. Hunt.

Plate 15

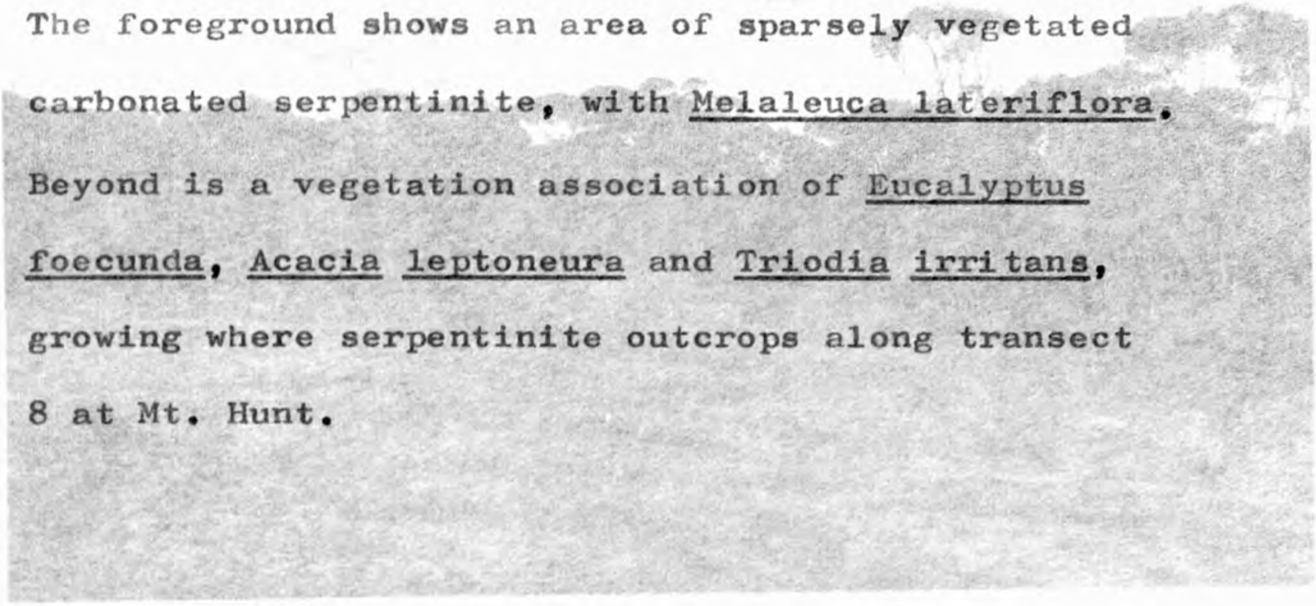


Eucalyptus foecunda, Acacia leptoneura and Triodia irritans growing on serpentinite at Mt. Hunt.

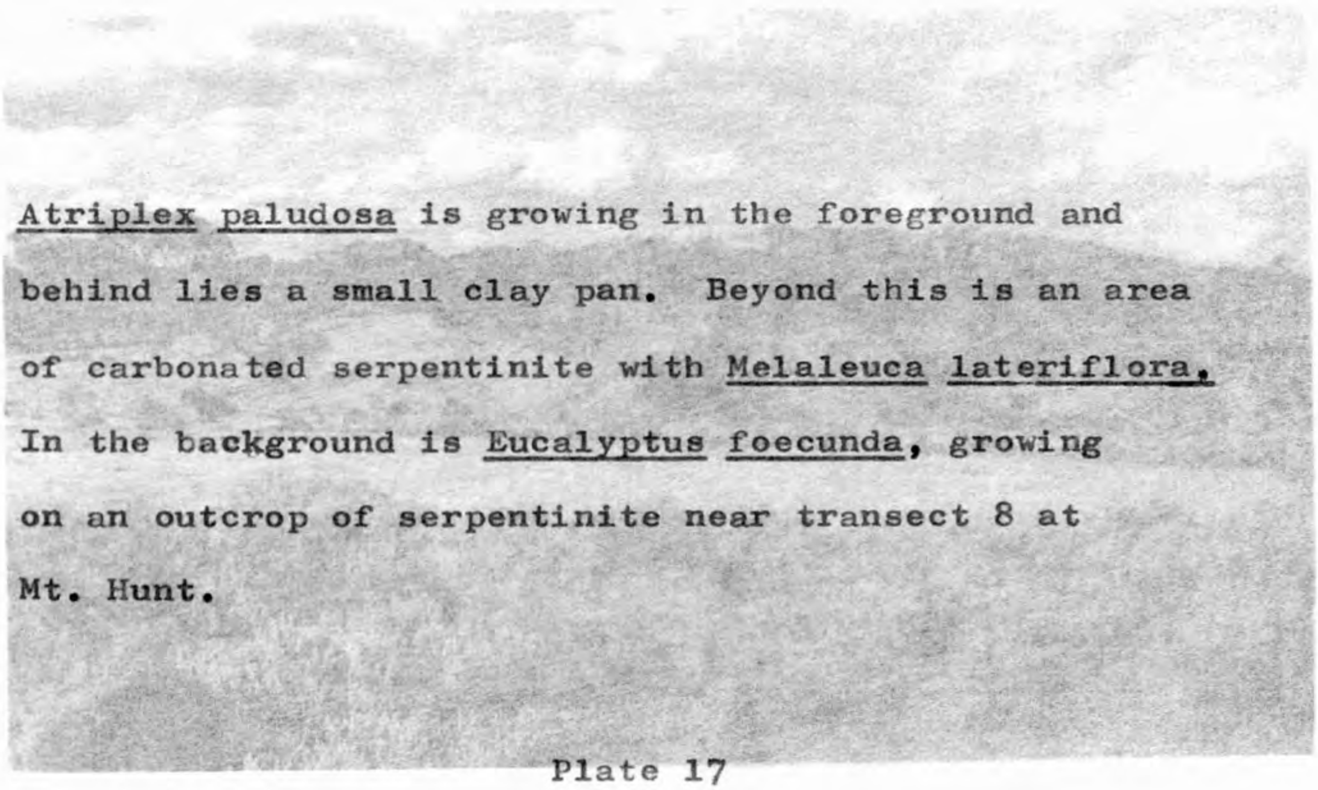


Acacia leptoneura and Triodia irritans growing over soil covered ultrabasic rocks at Mt. Hunt.

Plate 16



The foreground shows an area of sparsely vegetated carbonated serpentinite, with Melaleuca lateriflora. Beyond is a vegetation association of Eucalyptus foecunda, Acacia leptoneura and Triodia irritans, growing where serpentinite outcrops along transect 8 at Mt. Hunt.



Atriplex paludosa is growing in the foreground and behind lies a small clay pan. Beyond this is an area of carbonated serpentinite with Melaleuca lateriflora. In the background is Eucalyptus foecunda, growing on an outcrop of serpentinite near transect 8 at Mt. Hunt.

Plate 17

the halophytic species disappear.

Similar relationships occur along transect 8, although here they are not always so precise as along transect 7. The large outcrop of serpentinite on the west shore of Hannan's Lake, part of which is included on the eastern edge of transect 8, is characterised by an association dominated by Eucalyptus foecunda, Acacia leptoneura, Dodonaea stenozyga and Triodia irritans (Plate 16). Where the adjacent underlying bedrock is carbonated serpentinite the association is entirely different (Plate 17). The density of the vegetation falls and the area is dominated by Melaleuca lateriflora. In some localities over this rock type the ground becomes saline and clay pans occur. Halophytic species, such as Atriplex paludosa, Frankenia interioris, Arthrocnemum halocnemoides and Disphyma australe, enter the association, while Melaleuca lateriflora is restricted to the local areas of higher ground where the soil is less saline. The area of carbonated serpentinite further west, from about 1750 feet west to 2100 feet west, is not comparable in the vegetation it supports with that growing on the carbonated serpentinite described above: plant growth is denser with more variety. The association is dominated by Eucalyptus foecunda, Eremophila interstans, Cassia eremophila, and Atriplex paludosa, although a number of other shrubs occur with low frequency, including Acacia graffiana, Dodonaea lobulata, Scaevola spinescens and Atriplex nummularia.

On this transect, metadolerite does not consistently support the same association, as was the case along transect 7. The outcrop between 2440 feet west and 2720 feet west can be traced by its association of Acacia quadrimarginea, Eremophila sp. J.B./W.A. III, Dodonaea boroniaefolia and Helipterum adpressum, Prostanthera aspalathoides and Ptilotus obovatus occur occasionally. Along transect 7 this particular association is characteristic of metabasalt rather than metadolerite. The metadolerite outcrop at 2900 feet west is very weathered. It is too small to have any observable geobotanical relationship. The outcrop of this same rock type from 3250 feet west to 3300 feet west is not marked by the occurrence of the species which are characteristic of metadolerite along transect 7. There is, instead, a varied assemblage of species, many of which grow in the surrounding soil covered area. These include Eucalyptus lesouefii, Eremophila interstans, Cassia eremophila, Acacia erinacea, Eremophila weldii, Scaevola spinescens, Olearia muelleri and Westringia rigida. Further north, however, the outcrop widens and here, besides those species enumerated, grow Acacia quadrimarginea, Eremophila duttoni, Dodonaea lobulata and Ptilotus obovatus, shrubs which are characteristic of many of the metadolerite outcrops at Mt. Hunt.

The area of zoisitic lava at the west end of transect 8 can be traced by the vegetation association it supports. This is composed of Acacia quadrimarginea, Dodonaea lobulata, Eremophila sp. J.B./W.A. III, and Ptilotus obovatus, and differs from that of the metadolerite outcrops only in the species of Eremophila growing here.

The soil covered areas along transect 8 do not provide much geobotanical information, excepting for the area between 2800 feet west and about 3120 feet west. Eucalyptus foecunda, Acacia graffiana and Cassia eremophila grow here with Triodia irritans occurring over part of the area in conjunction with such shrubs as Acacia leptoneura, Westringia rigida, Eremophila weldii and Olearia muelleri (Plate 16). This assemblage is indicative of ultrabasic rocks in the Mt. Hunt area.

The metajaspilite is not marked by any particular collection of shrubs. This may be due to the fact that this rock type occurs only in narrow bands. It may be noted that where a particular rock type outcrops or is traceable only over a small area the vegetation supported is not necessarily that which is characteristic of larger outcrops of that rock type within this area. This is the case on the metadolerite outcrop where it is crossed by transect 8 between 3250 feet west and 3300 feet west. Over this distance of fifty feet the vegetation association which is characteristic of a number of metadolerite outcrops in the Mt. Hunt area does not occur. However, as the outcrop broadens further to the north the characteristic shrubs grow.

Another example of this kind was observed in the field near 2300 feet west on transect 7. Here a small pod of serpentinite outcrops, but instead of the association of Eucalyptus foecunda, Acacia leptoneura, Dodonaea stenozyga and Triodia irritans, characteristic of the large serpentinite outcrop to the east of Mt. Hunt, the association is one of Acacia quadrimarginea, Eremophila sp. J.B./W.A. III, Dodonaea boroniaefolia, and Helipterum adpressum, with Prostanthera aspalathoides and Ptilotus obovatus occurring less frequently. It appears that the association from the adjacent area of variolitic lavas has extended over the area of serpentinite. This cannot be a case of an association extending downhill as variolitic lava float spreads over otherwise less favoured rock types, for the serpentinite pod forms a small knoll which would not be a reception area for float. The area underlain by ultrabasic rocks adjacent and downslope from the variolitic lava may carry a small amount of float but does not support the lava association. The relationship appears to be partly a function of the small size of the serpentinite outcrop.

It is evident that over a large part of Mt. Hunt the geology is important in controlling the vegetation distribution. This control may be expressed through either the physical or the chemical characteristics of the rock types and the soils to which they give rise. The geochemical analyses carried out on the Mt. Hunt soil samples indicated that the vegetation distribution is not influenced to any great extent by the elements which have been considered. Other elements may play a more important part in the soil environment in controlling the distribution of certain species, but further analyses would need to be undertaken to ascertain how far this is the case. Many of the rock types outcrop at the surface which is therefore often rocky and scree covered, and these conditions are suitable for those species found. However, this cannot be the only factor involved, particularly in areas where different rock types provide similar physical environments and yet support different associations.

A combination of physical and chemical factors must operate in all plant environments, and it may not be possible to ascertain which are the most important in influencing plant distribution in a given area. An interesting relationship in this area is the replacement of Eremophila duttoni by Eremophila sp. J.B./W.A. III, and Dodonaea lobulata by D. boroniaefolia as outcropping metadolerite gives place to outcropping metabasalt. Geochemically both rock types are alike; they provide a similar rocky, scree covered surface over the greater part of their occurrence, and these areas are well-drained. However, the rate of weathering may differ between a dolerite and a basalt due to the disparity in grain size. Elements therefore become available at different rates, even though the chemical composition of these two rock types is the same. A particle of basalt two millimetres across is a lithic fragment with a composition approximating to the average composition of the basalt. A similar sized particle from a dolerite is likely to be a mineral grain, so that as feldspars and ferromagnesian minerals weather at different rates a more uneven distribution of elements is to be expected between those becoming available in the soil solution and those in mechanical particles in the dolerite. The relative importance of such factors in the environment cannot be determined without further studies. Nevertheless, the fact that geology influences the distribution of the vegetation associations at Mt. Hunt is clearly evident.

PART 5

THE KAMBALDA - WIDGIEMOOLTHA AREA

(A) KAMBALDA

1. The geographical environment

The area is one of marked relief, bringing variety into a region which is characteristically subdued and inclined to be flat. Two ridges lie to the north and south of Kambalda orientated approximately west-east (Figure 46). Red Hill is the highest point in the southern ridge, exceeding 1260 feet above sea level, while the northern ridge reaches slightly over 1200 feet above sea level. To the east both areas of higher ground terminate abruptly along the western margin of Lake Lefroy. To the west relief becomes lower, giving a gently undulating, almost flat topography, while further north lie other areas of higher ground. Lake Lefroy runs in an approximate north-south direction for about thirty miles, its southern extent lying in the latitude of Widgiemooltha. A number of small, low islands in the vicinity of Kambalda hardly relieves the monotony of its flat surface.

Drainage from the hills follows a radial pattern, but the creeks are dry for most of the year. Lake Lefroy forms the local drainage base level. It is quite waterless excepting after heavy rain, its surface gleaming white with the salts left after evaporation.

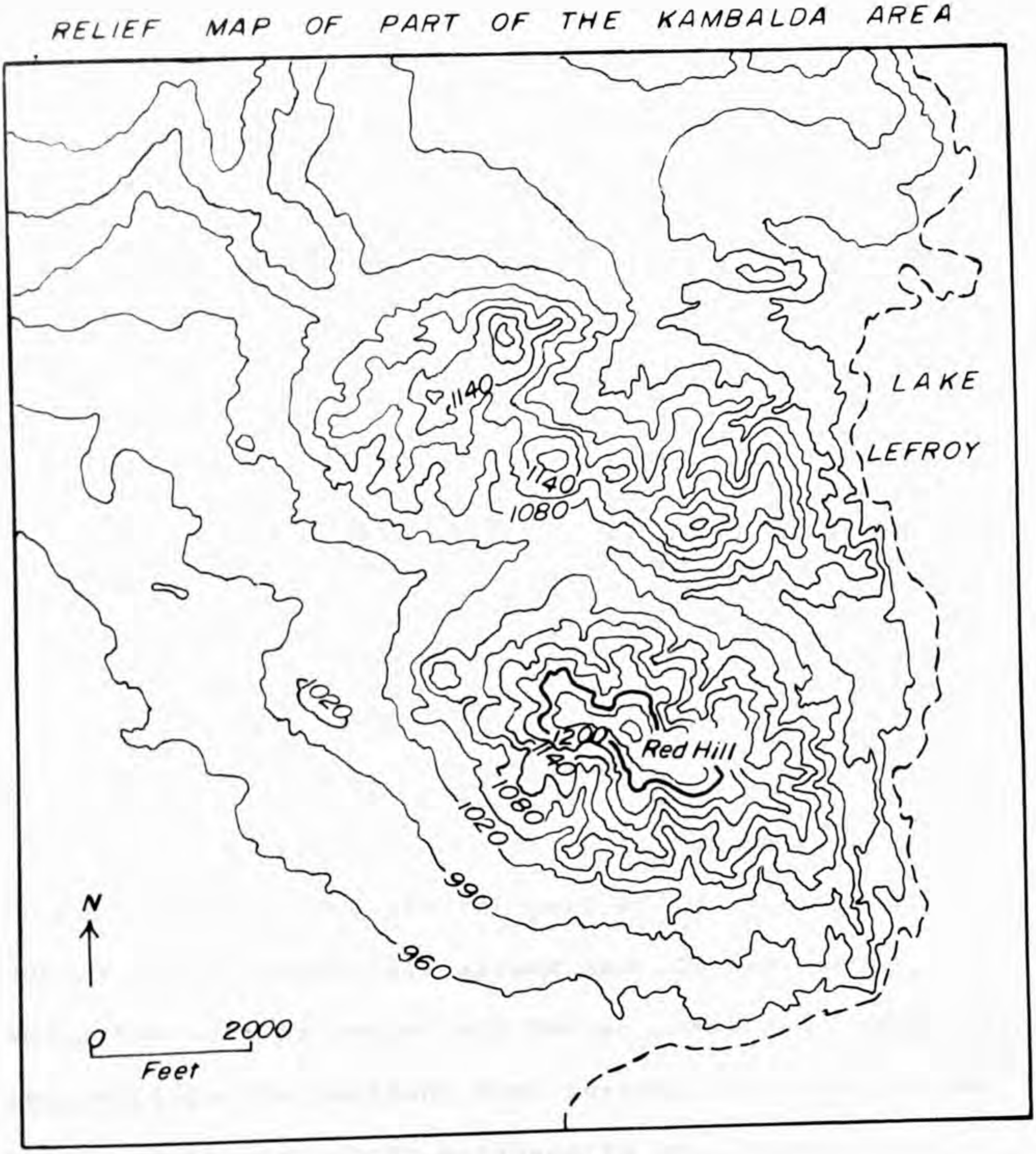

RELIEF MAP OF PART OF THE KAMBALDA AREA
LAKE
LEFROY
1140
1140
1080
1020
1200
1140
Red Hill
1080
1020
990
960
N
0
2000
Feet

Figure 46

2. The distribution of the vegetation associations

There are two distinct physiognomic types of vegetation around Kambalda. The greater part of the area is covered by open woodland, varying locally in its tree density, the upper stratum sometimes being composed of Acacia shrubs rather than Eucalypts.

The second vegetation type occupies the formerly active, wide, saline water course which traverses the country further to the north and west before entering the Kambalda area. This tract of land, approximately two miles wide here, is almost completely treeless, characterised by low, salt-tolerant shrubs.

These two vegetation types will now be considered in more detail. The greater part of the tree growth occurs on the lower hill slopes and flatter ground, where the soil is deeper and better developed. Eucalyptus lesouefii is the dominant tree species over most of the area, growing over both metabasalts and serpentinite. It often forms dense stands, prohibiting the development of most shrubs in the understorey, which only grows to a maximum height where tree density is lower. On the metabasaltic areas E. lesouefii tends to form small groves and here is generally associated with Eremophila interstans. Elsewhere it may occur with Scaevola spinescens, Eremophila duttoni, Atriplex paludosa and Dodonaea lobulata. Eucalyptus foecunda and E. torquata grow in the area to a lesser extent, appearing to prefer soils developed from the serpentinites, often where there is evidence of serpentinite float and chips in the soil. E. salmonophloia, Eucalyptus sp. J.B./W.A. 303 and E. gracilis grow over limited areas where soil is better developed and has greater depth. The small trees Santalum acuminatum and S. spicatum are scattered throughout the area over both metabasalts and serpentinites. Brachychiton Gregorii, the kurrajong, also occurs throughout; these trees grow individually or frequently, their thick green crowns and thick-set fissured trunks contrasting markedly with the Eucalypts.

Eucalypts are found only rarely where the soil is skeletal and outcrop of either metabasalt or serpentinite prominent. Acacia quadrimarginea often dominates the upper stratum in such areas and is associated with a number of other shrubs including A. tetragonophylla, Eremophila duttoni, Dodonaea lobulata, Scaevola spinescens, Ptilotus obovatus and a small tree Santalum spicatum. This association occasionally extends down-slope to dovetail in with the groves of Eucalyptus lesouefii and its associated shrubs which may include Eremophila interstans and Atriplex paludosa.

An association of Acacia acuminata and Ptilotus obovatus covers those areas underlain by porphyry, and Eucalypts are generally absent from such localities.

A psammophytic vegetation association occurs on the sand dunes around parts of the shores of Lake Lefroy. Acacia quadrimarginea dominates the association which includes A. ?salicina, Grevillea sarissa, Jacksonia hakeoides and Atriplex nummularia. Shrub growth is not very dense in this environment, which is presumably marked by a poor water-holding capacity.

The second physiognomic type of vegetation found in the Kambalda area occurs over the more limited area of a former water-course, which runs into Lake Lefroy and is markedly sandy and saline. The peripheries of this association are characterised by the presence of Pittosporum phillyraeoides, but elsewhere tree growth is generally absent and an association composed of low shrubs stretches over the area for a width of approximately two miles. Atriplex paludosa, Frankenia interioris, _Cratystylis subspinescens_ and _Arthrocnemum halocnemoides_ occur here. _Eremophila interstans_ may grow on the edges of this association, but does not extend beyond the periphery.

3. The factors governing the distribution of the vegetation associations

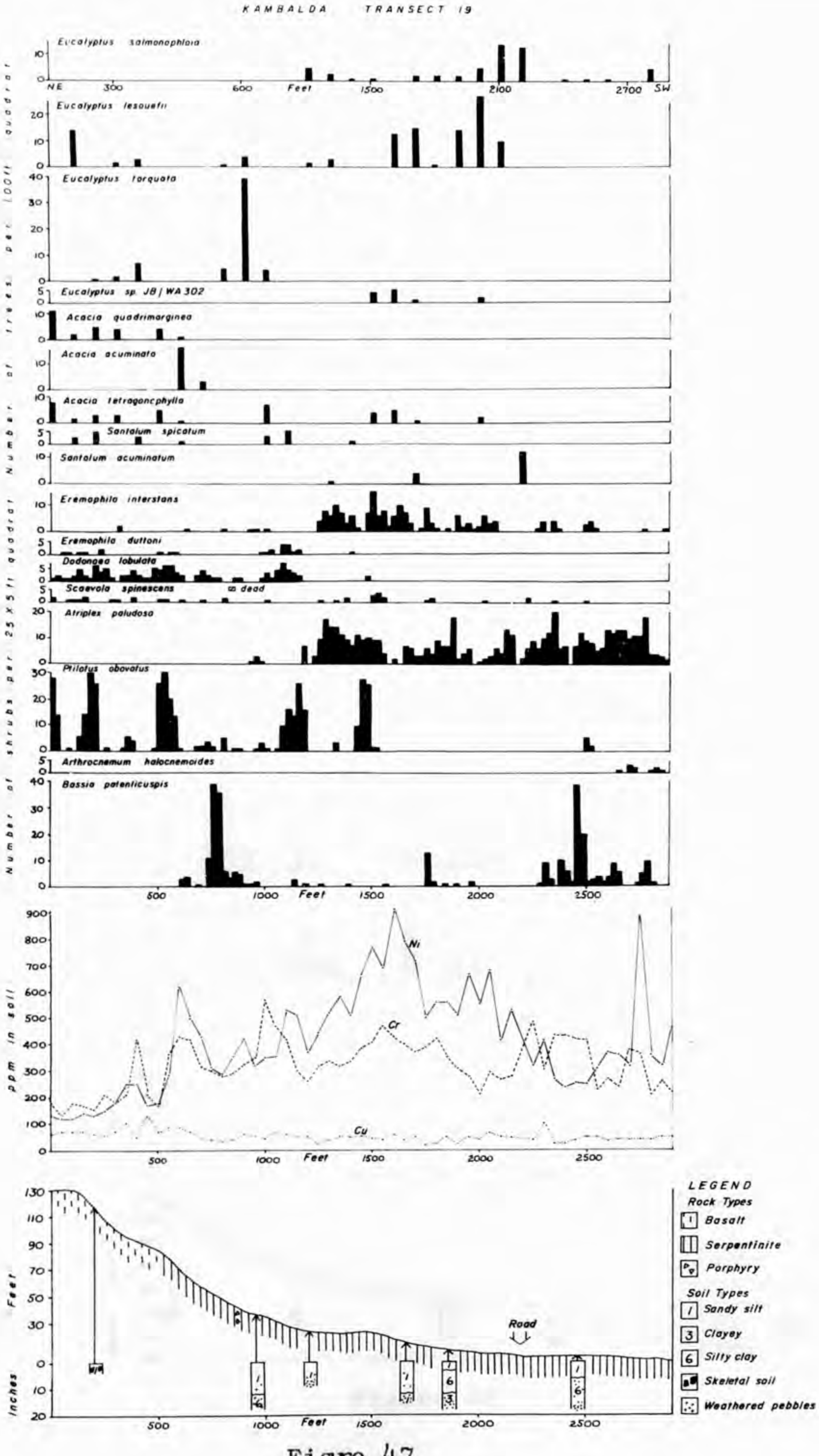
A consideration of the data presented on the Kambalda transects 19 to 23 (Figures 47 - 51) indicates that relief, soil depth and geology are the most important factors controlling the development of vegetation associations. It is also evident that where soil nickel values are exceptionally high, as along part of transect 22 (Figure 50), certain species that would normally be expected to grow are excluded.

The relief of the Kambalda area presents a certain amount of variety which has been commented upon in a previous section (Part 5, 1.). Red Hill and the hills around it rise from the flat and gently undulating surrounding terrain. In these higher areas the ground often falls steeply; outcrop is frequent and soils are consequently skeletal and covered with scree. Products of weathering tend to be removed fairly rapidly from such an environment, and the soil necessarily remains immature. Metabasalt forms the highest parts of the hills with serpentinite underlying the lower slopes and forming smaller prominences.

In such areas, where metabasalt is the underlying rock type, a distinctive association occurs. Acacia quadrimarginea is the dominant tree, and associated with it are A. tetragonophylla, Eremophila duttoni, Santalum spicatum, Dodonaea lobulata, Scaevola spinescens and Ptilotus obovatus. The summits of the highest hills support a somewhat modified association; the density of the vegetation becomes lower, and here A. quadrimarginea grows with D. lobulata, Prostanthera wilkiana, Eremophila sp. J.B./W.A. III, Scaevola spinescens and Helipterum adpressum.

The soils occurring on these metabasaltic ridges and hills, where the rock outcrops or lies close to the surface, have very little depth and no profile development, for erosion prohibits the growth of a deeper soil. The soil is reddish brown to dark reddish brown (5YR 4/4 to 5YR 4/6), and in texture is a sandy-silt. Aspects of the chemistry of these soils are commented upon in the following section.

The areas of serpentinite tend to be more subdued in relief, with mature soils, in comparison with the metabasaltic areas. A number of Eucalyptus species grows in these deeper soils, the most frequent being Eucalyptus lesouefii, E. torquata, and E. foecunda. The


KAMBALDA TRANSECT 19
Eucalyptus salmonophloia
Eucalyptus lesouefii
Eucalyptus torquata
Eucalyptus sp. JB / WA 302
Acacia quadrimarginea
Acacia acuminata
Acacia tetragonophylla
Santalum spicatum
Santalum acuminatum
Number of trees per 100 ft quadrat
Eremophila interstans
Eremophila duttoni
Dodonaea lobulata
Scaevola spinescens
dead
Atriplex paludosa
Ptilotus obovatus
Arthrocnemum halocnemoides
Bassia patenticuspis
Number of shrubs per 25 x 5 ft quadrat
NE
SW
Feet
ppm in soil
Ni
Cr
Cu
Road
Inches
LEGEND
Rock Types
Basalt
Serpentinite
Porphyry
Soil Types
Sandy silt
Clayey
Silty clay
Skeletal soil
Weathered pebbles

Figre 47

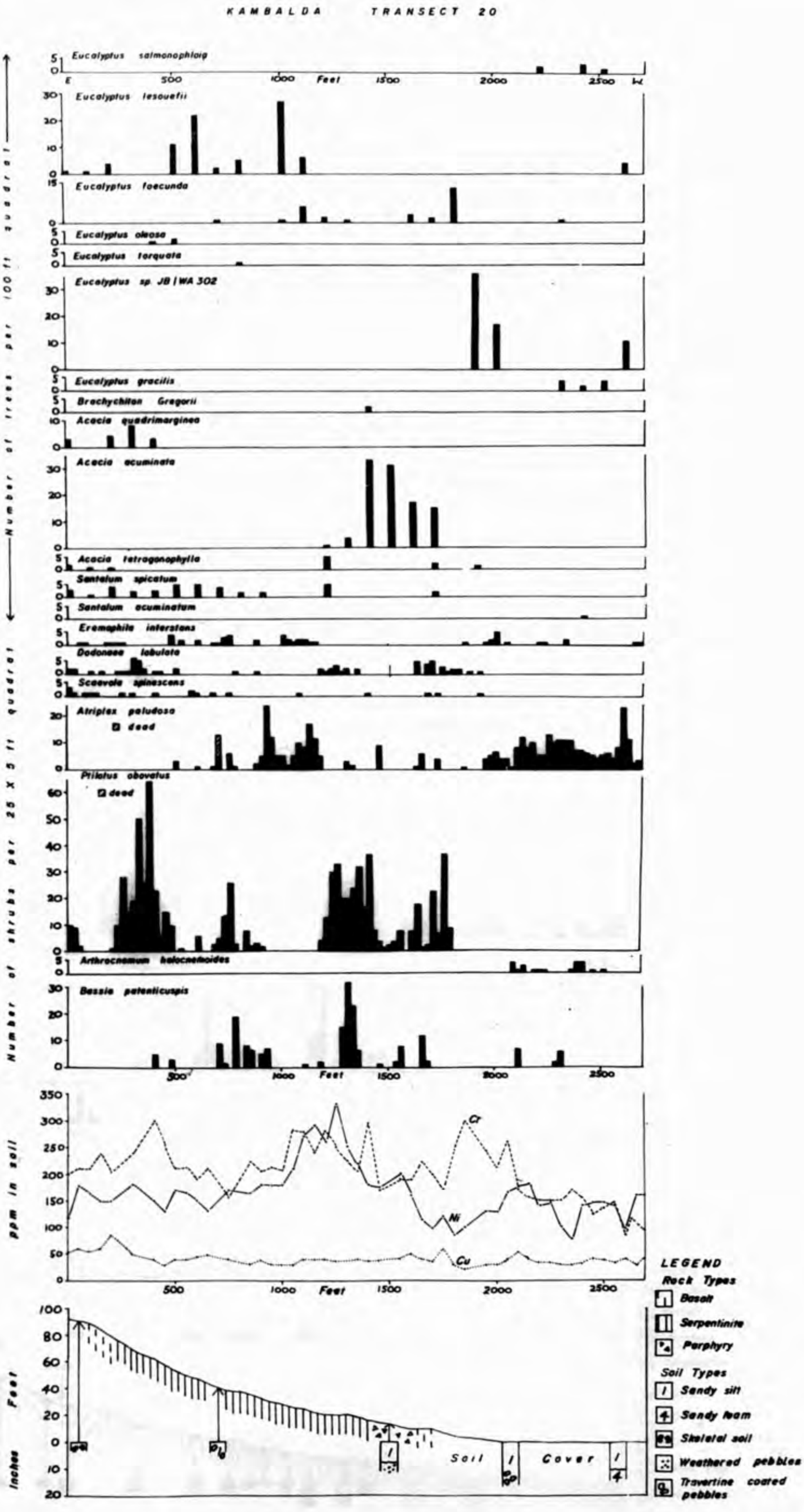

KAMBALDA TRANSECT 20
Eucalyptus salmonophloia
Eucalyptus lesouefii
Eucalyptus foecunda
Eucalyptus oleosa
Eucalyptus torquata
Eucalyptus sp. JB I WA 302
Eucalyptus gracilis
Brachychiton Gregorii
Acacia quadrimarginea
Acacia acuminata
Acacia tetragonophylla
Santalum spicatum
Santalum acuminatum
Eremophila interstans
Dodonaea lobulata
Scaevola spinescens
Atriplex paludosa
dead
Ptilotus obovatus
dead
Arthrocnemum halocnemoides
Bassia patenticuspis
Number of trees per 100 ft quadrat
Number of shrubs per 25 X 5 ft quadrat
Feet
ppm in soil
Cr
Ni
Cu
Feet
Inches
Soil Cover
LEGEND
Rock Types
Basalt
Serpentinite
Porphyry
Soil Types
Sandy silt
Sandy loam
Skeletal soil
Weathered pebbles
Travertine coated pebbles

Figure 48

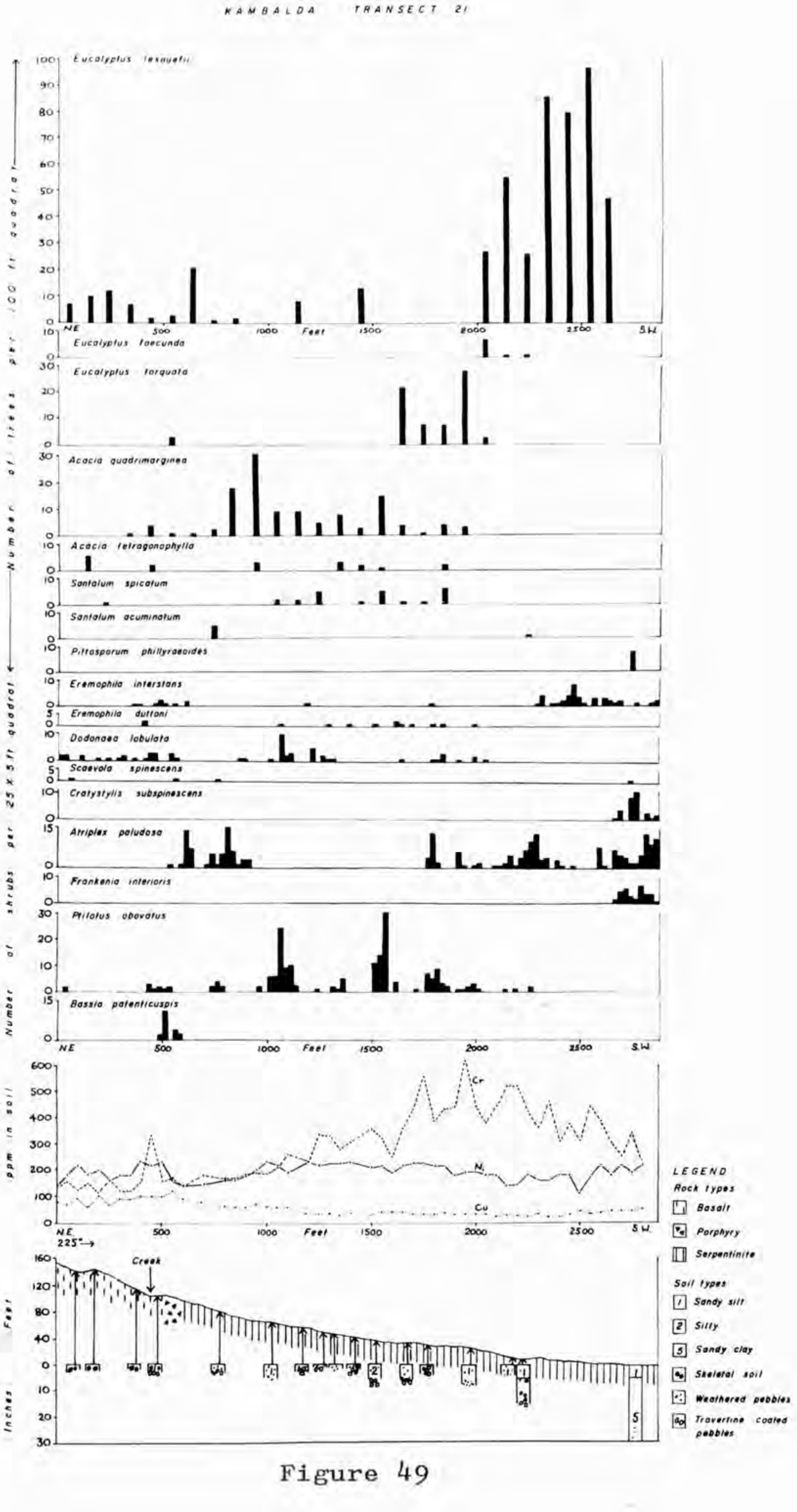

KAMBALDA TRANSECT 21
Eucalyptus lesouefii
Eucalyptus foecunda
Eucalyptus torquata
Acacia quadrimarginea
Acacia tetragonophylla
Santalum spicatum
Santalum acuminatum
Pittosporum phillyraeoides
Eremophila interstans
Eremophila duttoni
Dodonaea lobulata
Scaevola spinescens
Cratystylis subspinescens
Atriplex paludosa
Frankenia interioris
Ptilotus obovatus
Bassia patenticuspis
Number of trees per 100 ft quadrat
Number of shrubs per 25 x 5 ft quadrat
ppm in soil
Cr
Ni
Cu
NE
SW
Feet
Creek
225°→
Feet
Inches
LEGEND
Rock types
Basalt
Porphyry
Serpentinite
Soil types
1 Sandy silt
2 Silty
5 Sandy clay
Skeletal soil
Weathered pebbles
Travertine coated pebbles

Figure 49

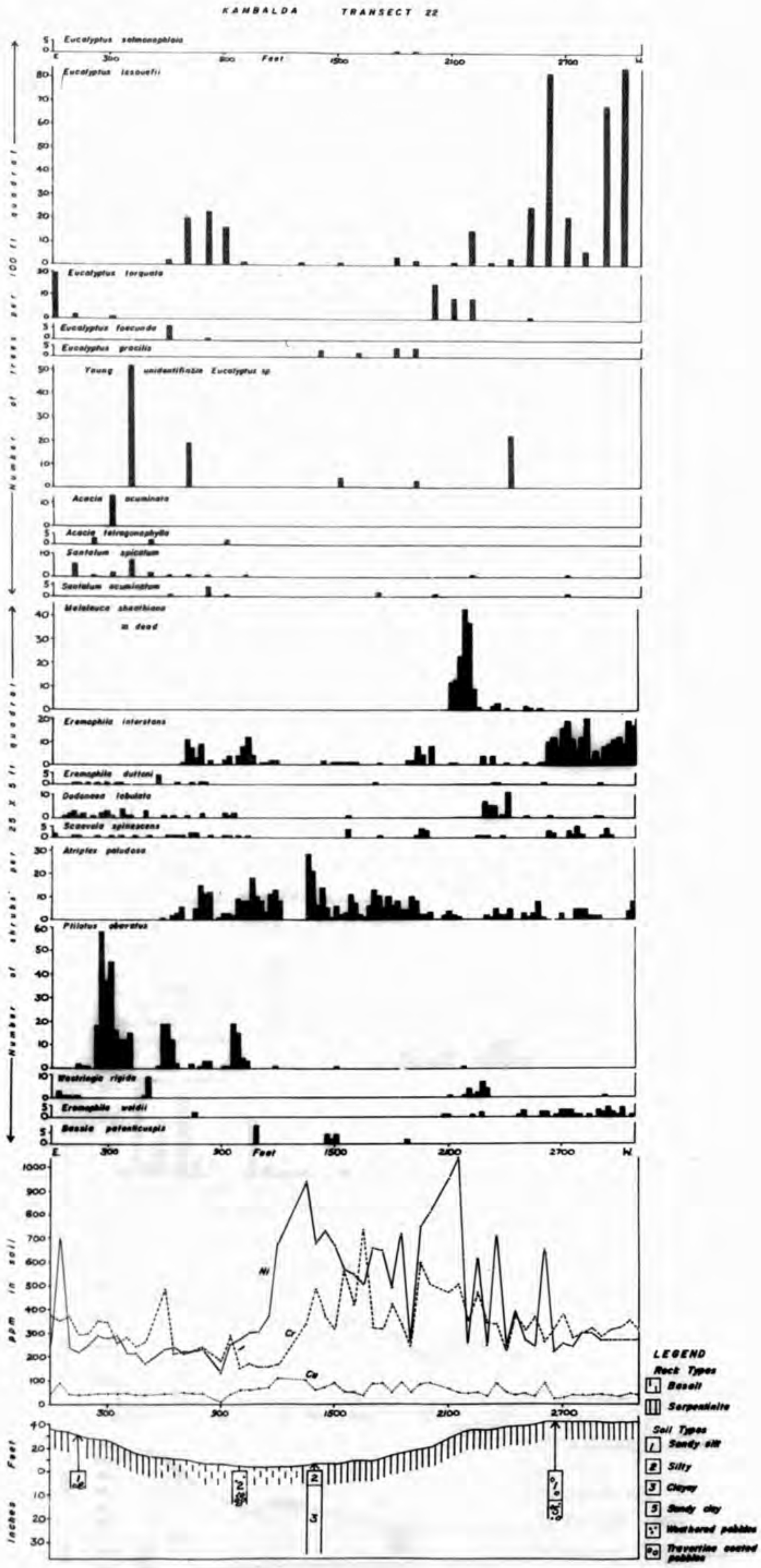

KAMBALDA TRANSECT 22
Eucalyptus salmonophloia
Eucalyptus lesouefii
Eucalyptus torquata
Eucalyptus foecunda
Eucalyptus gracilis
Young unidentifiable Eucalyptus sp.
Acacia acuminata
Acacia tetragonophylla
Santalum spicatum
Santalum acuminatum
Number of trees per 100 ft quadrat
Melaleuca sheathiana
m dead
Eremophila interstans
Eremophila duttoni
Dodonaea lobulata
Scaevola spinescens
Atriplex paludosa
Ptilotus obovatus
Westringia rigida
Eremophila weldii
Bassia patenticuspis
Number of shrubs per 25 x 5 ft quadrat
E
W
Feet
300
900
1500
2100
2700
ppm in soil
Ni
Cr
Co
Feet
Inches
LEGEND
Rock Types
Basalt
Serpentinite
Soil Types
Sandy silt
Silty
Clayey
Sandy clay
Weathered pebbles
Travertine coated pebbles

Figure 50

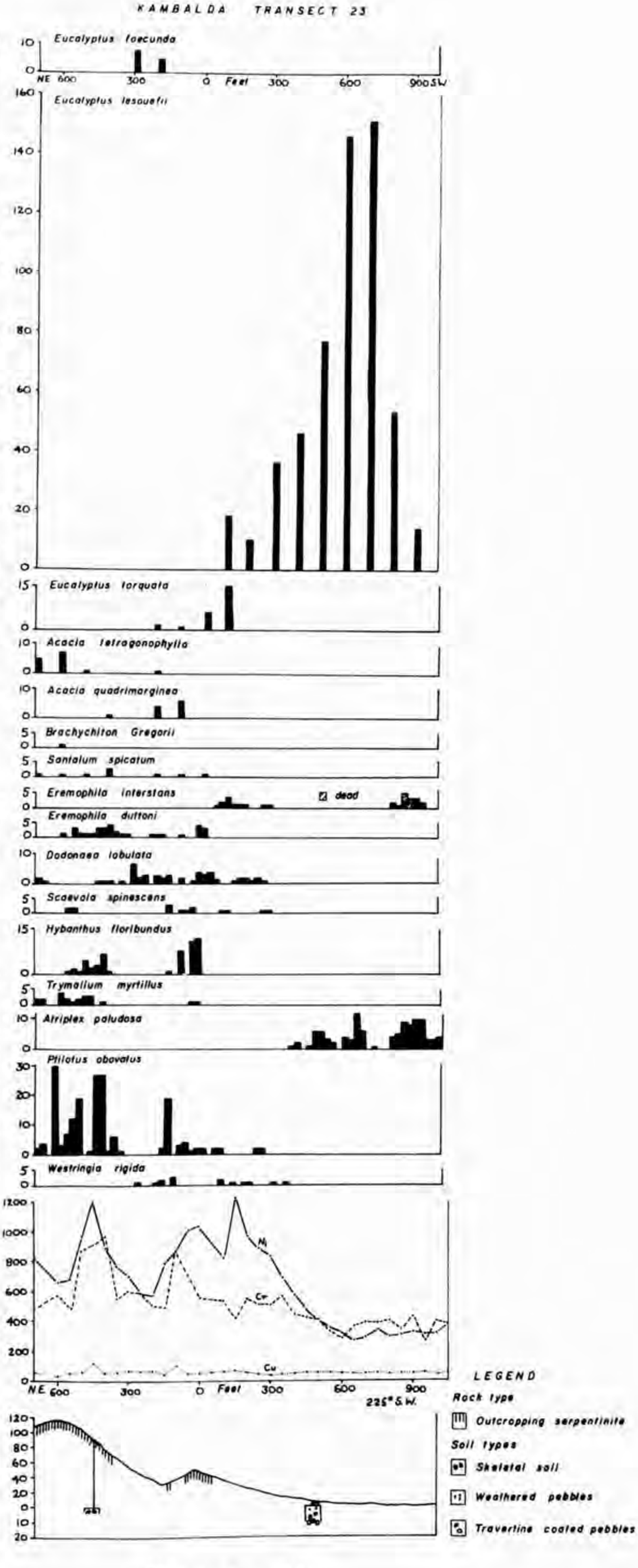

KAMBALDA TRANSECT 23
Eucalyptus foecunda
Eucalyptus lesouefii
Eucalyptus torquata
Acacia tetragonophylla
Acacia quadrimarginea
Brachychiton Gregorii
Santalum spicatum
Eremophila interstans
dead
Eremophila duttoni
Dodonaea lobulata
Scaevola spinescens
Hybanthus floribundus
Trymalium myrtillus
Atriplex paludosa
Ptilotus obovatus
Westringia rigida
Number of trees per 100 ft quadrat
Number of shrubs per 25 X 5 ft quadrat
ppm in soil
Ni
Cr
Cu
NE 600
300
0 Feet
900 SW
225° S.W.
Feet
Ins
LEGEND
Rock type
Outcropping serpentinite
Soil types
Skeletal soil
Weathered pebbles
Travertine coated pebbles

Figure 51

shrub species growing in the understorey of the trees vary between localities, and include Eremophila interstans, Dodonaea lobulata, Scaevola spinescens, Acacia erinacea, Olearia muelleri, Westringia rigida and Atriplex paludosa.

The soils developing over the serpentinites are solonised brown soils. The A horizon extends from the surface to a maximum depth of twelve inches. The soil is reddish brown to dark reddish brown (5YR 4/4, 5YR 3/4, 5YR 4/6) and is generally a sandy-silt, the percentage of silt predominating over that of sand. The B horizon extends to a depth of eighteen inches and deeper, and is usually paler in colour (7.5YR 5/4) with a higher proportion of clay and calcium carbonate. Magnesite appears in small patches of float but does not appear to be important in the B soil horizon. Its texture is looser and more powdery and travertine-coated pebbles may occur in increasing size and abundance down the profile. This soil type is alkaline in reaction, the pH generally lying between 8.0 and 9.0, although at one point a reading as high as 10.0 was obtained (transect 22, 1400 feet west at 35 inches depth).

Occasionally the serpentinite forms strong outcrops, as at the north-eastern end of transect 23 (Figure 51), and here the association changes. The critical factors here seem to be the skeletal nature of the soil and its reduced depth, with the chemical environment playing some part. Eucalypts are absent, and the association comprises Eremophila duttoni, Acacia tetragonophylla, Scaevola spinescens, Cassia artemisioides, Trymalium myrtillus, Dodonaea lobulata, Alyxia buxifolia, Hybanthus floribundus, Ricinocarpus stylosus and Ptilotus obovatus. It will be noted that some of the species listed here also characterise the areas of metabasalt outcrop; such species appear to have the ability to grow where soils are thin and easily drained, and these factors are indicated to be of primary importance in determining their occurrence here. Three shrub species were observed as growing only over serpentinite outcrops in the Kambalda area; Trymalium myrtillus, Ricinocarpus stylosus and Hybanthus floribundus were found nowhere else in this locality excepting the two serpentinite outcrops along transect 23. A certain degree of geological control is indicated, together with the physical nature of the environment, although the geochemistry of this area is also likely to be important, and is referred to in the following section.

In certain localities on the lower hillslopes a large proportion of metabasalt float masks the underlying serpentinite. The association typical of the metabasaltic areas grows here. Physical factors may be of prime importance in this type of plant distribution; most of the species typical of the metabasalt may also grow over outcropping serpentinite where conditions of soil depth, scree cover and drainage are similar. It appears that the skeletal and stony nature of the soil is influential in extending the growth of the metabasalt association over the underlying serpentinite. Limited soil analyses indicated that geochemical factors have a secondary significance; most of the species from the metabasalt association appear to be indifferent to the concentrations of nickel, chromium and copper in the soil here. However, it is possible that other elements, for which no analyses were undertaken, may be influential among the controlling factors in this distribution.

Outcrops of porphyry are frequent in the Kambalda area, both on hillsides and in the lower-lying areas. These areas are characterised by a sandy-silt of varying depth, but usually bedrock lies within approximately a foot of the surface, if not actually outcropping. In most of the porphyry areas geological control of the vegetation association is markedly apparent. Brachychiton Gregorii grows with low frequency in the tree stratum of some of the outcrops, although this species is not limited to this environment and also grows on the sides of the metabasalt ridges and over serpentinite. Characteristic shrubs are Acacia acuminata and Ptilotus obovatus. The chemical and physical factors of the soil environment must stem directly from the porphyry and must be influential in determining the association, excepting those outcrops where there is some degree of float from adjacent rock types.

The porphyry soils tend to be well drained, but water may lie in hollows in the outcropping rock, and the species may take advantage of the run-off from the rock surfaces. The run-off along the edges of the outcrops helps to promote the development of annuals in the spring for more water is available in this environment without the soil becoming waterlogged. The only pH reading from the porphyry was taken at a depth of eleven inches, just above weathered bedrock; the soil here gave a reading of 7.4.

Over part of the Kambalda area, particularly on hillslopes, the underlying porphyry is masked by metabasalt float from higher abutting outcrops. The ground is covered with varying amounts of metabasaltic scree, and in such localities the association developed may be somewhat similar to that of the adjacent metabasalt areas. Where there is an abundance of scree and the soils overlying the porphyry are not well developed the association may show a mixing of the species characterising the metabasalt with those characterising the porphyry. Such an association comprises *Acacia quadrimarginea*, *Brachychiton Gregorii*, *Acacia acuminata*, *Casuarina campestris*, *Dodonaea lobulata*, *Scaevola spinescens*, *Eremophila* sp. J.B./W.A. III, *Prostanthera aspalathoides* and *Dampiera trigona* var. *latealata*. *Eucalyptus lesouefii* and *E. oleosa* may grow where the metabasaltic scree is finer and the soil overlying the porphyry is deeper. In one locality these trees were associated with *Dodonaea lobulata*, *Eremophila interstans*, *Scaevola spinescens*, *E. glabra*, *Acacia erinacea*, *Olearia muelleri* and *Bassia patenticuspis*.

It appears that the soil chemical environment may well be influential here, for the physical environment over both rock types is similar, providing a relatively shallow, well-drained soil together with much scree. It is noticeable that the metabasalt float introduces a certain amount of travertine to the environment and this material would normally be absent where porphyry forms the underlying bedrock; this may influence the growth of the metabasalt-type association. None of the Kambalda transects crossed an area such as this and no soil samples were taken.

An association dominated by various shrub species occurs to the west of Kambalda on the site of a former water course which runs into Lake Lefroy. Trees are generally absent and shrub species growing here are Cratystylis subspinescens, Frankenia interioris, Atriplex paludosa and Arthrocnemum halocnemoides. A small section of this area was examined at the western end of transect 21. Relief is low, tending to be almost uniformly flat, as the local base level of Lake Lefroy is nearby. This formerly active water course still provides a drainage channel after very heavy rain. A soil profile here revealed an A horizon extending from the surface to six inches. The soil is dark red in colour (2.5YR 3/6) and its texture that of a sandy-silt, the immediate surface marked by a sandy veneer. The pH recorded was 8.7. The B horizon extended from six to thirty two inches and continuing. Its colour could not be adequately matched in the Munsell soil colour chart, being more pinky than 5YR 5/6 (yellowish red). The soil is a sandy clay in texture and is more friable than the A horizon. The pH recorded at thirty two inches was 9.8. The geochemistry of the soil is considered later.

The factors controlling the distribution of the psammophytic association of the Kambalda area can be commented upon but briefly. The sand dunes occurring around parts of the shores of Lake Lefroy were examined by field observation only. Their average height is approximately ten feet above the lake surface. The dunes are well drained, except where lying only two feet or so above the level of the lake, and drainage is directly onto the lake surface. Water holding capacity in these soils is probably low. No soil samples were taken for analysis, but the soils on the shoreline dunes are siliceous, while those on the islands in the lake are composed of gypsum. The shoreline dunes only were examined in the field. The domination of these dunes by Acacia quadrimarginea suggests that drainage is an important factor in the environment. This species grows over areas where soils are well drained and skeletal, with consequently low water-holding capacity, and probably a low cation exchange capacity.

4. The relationships between the distribution of the vegetation associations and the nickel, chromium and copper of the soils

Geochemical soil analyses of the three elements nickel, chromium and copper were carried out on samples collected at fifty foot intervals along the transects.

Analysis of samples from the metabasalt areas revealed that these elements were present in amounts which are usual for soils developing over this rock type. Nickel values ranged from 120 to 275 ppm and chromium from 150 to 275 ppm. Copper values remained rather uniform, around 50 ppm. These results can be seen in Figures 47-51. It does not appear that these elements play an important part in determining the distribution and composition of the association here for a number of these species are able to grow equally well where concentrations of nickel and chromium in the soil are much higher. Physical factors in the soil environment are probably of prime importance. Soil from one of the metabasalt areas was analysed for four major elements; sodium, potassium, calcium and magnesium. These were present in normal amounts: sodium 560 ppm, potassium 2300 ppm, calcium 1.6%, and magnesium 1.2%.

Analysis of plant samples from the metabasaltic areas showed that the plant ash from the various species contained normal amounts of these three elements (Table X). Some of the plant samples reveal slightly more copper in their ash than the amount of this metal present in the soil, but amounts of nickel and chromium in ash were, with one exception, always well below the amount in the soil. Nickel is usually below 100 ppm in plant ash and chromium is usually present in lesser amounts than is nickel, only exceeding 100 ppm in some of the samples of *Ptilotus obovatus*.

Geochemical analyses from soils overlying serpentinite showed that nickel and chromium occurred in varying amounts which were sometimes anomalous. The normal background for these two elements in the soil overlying serpentinite here is 100 to 300 ppm. It is unlikely that these normal soil concentrations influence the development of the vegetation to any unusual extent, and the species which grow here rather than on the metabasalt, where nickel and chromium soil concentrations are similar, may be favouring the deeper soils. The soil copper concentration remains fairly uniform throughout the areas of serpentinite, with values averaging about 50 ppm.

The amount of nickel and chromium present in the ash of plants collected from areas underlain by serpentinite is usually more than that occurring in plant samples from the metabasalts (Table X). The amount of these metals in the soil exceeds that present in the plant ash, again with one exception. Of the aerial organs analysed, Eucalyptus leaves contain the greatest amount of nickel. The amount of chromium in the aerial organs is always less than that of nickel. Chromium rarely exceeds 45 ppm in all the species sampled, with the exception of Ptilotus obovatus, which often contains over 100 ppm chromium in its tissues, one sample containing a maximum of 190 ppm. A smaller amount of chromium in the plant ash, as opposed to the amount of nickel present, does not imply that less chromium is taken up by plants. Two root samples were collected from two Eucalypts and both contained more chromium than was present in the aerial organs. Although no conclusion can be drawn from two samples only, it seems likely that this metal, being unnecessary in plant metabolism, is usually precipitated in the roots so that a lesser amount actually reaches the aerial organs. The amount of copper absorped by plants is similar to that observed in the plants growing over the metabasaltic areas. The amount in the plant ash is usually below 100 ppm, sometimes exceeding the amount present in the soil.

The geochemical anomaly, discovered by Western Mining Corporation and examined in transect 22, gave maximum values of 1040 ppm nickel and 738 ppm chromium. The high concentrations on the eastern edge of the anomaly have affected the vegetation association in prohibiting the development of trees and some shrub species. The cut-out of the Eucalyptus species in this area is obvious in the field. The western section of the anomaly, however, cannot be correlated with a cut-out of vegetation. Eucalyptus lesouefii and E. torquata grow, and there is a grove of Melaleuca sheathiana. These trees have a variety of shrubs associated with them - Eremophila duttoni, Dodonaea lobulata, D. stenozyga, Scaevola spinescens, Atriplex nummularia, Acacia erinacea, Eremophila weldii and Ptilotus obovatus. They all appear to be unaffected by the high nickel and chromium values.

It is suggested that the normal vegetation association and the presence of Melaleuca sheathiana over the western part of the anomaly is related to the large amount of calcium carbonate which is apparent in the soil here. Around point 2100 feet west on transect 22 the soil becomes noticeably looser and more powdery, with an increased amount of calcium carbonate and hence a high pH: stones within the soil are coated with travertine. It has been noted throughout the areas of study in the Goldfields that M. sheathiana appears to favour soils which are rich in this compound. Carbonate removes nickel from solution under a high pH so that the amount of this element available for uptake by plants is reduced. Thus, although the total amount of nickel in the soil at this point is over 1000 ppm, the high values are not revealed geobotanically. This contrasts with the eastern half of the anomaly where the soil appears to contain less calcium carbonate: hence there is more nickel in solution and available for plant uptake than is favourable for growth, and some species are prohibited from developing.

Where the serpentinite outcrops strongly and soils are skeletal the chemical environment of the soil may well play a part in determining the distribution of the three shrub species Trymalium myrtillus, Ricinocarpus stylosus and Hybanthus floribundus. They were found only on the serpentinite outcrops on transect 23 where soil nickel values are high, reaching a maximum of 1230 ppm. Soil chromium values are correspondingly high, reaching to 970 ppm. If physical factors alone were responsible for the development of these three species it is likely that they would grow also over metabasalt outcrops. It appears that both the physical and the chemical environments of the soil here provide suitable conditions for their growth. However, without further studies it cannot be said if high concentrations of these two elements, together with the physical background provided by an outcrop, are necessary and determining factors in the distribution of these three shrub species in this area. Although these factors appear to play some part in the plant development their degree of control is unknown. The plants composing the vegetation association on these serpentinite outcrops, with their high concentration of nickel and chromium, may be able to tolerate high concentrations in their tissues or else have the ability to reject the uptake of toxic concentrations. Limited numbers of plant samples were collected for analysis and none was taken from the areas of outcrop. Results of these analyses are shown in Table X.

The serpentinite is masked by soil cover south-west of the areas of outcrop and here the background figures for nickel and chromium tend to be approximately 315 and 380 ppm respectively. These levels are slightly above the background levels for the other soil covered areas due to dispersion of these metals downslope from the outcrops.

In the areas of porphyry limited information was gathered on the chemical nature of the soil. Nickel and chromium soil values ranged between 150 and 300 ppm, with copper generally below 100 ppm. These values conform to background in the Kambalda area and it appears that they do not play an important part in determining or influencing the vegetation association which develops over this rock type, except in allowing the normal plant assemblage to develop.

The soil covered area of the former water course lying west of Kambalda was examined geochemically over a small area for nickel, chromium and copper. Nickel and chromium values in the soil ranged from 190 to 340 ppm, while copper values remained well below 100 ppm. These concentrations fall into the background range for the area and do not appear to be related to the development of the shrub association here except in that they allow the species present to grow normally. No analyses were carried out for other elements, but it appears from field observation that the concentration of salt in the soil is the most important factor controlling the distribution of this association. Tree growth is largely prohibited because of the high salt concentration and only halophytic species can thrive. It if were not for the adverse chemical environment the physical soil environment would certainly be adequate to support tree growth for soil depth, texture and drainage appear favourable over the greater part of the area. It is only rarely, after exceptionally heavy rain, that water tends to flow here and lie in pools, and these pools occupy limited areas only.

In conclusion it may be said that over those parts of the Kambalda area where the nickel and chromium values in the soil fall within the background concentration the vegetation associations developed do not appear to be greatly influenced by these two metals; other factors in the plant environment, such as the degree to which the soil has developed, play a more direct and influential role. Nickel and chromium are not considered essential minerals in plant metabolism and the background soil concentrations found here do not affect the development of species, for this concentration is tolerable for normal growth and development. By contrast, copper is an essential plant element, and is present here in concentrations which are sufficient but not toxic for plant requirements. Thus it is related to plant distribution in that it allows normal growth to proceed, for, if it were absent, deficiencies would be likely to occur.

Where the nickel and chromium in the soil reach anomalous concentrations the response of the vegetation will depend on a number of factors, including the amount of carbonate present in the soil, and the depth of the soil cover. Where there is much carbonate and hence a high soil pH less nickel is available in the soil solution for uptake by plants, and although geochemical soil concentrations may be high toxic amounts will not be present in the plant environment and normal growth can proceed. Where toxic concentrations are available for uptake the vegetation may be affected in that certain species are prevented from growing and developing and the association is marked by a cut-out, particularly of tree species. By contrast, where high nickel and chromium values are present in skeletal soil overlying serpentinite outcrops the vegetation association is varied and well-developed, and for the most part the association here appears to be a response to the rocky nature of the habitat rather than to any anomalous metal concentrations in the soil environment.

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Cu	ppm, Oven-dried Ni	Cr	Cu	ppm, Soil Ni	Cr	Cu	Rock Type
68	Ptilotus obovatus	T 19 00	Leaves & stems	4.5	45	60	95	2.0	2.7	4.2	130	180	60	Basalt
70	Ptilotus obovatus	T 19 200	Leaves & stems	4.9	35	40	50	1.7	1.9	2.4	130	155	60	"
88	Acacia quadrimarginea	T 19 200	Leaves	6.2	33	15	95	1.7	0.9	5.8				"
89	Acacia quadrimarginea	T 19 200	Twigs	5.1	23	20	85	1.3	1.0	4.3				"
80	Eucalyptus torquata	T 19 420	Fruit	4.1	83	20	90	3.3	0.8	3.6	250	418	50	"
81	Eucalyptus torquata	T 19 420	Leaves	4.1	105	20	50	4.3	0.8	2.0				"
78	Eucalyptus torquata	T 19 420	Young twigs	5.8	53	70	20	3.0	1.1	4.0	250	418	50	"
83	Eucalyptus torquata	T 19 420	Old twigs	3.5	35	20	90	1.2	0.7	3.1				"
82	Ptilotus obovatus	T 19 500	Leaves & stems	4.1	70	70	100	2.8	2.8	4.1	180	170	70	"
69	Ptilotus obovatus	T 19 700	Leaves & stems	5.1	115	115	75	5.8	5.8	3.8	430	318	45	Serpentinite
84	Acacia quadrimarginea	T 19 739	Leaves	5.6	413	25	175	230	1.4	9.8				"

Analyses of unmilled, dry-ashed plant material.
KV series samples.

TABLE X

KAMBALDA

Sample	Species	Locality	Organ	% Ash	ppm, Ashed Ni	ppm, Ashed Cr	ppm, Ashed Cu	ppm, Oven-dried Ni	ppm, Oven-dried Cr	ppm, Oven-dried Cu	ppm, Soil Ni	ppm, Soil Cr	ppm, Soil Cu	Rock Type
85	Acacia quadrimarginea	T 19 739	Twigs	5.6	32	30	175	1.7	1.6	4.2				Serpentinite
79	Eucalyptus torquata	T 19 800	Fruit	4.0	210	10	50	8.4	0.4	2.0	290	285	35	"
73	Eucalyptus torquata	T 19 800	Leaves	4.3	285	20	60	12.2	0.8	2.5				"
72	Eucalyptus torquata	T 19 800	Young twigs	6.9	85	35	30	5.8	2.4	2.0				"
71	Eucalyptus torquata	T 19 800	Old twigs	-	140	20	30	-	-	-				"
90	Ptilotus obovatus	T 19 1000	Leaves & stems	4.2	115	140	45	4.8	5.8	1.8	350	572	45	"
76	Ptilotus obovatus	T 19 1500	Leaves & stems	6.8	200	145	65	13.6	9.8	4.4	765	410	45	"
77	Ptilotus obovatus	T 19 2550	Leaves & stems	5.3	210	190	115	11.1	10.0	6.0	310	230	50	Soil covered
74	Acacia quadrimarginea	T 20 00	Leaves	6.9	30	20	30	2.0	1.3	2.0	120	200	52	Basalt
75	Acacia quadrimarginea	T 20 00	Twigs	6.5	33	25	50	2.0	1.6	3.2				"
67	Ptilotus obovatus	T 20 00	Leaves & stems	5.5	33	105	80	1.7	5.7	4.4				"

Analyses of unmilled, dry-ashed plant material.
KV series samples

TABLE X cont.

KAMBALDA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Cu	ppm, Oven-dried Ni	Cr	Cu	ppm, Soil Ni	Cr	Cu	Rock Type
66	Ptilotus obovatus	T 20 400	Leaves & stems	4.5	57	65	100	2.5	2.9	4.5	150	300	40	Serpentinite
86	Acacia quadrimarginea	T 20 400	Leaves	3.7	33	25	115	1.1	0.9	4.2				"
87	Acacia quadrimarginea	T 20 400	Twigs	4.4	23	20	90	0.9	0.8	3.9				"
23	Ptilotus obovatus	T 20 1300	Leaves & stems	5.5	85	50	90	4.6	2.7	4.9	250	225	148	"
21	Ptilotus obovatus	T 20 1700	Leaves & stems	4.9	45	125	85	2.2	6.1	4.1	98	200	35	Porphyry
11	Eucalyptus lesouefii	T 21 200	Leaves	5.2	90	10	45	4.6	0.5	2.3	200	115	100	Basalt
12	Eucalyptus lesouefii	T 21 200	Young twigs	7.8	37	15	50	2.9	1.2	3.9				"
4	Eucalyptus lesouefii	T 21 200	Old twigs	6.2	47	25	65	2.9	1.5	4.0				"
7	Ptilotus obovatus	T 21 450	Leaves & stems	4.6	23	50	110	1.0	2.3	4.0	216	330	102	"
2	Eucalyptus torquata	T 21 550	Leaves	3.5	83	25	55	2.8	0.8	1.9	160	170	122	"
1	Eucalyptus torquata	T 21 550	Young twigs	5.4	35	5	45	1.8	0.2	2.4				"

Analyses of unmilled, dry-ashed plant material.
KV series samples.

TABLE X cont. KAMBALDA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	ppm, Ashed Cr	ppm, Ashed Cu	ppm, Oven-dried Ni	ppm, Oven-dried Cr	ppm, Oven-dried Cu	ppm, Soil Ni	ppm, Soil Cr	ppm, Soil Cu	Rock Type
I6	Eucalyptus torquata	T 2I 550	Old twigs	3.8	47	70	35	I.7	2.6	I.9	I60	I70	I22	Basalt
3	Eucalyptus lesouefii	T 2I 700	Leaves	4.0	240	5	75	9.6	0.2	3.0	I45	I80	82	Serpentinite
I5	Eucalyptus lesouefii	T 2I 700	Young twigs	5.7	72	20	70	4.I	I.I	3.2				"
5	Eucalyptus lesouefii	T 2I 700	Old twigs	4.0	70	5	90	2.8	0.2	3.6				"
24	Acacia quadrimarginea	T 2I 975	Leaves	4.3	27	35	I25	I.I	I.5	5.3				"
25	Acacia quadrimarginea	T 2I 975	Twigs	3.2	32	20	45	I.0	0.6	I.4				"
8	Ptilotus obovatus	T 2I I050	Leaves & stems	3.7	II5	I45	II0	4.2	5.3	4.0	2I5	2I0	58	"
I4	Eucalyptus lesouefii	T 2I II50	Leaves	4.6	247	25	60	II.3	I.I	3.0				"
9	Eucalyptus lesouefii	T 2I II50	Young twigs	6.8	90	I5	70	6.I	I.0	4.7				"
I3	Eucalyptus lesouefii	T 2I II50	Old twigs	5.I	II5	I5	60	5.8	0.7	4.6				"
6	Ptilotus obovatus	T 2I I560	Leaves & stems	3.4	77	70	-	2.6	2.3	-	2I5	322	38	"

Analyses of unmilled, dry-ashed plant material.
KV series samples.

TABLE X cont. KAMBALDA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Cu	ppm, Oven-dried Ni	Cr	Cu	ppm, Soil Ni	Cr	Cu	Rock Type
26	Acacia quadrimarginea	T 2I I570	Leaves	8.3	20	35	85	I.6	2.9	7.0				Serpentinite
27	Acacia quadrimarginea	T 2I I570	Twigs	5.8	20	30	70	I.I	I.7	4.0				"
I9	Eucalyptus torquata	T 2I I700	Leaves	4.2	I42	25	60	5.9	I.0	2.5	225	430	32	"
44	Eucalyptus torquata	T 2I I700	Young twigs	5.7	II5	40	75	6.5	2.2	4.2				"
43	Eucalyptus torquata	T 2I I700	Old twigs	3.9	90	25	70	3.5	0.9	2.7				"
62	Ptilotus obovatus	T 2I I800	Leaves & stems	4.8	95	I85	60	4.5	8.8	2.8	215	385	32	"
56	Eucalyptus torquata	T 22 50	Leaves	4.I	II5	-	70	4.7	-	2.9	700	350	90	"
58	Eucalyptus torquata	T 22 50	Fruit	4.8	35	20	75	I.7	I.0	3.6				"
I0	Eucalyptus torquata	T 22 50	Young twigs	5.3	75	35	I20	3.9	I.8	6.3				"
57	Eucalyptus torquata	T 22 50	Old twigs	3.3	80	20	90	2.6	0.7	3.0				"
22	Ptilotus obovatus	T 22 300	Leaves & stems	5.3	75	85	75	3.9	4.5	3.9	280	345	45	"

Analyses of unmilled, dry-ashed plant material.
KV series samples.

TABLE X cont. KAMBALDA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Cu	ppm, Oven-dried Ni	Cr	Cu	ppm, Soil Ni	Cr	Cu	Rock Type
60	Eucalyptus ?lesouefii	T 22 500	Leaves	3.9	I05	40	35	4.I	I.6	I.4	I70	262	40	Basalt
6I	Eucalyptus ?lesouefii	T 22 500	Young twigs	5.8	I07	20	45	6.2	I.2	2.6				"
59	Eucalyptus ?lesouefii	T 22 500	Old twigs	4.0	45	30	70	I.8	I.2	2.8				"
65	Ptilotus obovatus	T 22 600	Leaves & stems	4.6	II5	I20	70	5.3	5.5	3.2	230	485	48	"
45	Eucalyptus lesouefii	T 22 I050	Leaves	4.5	465	25	75	20.9	I.I	3.3	300	I68	60	"
20	Eucalyptus lesouefii	T 22 I050	Young twigs	5.8	I80	20	75	I0.4	I.I	4.3				"
46	Eucalyptus lesouefii	T 22 I050	Old twigs	4.8	I90	I5	75	9.I	0.7	3.6				"
49	Eucalyptus JB/WA 304	T 22 I400	Leaves	4.7	520	70	90	24.4	3.2	4.2	680	485	62	Serpentinite
47	Eucalyptus JB/WA 304	T 22 I400	Fruit	4.8	82	45	45	3.9	2.I	2.I				"
52	Eucalyptus JB/WA 304	T 22 I400	Young twigs	4.6	425	45	90	I9.5	2.I	4.I				"
48	Eucalyptus JB/WA 304	T 22 I400	Old twigs	3.2	82	30	85	3.9	0.9	2.7				"

Analyses of unmilled, dry-ashed plant material.
KV series samples.

TABLE X cont.

KAMBALDA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Cu	ppm, Oven-dried Ni	Cr	Cu	ppm, Soil Ni	Cr	Cu	Rock Type
5I	Eucalyptus torquata	T 22 2000	Leaves	3.8	II5	25	65	4.4	0.9	2.5	805	505	90	Serpentinite
I8	Eucalyptus torquata	T 22 2000	Fruit	3.4	95	5	50	3.2	0.I	I.7				"
50	Eucalyptus torquata	T 22 2000	Young twigs	4.7	82	20	85	3.9	0.9	4.0				"
55	Eucalyptus torquata	T 22 2000	Old twigs	4.4	70	I5	70	3.I	0.7	3.I				"
40	Eucalyptus torquata	T 22 2275	Leaves	4.3	II5	20	60	4.9	0.8	2.5				"
42	Eucalyptus torquata	T 22 2275	Fruit	3.6	57	45	60	2.0	I.6	2.I				"
38	Eucalyptus torquata	T 22 2275	Young twigs	5.3	77	20	I0	4.0	I.0	0.5				"
4I	Eucalyptus torquata	T 22 2275	Old twigs	4.6	82	I5	55	3.7	0.6	2.5				"
64	Unidentified Eucalyptus sp.	T 22 2500	Roots	6.8	II5	240	60	7.8	I6.3	4.I	270	3I0	48	"
53	Eucalyptus lesouefii	T 22 2800	Leaves	4.2	I65	30	45	6.9	I.3	I.9	300	298	40	"
I7	Eucalyptus lesouefii	T 22 2800	Young twigs	5.2	40	20	25	2.0	I.0	I.3				"

Analyses of unmilled, dry-ashed plant material.
KV series samples.

TABLE X cont. KAMBALDA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Cu	ppm, Oven-dried Ni	Cr	Cu	ppm, Soil Ni	Cr	Cu	Rock Type
54	Eucalyptus lesouefii	T 22 2800	Old twigs	3.4	57	25	40	I.9	0.8	I.4	300	298	40	Serpentinite
I99	Eucalyptus torquata	T 23 75	Leaves	4.5	I00	25	65	4.5	I.I	2.9				"
I92	Eucalyptus torquata	T 23 75	Fruit	4.0	90	I5	70	3.6	0.6	2.8				"
I95	Eucalyptus torquata	T 23 75	Young twigs	5.6	95	20	90	5.3	I.I	5.0				"
I93	Eucalyptus torquata	T 23 75	Old twigs	4.4	57	20	80	2.5	0.9	3.5				"
200	Eucalyptus lesouefii	T 23 200	Leaves	4.6	90	30	50	4.I	I.3	2.3	970	550	58	Soil covered
I94	Eucalyptus lesouefii	T 23 200	Young twigs	5.0	57	20	50	2.9	I.0	2.5				"
I97	Eucalyptus lesouefii	T 23 200	Old twigs	3.8	56	25	65	2.I	0.9	2.4				"
33	Eucalyptus lesouefii	T 23 480	Leaves	5.2	330	45	45	I7.2	2.3	2.3				"
35	Eucalyptus lesouefii	T 23 480	Young twigs	5.8	95	20	50	5.5	I.2	2.9				"
3I	Eucalyptus lesouefii	T 23 480	Old twigs	4.0	97	20	30	3.9	0.8	I.2				"

Analyses of unmilled, dry-ashed plant material.
KV series samples.

TABLE X cont. KAMBALDA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed			ppm, Oven-dried			ppm, Soil			Rock Type
					Ni	Cr	Cu	Ni	Cr	Cu	Ni	Cr	Cu	
36	Eucalyptus lesouefii (dead)	T 23 480	Leaves	5.4	I72	25	45	9.3	I.3	2.4				Soil covered
32	Eucalyptus lesouefii (dead)	T 23 480	Young twigs	6.8	II5	I5	70	7.8	I.0	4.8				"
34	Eucalyptus lesouefii (dead)	T 23 480	Old twigs	4.5	90	I5	30	4.0	0.7	I.3				"
39	Eucalyptus lesouefii (dead)	T 23 480	Roots	4.9	240	I90	60	II.7	9.3	2.9				"
30	Eucalyptus lesouefii	T 23 750	Leaves	4.7	I00	30	45	4.7	I.4	2.I	340	390	58	"
29	Eucalyptus lesouefii	T 23 750	Young twigs	5.4	32	20	40	I.7	I.I	2.2				"
28	Eucalyptus lesouefii	T 23 750	Old twigs	5.0	40	20	40	2.0	I.0	2.0				"
204	Eucalyptus lesouefii	T 23 980	Leaves	6.I	350	20	45	2I.3	I.2	2.7				"
37	Eucalyptus lesouefii	T 23 980	Young twigs	7.9	II5	5	45	9.I	0.4	3.6				"

Analyses of unmilled, dry-ashed plant material.
KV series samples.

TABLE X cont.

KAMBALDA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Ni	Cr	Cu	ppm, Oven-dried Ni	Cr	Cu	ppm, Soil Ni	Cr	Cu	Rock Type
203	Eucalyptus lesouefii	T 23 980	Old twigs	6.4	95	I5	45	6.0	0.9	2.8				Soil covered
I9I	Eucalyptus torquata	T 23 I60	Leaves	4.0	II5	25	70	4.6	I.0	2.8	790	485	52	Serpentinite
I90	Eucalyptus torquata	T 23 I60	Young twigs	4.7	63	I0	70	3.0	0.5	3.3				"
I89	Eucalyptus torquata	T 23 I60	Old twigs	3.7	90	20	0	3.3	0.7	0				"
20I	Eucalyptus foecunda	T 23 225	Leaves	4.8	402	I5	70	I9.2	0.7	3.3				"
I98	Eucalyptus foecunda	T 23 225	Fruit	4.I	I75	20	70	7.I	0.8	2.8				"
I96	Eucalyptus foecunda	T 23 225	Young twigs	5.6	I3I	I5	50	7.3	0.8	2.8				"
202	Eucalyptus foecunda	T 23 225	Old twigs	4.6	II2	20	50	5.I	0.9	2.3				"
63	Unidentified Eucalyptus sp.	Winze I00800N II-47' depth	Roots	I0.2	6400	-	-	652.8	-	-				Gossan

Analyses of unmilled, dry-ashed plant material.
KV series samples. TABLE X cont. KAMBALDA

(B) WIDGIEMOOLTHA-HORAN'S COPPER PROSPECT

1. The geographical environment

Horan's copper prospect lies three miles along the track which leads in an easterly direction from the Widgiemooltha-Norseman road, near the 408 mile peg (Figure 52). Most of the area is gently undulating; the topography in the locality studied is more or less flat, excepting for a slight north-south ridge lying to the west of the copper working. Outside the immediate study area the only prominent relief feature is the Cowan Dyke, about one mile south of the prospect and running in an east-west direction.

The following geological information is after E. Cameron (1966). There are very few outcrops in the area, but the geological setting is generally one of slates and of fine-grained amphibolites, which may be found as dykes. In the limited areas where outcrops occur they may be coated with travertine or obscured by ferruginous gravel. The copper minerals malachite, azurite, and ?tenorite are found in veins and as coatings over the fractures in slates, but there is no extensive mineralisation. The secondary carbonate worked here has averaged between 7% and 8% copper.

2. The distribution of the vegetation associations

The area is one of open woodland. In the vicinity of the propsect the _Eucalyptus_ species growing are _lesouefii_ and _salmonophloia_, dominating an association in which the most important shrub species are _Eremophila interstans_, _Cratystylis conocephala_, and _Atriplex paludosa_. _Melaleuca sheathiana_ shows a sporadic distribution within this general association, becoming abundant in localised areas.

The association changes over a small area adjacent to the eastern side of the copper working. _E. lesouefii_ and _E. salmonophloia_ give place to _E. torquata_, which becomes the dominant species in the tree stratum. A A greater variety of shrub species is also noticeable; _Cassia eremophila_, _Scaevola spinescens_ and _Westringia rigida_ grow. A number of shrubs appear to be exclusive to this association, such as _Alyxia buxifolia_, _Eremophila decipiens_ and _Ptilotus obovatus_, while the species from the more widely spread surrounding association either become far less important (_Eremophila interstans_, _Atriplex paludosa_) or do not occur at all (_Cratystylis conocephala_).

LOCALITY MAP OF HORAN'S COPPER PROSPECT WIDGIEMOOLTHA. (After E. Cameron).

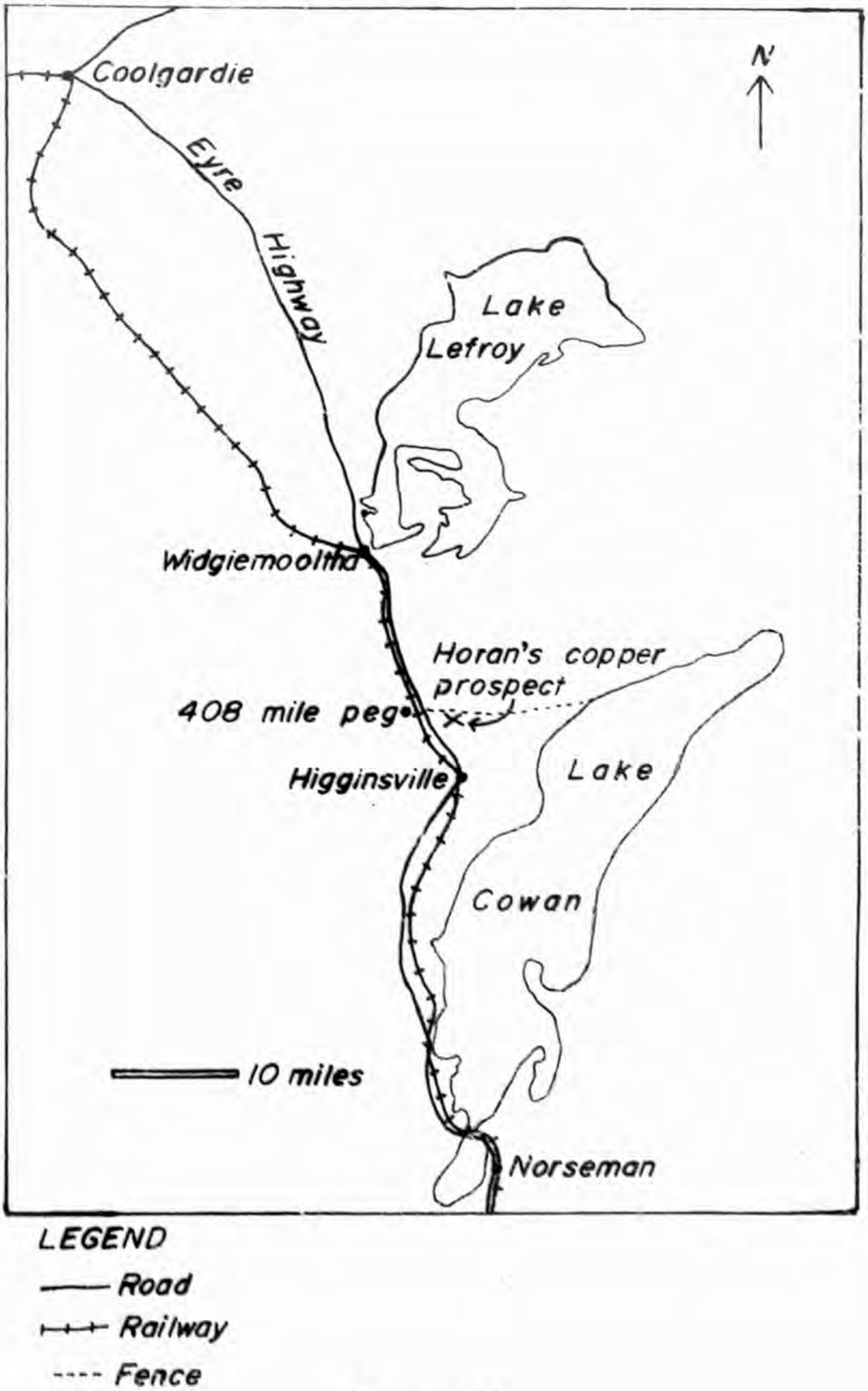


Figure 52

Further to the east this association gradually merges with that surrounding it. E. lesouefii and E. salmonophloia appear as infrequent species within the area dominated by E. torquata. They gradually become more prominent as the shrubs C. conocephala, Atriplex nummularia and A. paludosa assume more importance, although they may still occur with species from the more varied adjacent association. Approximately 700 feet east of the prospect the smaller association has given way completely to one of E. lesouefii, E. salmonophloia, Eremophila interstans, C. conocephala and Olearia muelleri.

3. The factors governing the distribution of the vegetation associations

The distribution of the two vegetation associations cannot be explained by reference to the features which compose the geographical environment in this area. Relief is subdued, the ground sloping gently to the east in the area of field study and presenting no observable feature which could account for the presence of the two associations which have developed here. No creeks were seen in the general locality, and drainage, following the lie of the land, is in an easterly direction. Many of the drainage channels in the district eventually debouch into Lake Lefroy.

Paucity of outcrop has limited the information available on the underlying bedrock. The locality falls generally within the area of greenstones, and around the prospect slates and amphibolites form part of the geological setting. There is no information on the bedrock immediately underlying the smaller of the two associations, dominated by _Eucalyptus torquata_, _Cassia eremophila_, _Scaevola spinescens_, _Westringia rigida_ and _Ptilotus obovatus_, restricted in area to the eastern side of the prospect.

Solonised brown soils are developing within the area studied. Occasionally no differentiation into horizons has occurred within the depth of augering, which was possible to a maximum depth of eighteen inches, the soil having throughout a silty or silty-clay texture with travertine coated pebbles present. Elsewhere the A horizon extends from the surface to a depth of six to twelve inches, and is a yellowish red in colour (5YR 4/6). The soil texture is a silty-clay, more rarely a sandy-silt, with small weathered pebbles present, some of them coated with travertine. The B horizon extends downwards to a depth of eighteen inches and deeper. Where the texture is predominantly clayey the soil tends to maintain its yellowish red colour, but where the soil is a silty-clay with looser texture it becomes paler in colour (5YR 5/6 wet, 7.5YR 6/4 dry). Travertine coated pebbles persist throughout this horizon.

The nature of the bedrock underlying the association of E. torquata, C. eremophila, S. spinescens, W. rigida and P. obovatus has not been ascertained and it cannot be said whether the bedrock here differs in any way from that elsewhere in the vicinity where the vegetation association is different. Examination of soil profiles along the transects revealed that soils are uniformly well developed, and although augering was only possible to a depth of eighteen inches no signs of weathered bedrock were seen in any of the profiles examined. Soil depth and texture are sufficiently uniform to be negligible factors in influencing the distribution of the two associations in the area. Profiles examined between the origin and 300 feet south on transect 18 differed from those elsewhere along this transect in that travertine coated pebbles and nodules were more abundant and present throughout the profile, unlike the profiles further to the north and south where such pebbles become evident only in the B horizon. It will be noted from the transect data (Figures 53 and 54) that the association of E. torquata, C. eremophila, S. spinescens, W. rigida and P. obovatus coincides in its distribution with the area which contains the greater amount of travertine coated pebbles within the soil profile. However, this seems unlikely to be an important factor in the distribution of the association: profile information along transect 24, although more limited, does not substantiate any such correlation. Profiles examined at the origin and 900 feet south revealed that travertine coated pebbles were present throughout, yet the association of E.

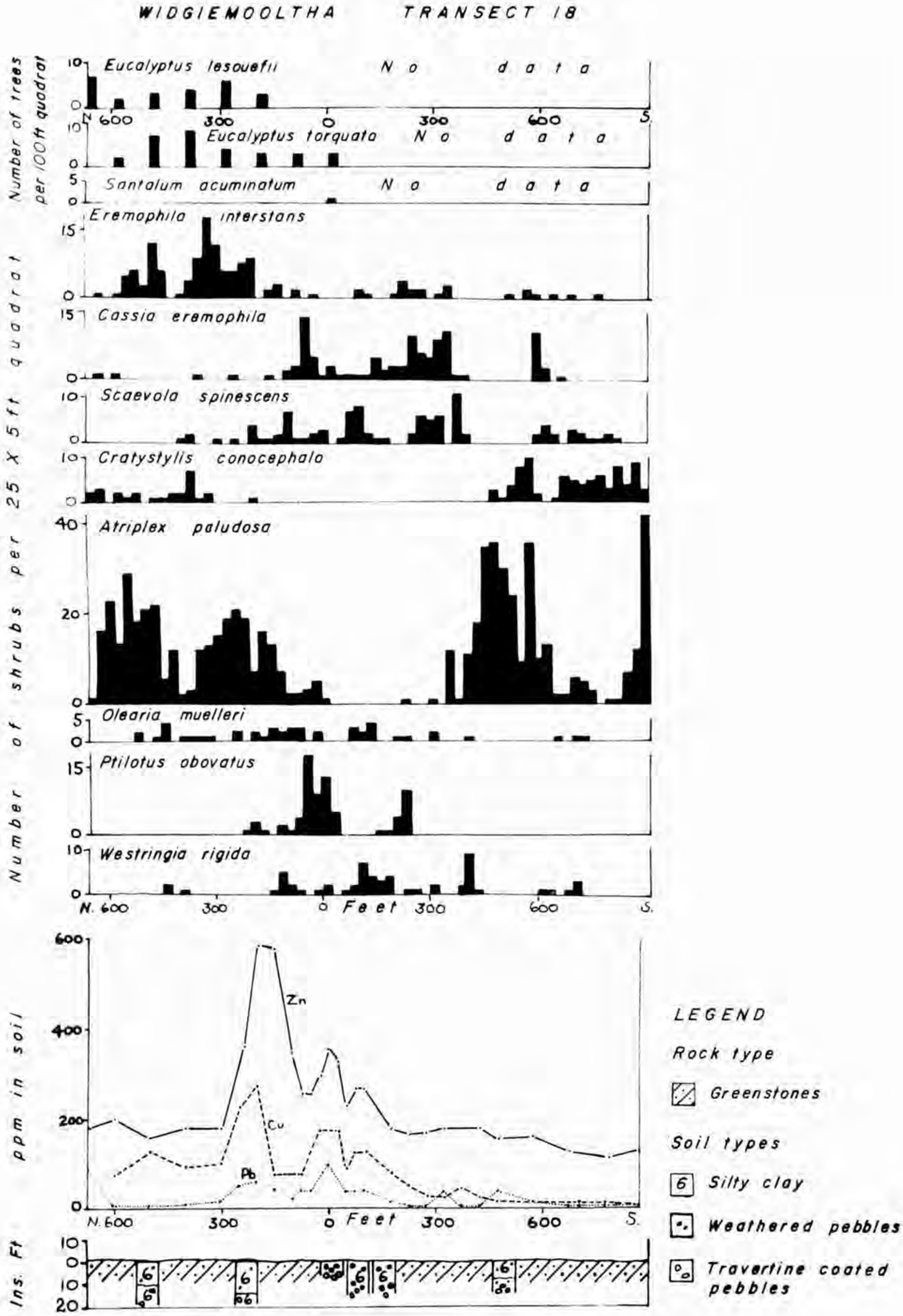

WIDGIEMOOLTHA TRANSECT 18
Number of trees per 100 ft quadrat
Eucalyptus lesouefii
No data
Eucalyptus torquata
Santalum acuminatum
Eremophila interstans
Cassia eremophila
Scaevola spinescens
Cratystylis conocephala
Atriplex paludosa
Olearia muelleri
Ptilotus obovatus
Westringia rigida
Number of shrubs per 25 X 5 ft quadrat
N. 600
300
0
Feet
300
600
S.
ppm in soil
Zn
Cu
Pb
Ins. Ft
LEGEND
Rock type
Greenstones
Soil types
Silty clay
Weathered pebbles
Travertine coated pebbles

Figure 53

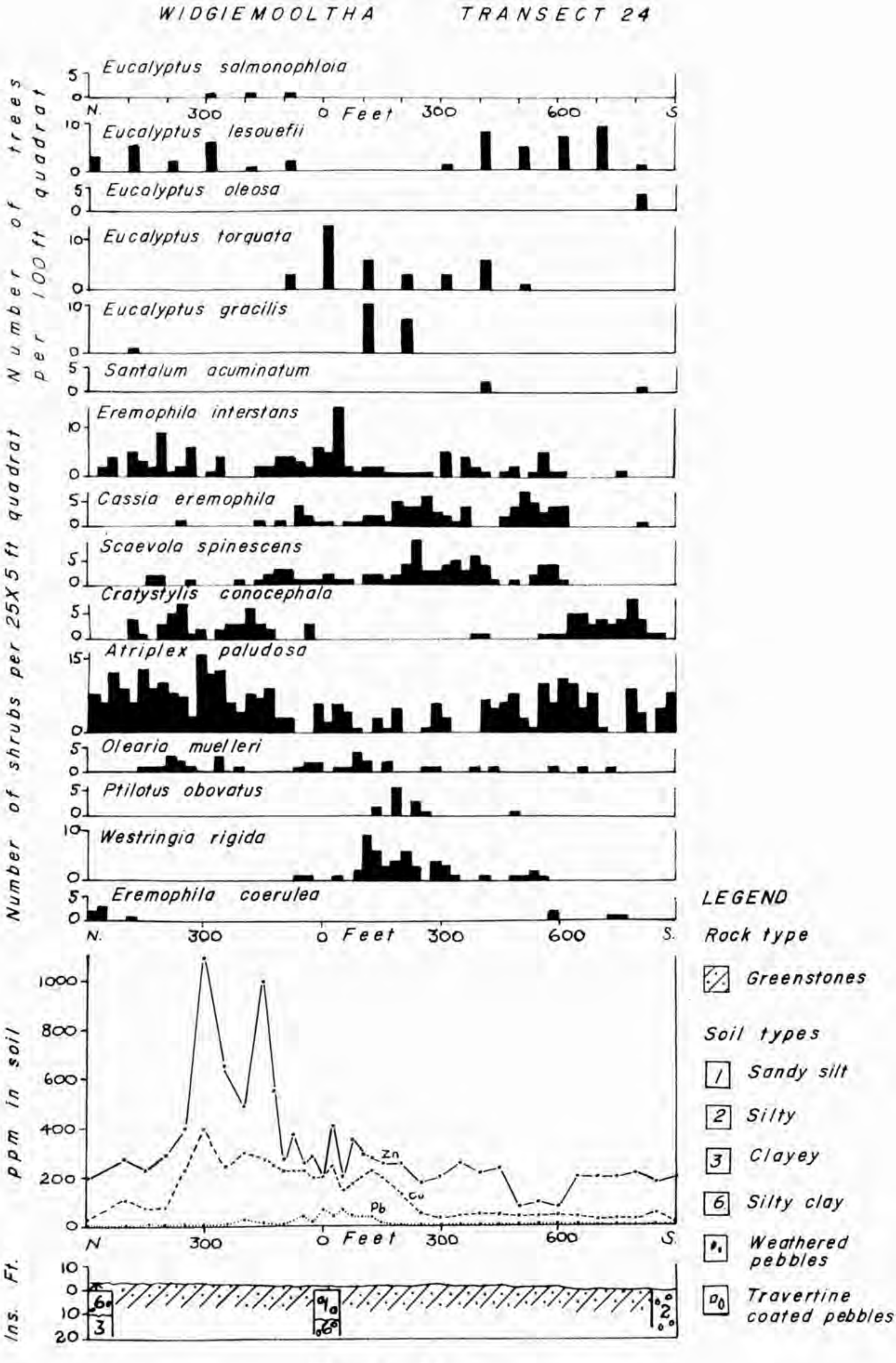

WIDGIEMOOLTHA TRANSECT 24
Number of trees per 100 ft quadrat
Eucalyptus salmonophloia
Eucalyptus lesouefii
Eucalyptus oleosa
Eucalyptus torquata
Eucalyptus gracilis
Santalum acuminatum
Number of shrubs per 25X5 ft quadrat
Eremophila interstans
Cassia eremophila
Scaevola spinescens
Cratystylis conocephala
Atriplex paludosa
Olearia muelleri
Ptilotus obovatus
Westringia rigida
Eremophila coerulea
N. 300 0 Feet 300 600 S.
ppm in soil
Zn
Cu
Pb
Ft.
Ins.
LEGEND
Rock type
Greenstones
Soil types
1 Sandy silt
2 Silty
3 Clayey
6 Silty clay
Weathered pebbles
Travertine coated pebbles

Figure 54

torquata, C. eremophila, S. spinescens, W. rigida and P. obovatus does not occur as far south as 900 feet. The application of dilute hydrochloric acid to the soil showed an abundance of free lime present, and the pH ranged from 7.1 to 8.0. Without further studies it cannot be known to what extent, if at all, the distribution of the vegetation associations is influenced by the amount of calcium carbonate within the soil. Insufficient numbers of bulk soil samples were collected from this area to allow satisfactory conclusions to be drawn from the results of analyses for calcium and magnesium (Table XII).

4. The relationships between the distribution of the vegetation associations and the copper, zinc and lead of the soils

Although much of the vegetation had been disturbed by workings around the copper prospect, geobotanical field observation suggested that the association dominated by _Eucalyptus torquata_, _Cassia eremophila_, _Scaevola spinescens_, _Westringia rigida_ and _Ptilotus obovatus_ adjacent to the prospect on its eastern side could owe its development either to an underlying extension of the copper mineralisation, or else to the dispersion of copper minerals downslope. In either case the development of the association over this restricted area could be a direct result of an increase in the copper concentration in the soil. Field studies were directed to ascertain how far this might be the case.

Geochemical soil samples were analysed for copper, zinc and lead. It is evident from the results that copper and zinc anomalies are present along both transects. In transect 18, which ran nearest to the copper workings, the copper values of the soil are highest over an approximate distance from 225 feet north to 125 feet south. The highest soil concentration occurs at 175 feet north where the soil content is 275 ppm copper. Values fall towards the southern end of the transect, maintaining a fairly level background concentration of approximately 15 ppm.

Zinc soil values follow a similar trend along transect 18, but here the anomaly is more marked, the maximum concentration of 585 ppm occurring, as was the case with the soil copper content, at 175 feet north. The two smaller peaks correspond in their positions with the two similar peaks occurring in the copper content of the soil. Zinc background concentration approximates to 150 ppm.

The soil lead content remains low, but there tends to be some correspondence with the pattern observed for copper and zinc. Higher values, to a maximum of 100 ppm, correspond in their position with the anomalies shown for the elements copper and zinc. The lead soil content falls from this peak to a threshold of approximately 40 ppm. Background values are low, from 5 to 10 ppm.

Transect 24 lay 125 feet east of transect 18, the two transects running parallel. Analytical results again yielded anomalies for the soil content of the two elements copper and zinc. Copper reaches a maximum value of 400 ppm at 300 feet north, the anomaly extending from 350 feet north to 200 feet south before values fall to a background concentration of about 40 ppm copper.

Anomalous zinc values in the soil extend over a shorter distance, from approximately 300 feet north to 125 feet north, concentration reaching to a maximum of 1100 ppm at 300 feet north. Background for zinc approximates to 200 ppm.

Lead values in the soil remain relatively low, as along transect 18. There is a small increase in concentration from 50 feet north to 125 feet south, the maximum value reached being 65 ppm lead. Concentrations along the remainder of the transect fall within the background of 5 to 10 ppm.

Tree and shrub samples were collected from transects 18 and 24 for biochemical analysis. These results may be seen in Table XI.

Zinc was generally present in the plants in greater quantities than copper, and although all samples were analysed for lead none was present in the aerial organs. Plant sampling along the transects was rather irregular due to the random distribution of species within an association. However, it was possible to collect samples of the shrub Olearia muelleri at more regular intervals as this species grows in both associations and occurred quite frquently along transect 18. The content of copper and zinc in its aerial organs along transect 18 shows some correspondence with the content of these elements in the soil. Peaks in soil and plant material occur at 175 feet north, and around 50 feet south to 75 feet south. Values in both materials fall towards the southern end of the transect. Fewer samples of O. muelleri were collected from transect 24 and it is not therefore possible to ascertain the extent of correspondence between plant metal content and soil metal content along this transect.

An examination of the data presented for transects 18 and 24 reveals that the distribution of the two associations does not correspond to any precise degree with the geochemical anomalies. The association of E. torquata, C. eremophila, S. spinescens, W. rigida and P. obovatus, restricted in its area to the east of the copper workings, shows no exact coincidence with the anomaly along transect 18. Most of these species tend to occur approximately between 250 feet north and 425 feet south, beyond which approximate points the more widely spread association of E. lesouefii, E. salmonophloia, Eremophila interstans, Cratystylis conocephala, and Atriplex paludosa becomes dominant. Some overlap between the species of the two associations is to be expected where the associations meet, and occurs in such species as Scaevola spinescens and Atriplex paludosa. The geochemical anomaly also shows an overlap, and extends northwards over the boundary of the two associations, while its extension in a southerly direction does not reach to the boundary of the vegetation associations. Many of the species from the association dominated by E. torquata, C. eremophila, S. spinescens, W. rigida and P. obovatus occur where total copper and zinc soil values have fallen to background concentrations. The degree of control exercised over the distribution of the vegetation associations by the total amount of these elements in the soil does not appear to be as strong as was anticipated.

There is even less correspondence between the distribution of the associations along transect 24 and the geochemical anomaly. Whereas most of the species composing the association dominated by E. torquata, C. eremophila, S. spinescens, W. rigida and P. obovatus occur from approximately 150 feet north to 625 feet south, with the species of the more widespread association, dominated by E. lesouefii, E. salmonophloia, Eremophila interstans,

C. conocephala and A. paludosa, becoming dominant beyond these points, the geochemical anomaly occurs towards the northern end of the transect from approximately 150 feet south to 350 feet north.

If the association dominated by E. torquata, C. eremophila, S. spinescens, W. rigida and P. obovatus had been influenced strongly by the higher soil concentration of copper and zinc, the species growing here because they favoured or could tolerate these higher soil concentrations better than those species of the association of E. lesouefii, E. salmonophloia, Eremophila interstans, C. conocephala and A. paludosa, a greater degree of correspondence between the vegetation and the geochemical anomalies would have been expected. Had this been the case the species composing this latter association would be expected to cut out where copper and zinc soil values were higher than they could tolerate; such species as Atriplex paludosa would not be found overlapping onto ground where analyses revealed the highest peak of the anomaly to be. In the same manner these more widespread species -- E. lesouefii, E. salmonophloia, Eremophila interstans, C. conocephala and A. paludosa -- would be expected to grow more profusely at the southern end of the transects where background soil values return for, being more widely spread in distribution and tolerant of a wider variety of environmental conditions, they would be expected to grow up more rapidly and oust or dominate any species which were more finely adjusted to the environment. It appears, particularly from the data in transect 24, that E. lesouefii, E. salmonophloia, Eremophila interstans, C. conocephala and A. paludosa can tolerate both anomalous and background concentrations of total copper and zinc in the soil. The factors leading to the replacement of this association by another over a restricted area have not been resolved.

A small group of Eucalyptus torquata grows to the west of the copper prospect, forming a small community where Cratystylis conocephala and Atriplex paludosa are the two most abundant shrubs. Other species growing here are Atriplex nummularia, Scaevola spinescens, Westringia rigida and Eremophila coerulea. E. torquata is the dominant tree species within the small restricted association lying on the eastern side of the prospect, this association partly coinciding in its distribution with the geochemical soil anomaly. A small number of soil samples and samples of E. torquata were taken from this community in order to ascertain whether or not the soil concentration of copper and zinc was above background.

Soil samples and samples of *Eucalyptus lesouefii* were also taken from the area outside the community where the vegetation association is dominated by *E. lesouefii*, *C. conocephala* and *A. paludosa*. Results of these geochemical analyses revealed that throughout the community and in the surrounding association soil values of the three elements copper, zinc and lead fall within the background concentration. The results of the plant analyses were also comparatively low. It appears that the occurrence of this community of *E. torquata* cannot be related to the total soil content of copper, zinc and lead as values of these elements remain within the background range both within the community and the surrounding association.

No satisfactory conclusion can be drawn from the factors examined to explain the distribution of the associations in this locality near Widgiemooltha. The features of the geographical environment which were discussed appear to be sufficiently uniform throughout as to provide no explanation for the abrupt replacement of one association by another. The restricted occurrence of the association dominated by *E. torquata*, *C. eremophila*, *S. spinescens*, *W. rigida* and *P. obovatus*, adjacent to the copper prospect, suggested control by trace elements associated with the copper mineralisation. However, the geochemical analyses carried out gave results which showed no precise correlation between the total amount of elements in the soil and the distribution of the two vegetation associations. It is suggested that analyses of elements from cold extractions from soils may be more significant in geobotanical relations here. The association of Eucalyptus torquata, C. eremophila, S. spinescens, W. rigida and P. obovatus may be responding to the available amounts of copper and zinc in the soil rather than to the total amounts.

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	ppm, Oven-dried Pb	Zn	Cu	ppm, Soil Pb	Zn	Cu	Rock Type
68	Alyxia buxifolia	T 18 25N	Leaves	4.8	0	760	115	0	36.4	5.5	40	330	115	Greenstones
69	Alyxia buxifolia	T 18 25N	Twigs	3.4	0	1200	275	0	40.8	9.3				"
2N	Olearia muelleri	T 18 50N	Leaves & stems	4.8	0	1300	325	0	62.4	15.6	40	255	75	"
3N	Olearia muelleri	T 18 75N	Leaves & stems	4.3	0	800	275	0	34.4	11.8	25	255	75	"
4N	Olearia muelleri	T 18 125N	Leaves & stems	4.1	0	1300	275	0	53.3	4.1	40	330	75	"
5N	Olearia muelleri (unwashed)	T 18 175N	Leaves & stems	4.4	0	1500	375	0	66.0	16.5	60	570	275	"
5N	Olearia muelleri (washed)	T 18 175N	Leaves & stems	3.1	0	1800	375	0	55.8	11.6	60	570	275	"
18	Atriplex paludosa	T 18 225N	Leaves & stems	17.0	0	180	75	0	30.6	12.7	90	360	280	"
7N	Olearia muelleri	T 18 260N	Leaves & stems	4.9	0	800	325	0	39.2	15.9				"
77	Atriplex paludosa	T 18 325N	Leaves & stems	16.3	0	160	75	0	26.0	12.2				"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI

WIDGIEMOOLTHA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	ppm, Oven-dried Pb	Zn	Cu	ppm, Soil Pb	Zn	Cu	Rock Type
8N	Olearia muelleri	T 18 365N	Leaves & stems	3.9	0	800	265	0	31.2	10.3				Greenstones
9N (1)	Olearia muelleri (unwashed)	T 18 375N	Leaves & stems	4.2	0	800	275	0	33.6	11.5	10	180	90	"
9N (1)	Olearia muelleri (washed)	T 18 375N	Leaves & stems	3.7	0	1300	275	0	48.1	10.1				"
9N (2)	Olearia muelleri (unwashed)	T 18 375N	Leaves & stems	4.0	0	1300	275	0	52.0	11.0				"
9N (2)	Olearia muelleri (washed)	T 18 375N	Leaves & stems	3.9	0	1300	275	0	50.7	10.7				"
10N	Olearia muelleri	T 18 475N	Leaves & stems	3.7	0	600	175	0	22.2	6.4	5	140	125	"
55	Atriplex paludosa	T 18 500N	Leaves & stems	18.6	0	120	40	0	22.3	7.4				"
26	Eucalyptus torquata	T 18 525N	Leaves	4.2	0	380	55	0	15.9	2.3				"
4	Eucalyptus torquata	T 18 525N	Young twigs	5.6	0	460	70	0	25.7	3.9				"
1	Eucalyptus torquata	T 18 525N	Old twigs	4.6	0	400	50	0	18.4	2.3				"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI cont. WIDGIEMOOLTHA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	ppm, Oven-dried Pb	Zn	Cu	ppm; Soil Pb	Zn	Cu	Rock Type
15	Eucalyptus torquata	T 18 540N	Leaves	4.1	0	280	95	0	11.4	3.8				Greenstones
12	Eucalyptus torquata	T 18 540N	Fruit	3.4	0	260	140	0	8.8	4.7				"
14	Eucalyptus torquata	T 18 540N	Young twigs	4.5	0	700	150	0	31.5	6.7				"
13	Eucalyptus torquata	T 18 540N	Old twigs	3.4	0	500	150	0	17.0	5.1				"
31	Eucalyptus torquata	T 18 540N	Leaves	4.5	0	360	90	0	16.2	4.0				"
37	Eucalyptus torquata	T 18 540N	Fruit	3.6	0	240	110	0	8.6	3.9				"
33	Eucalyptus torquata	T 18 540N	Young twigs	5.5	0	700	125	0	38.5	6.8				"
25	Eucalyptus torquata	T 18 540N	Old twigs	3.2	0	800	140	0	25.6	4.4				"
40	Atriplex paludosa	T 18 550N	Leaves & stems	17.8	0	80	50	0	14.2	8.9				"
76	Atriplex paludosa	T 18 600N	Leaves & stems	17.8	0	120	65	0	21.3	11.5				"
20	Atriplex paludosa	T 18 650N	Leaves & stems	17.5	0	260	50	0	45.5	8.7				"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI cont. WIDGIEMOOLTHA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	ppm, Ashed Zn	ppm, Ashed Cu	ppm, Oven-dried Pb	ppm, Oven-dried Zn	ppm, Oven-dried Cu	ppm, Soil Pb	ppm, Soil Zn	ppm, Soil Cu	Rock Type
11N	Eucalyptus lesouefii (washed)	T 18 675N	Leaves	3.4	0	180	75	0	6.1	2.5	90	180	375	Greenstones
11N	Eucalyptus lesouefii (brushed)	T 18 675N	Leaves	3.4	0	130	75	0	4.4	2.5				"
11N	Eucalyptus lesouefii (washed)	T 18 675N	Young twigs	4.1	0	180	75	0	7.3	3.1				"
11N	Eucalyptus lesouefii (brushed)	T 18 675N	Old twigs	3.5	0	130	75	0	4.5	2.6				"
79	Alyxia buxifolia	T 18 25S	Leaves	3.2	0	1000	225	0	32.0	7.2	100	360	175	"
80	Alyxia buxifolia	T 18 25S	Twigs	2.7	0	1300	200	0	35.1	5.4				"
2S	Olearia muelleri	T 18 50S	Leaves & stems	4.1	0	1800	275	0	73.8	11.2	70	330	175	"
2S	Eucalyptus torquata (washed)	T 18 50S	Leaves	2.5	0	800	125	0	20.0	3.1				"
2S	Eucalyptus torquata (unwashed)	T 18 50S	Leaves	4.0	0	900	125	0	36.0	5.0				"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI cont. WIDGIEMOOLTHA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed			ppm, Oven-dried			ppm, Soil			Rock Type
					Pb	Zn	Cu	Pb	Zn	Cu	Pb	Zn	Cu	
2S	Eucalyptus torquata (washed)	T 18 50S	Fruit	3.6	0	90	125	0	3.2	4.6				Greenstones
2S	Eucalyptus torquata (unwashed)	T 18 50S	Fruit	3.8	0	230	125	0	8.7	4.7	70	330	175	"
2S	Eucalyptus torquata (washed)	T 18 50S	Young twigs	4.2	0	900	125	0	37.8	5.2				"
2S	Eucalyptus torquata (unwashed)	T 18 50S	Young twigs	5.0	0	900	125	0	45.0	6.2				"
2S	Eucalyptus torquata (washed)	T 18 50S	Old twigs	4.0	0	700	75	0	28.0	3.0				"
2S	Eucalyptus torquata (unwashed)	T 18 50S	Old twigs	4.0	0	700	75	0	28.0	3.0				"
3S	Olearia muelleri (washed)	T 18 75S	Leaves & stems	4.9	0	1800	350	0	88.2	17.1	40	230	90	"
3S	Olearia muelleri (unwashed)	T 18 75S	Leaves & stems	5.5	0	1800	350	0	99.0	19.4				"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI cont. WIDGIEMOOLTHA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed			ppm, Oven-dried			ppm, Soil			Rock Type
					Pb	Zn	Cu	Pb	Zn	Cu	Pb	Zn	Cu	
4S	Olearia muelleri	T 18 100S	Leaves & stems	4.8	0	1400	325	0	67.2	15.6	40	270	125	Greenstones
5S	Olearia muelleri (washed)	T 18 125S	Leaves & stems	4.2	0	1300	375	0	54.6	15.7				"
5S	Olearia muelleri (unwashed)	T 18 125S	Leaves & stems	3.5	0	1300	325	0	45.5	11.3	40	270	125	"
66	Alyxia buxifolia	T 18 150S	Leaves	4.5	0	1300	100	0	58.5	4.5	25	180	200	"
67	Alyxia buxifolia	T 18 150S	Twigs	3.4	0	1200	225	0	40.8	7.6				"
7S	Olearia muelleri	T 18 215S	Leaves & stems	4.0	0	800	175	0	32.0	7.0				"
8S	Olearia muelleri	T 18 275S	Leaves & stems	4.3	0	800	225	0	34.4	9.6	15	160	45	"
16	Alyxia buxifolia	T 18 250S	Leaves	4.7	0	700	160	0	32.9	7.5				"
17	Alyxia buxifolia	T 18 250S	Twigs	2.6	0	1200	200	0	31.2	5.2				"
63	Atriplex paludosa	T 18 350S	Leaves & stems	19.0	0	160	35	0	30.4	6.6				"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI cont. WIDGIEMOOLTHA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	ppm, Oven-dried Pb	Zn	Cu	ppm, Soil Pb	Zn	Cu	Rock Type
5	Eucalyptus torquata	T 18 370S	Leaves	5.0	0	360	60	0	18.0	3.0	15	170	45	Greenstones
36	Eucalyptus torquata	T 18 370S	Fruit	3.7	0	180	75	0	6.6	2.7				"
30	Eucalyptus torquata	T 18 370S	Young twigs	5.1	0	460	90	0	23.4	4.5				"
29	Eucalyptus torquata	T 18 370S	Old twigs	4.1	0	220	90	0	9.0	3.6				"
62	Atriplex paludosa	T 18 400S	Leaves & stems	18.9	0	80	50	0	15.1	9.4	5	170	45	"
39	Atriplex paludosa	T 18 450S	Leaves & stems	21.0	0	80	25	0	16.8	5.2				"
12S	Olearia muelleri	T 18 475S	Leaves & stems	4.8	0	800	175	0	38.4	8.4	5	170	35	"
73	Atriplex paludosa	T 18 500S	Leaves & stems	18.8	0	-	40	0	-	7.5	5	170	15	"
38	Atriplex paludosa	T 18 550S	Leaves & stems	17.2	0	80	35	0	13.7	6.0				"
61	Eucalyptus lesouefii	T 18 550S	Leaves	3.8	0	80	145	0	3.0	5.5				"
60	Eucalyptus lesouefii	T 18 550S	Fruit	4.0	0	80	100	0	3.2	4.0				"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI cont. WIDGIEMOOLTHA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	ppm, Oven-dried Pb	Zn	Cu	ppm, Soil Pb	Zn	Cu	Rock Type
49	Eucalyptus lesouefii	T 18 550S	Young twigs	4.2	0	240	150	0	10.0	6.3				Greenstones
64	Atriplex paludosa	T 18 600S	Leaves & stems	19.6	0	80	45	0	15.6	8.8				"
14S	Olearia muelleri	T 18 625S	Leaves & stems	4.2	0	800	175	0	33.6	7.3	5	150	15	"
15S	Olearia muelleri	T 18 675S	Leaves & stems	4.4	0	800	125	0	32.5	5.5	5	130	15	"
24	Atriplex paludosa	T 18 700S	Leaves & stems	14.7	0	80	50	0	11.7	7.3				"
59	Atriplex paludosa	T 18 750S	Leaves & stems	10 5	0	120	65	0	12.6	6.8				"
65	Eucalyptus lesouefii	T 18 775S	Leaves	3.9	0	80	40	0	3.1	1.5				"
50	Eucalyptus lesouefii	T 18 775S	Young twigs	5.0	0	220	35	0	11.1	1.7				"
48	Eucalyptus lesouefii	T 18 775S	Old twigs	4.3	0	460	40	0	19.7	1.7				"
16S	Eucalyptus lesouefii (washed)	T 18 800S	Leaves	3.5	0	80	35	0	2.8	2.2	5	100	15	"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI cont. WIDGIEMOOLTHA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	ppm, Oven-dried Pb	Zn	Cu	ppm, Soil Pb	Zn	Cu	Rock Type
16S	Eucalyptus lesouefii (unwashed)	T 18 800S	Leaves	3.6	0	80	35	0	2.8	1.2	5	100	15	Greenstones
16S	Olearia muelleri	T 18 850S	Leaves & stems	4.8	0	600	200	0	28.8	9.6				"
75	Atriplex paludosa	T 18 900S	Leaves & stems	17.9	0	60	40	0	10.7	7.1	5	130	5	"
51	Olearia muelleri	T 24 30N	Leaves & stems	3.8	0	700	500	0	26.6	19.0				"
58	Olearia muelleri	T 24 125N	Leaves & stems	3.9	0	760	350	0	29.6	13.6	10	500	225	"
35	Olearia muelleri	T 24 53S	Leaves & stems	4.5	0	700	275	0	31.5	12.3				"
22	Olearia muelleri	T 24 80S	Leaves & stems	4.5	0	400	300	0	18.0	13.5				"
53	Olearia muelleri	T 24 122S	Leaves & stems	4.1	0	760	400	0	31.1	16.4				"
54	Olearia muelleri	T 24 150S	Leaves & stems	4.0	0	660	300	0	24.6	12.0	15	260	200	"
56	Olearia muelleri	T 24 250S	Leaves & stems	4.6	0	400	215	0	18.4	9.8	0	180	50	"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI cont. WIDGIEMOOLTHA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	ppm, Oven-dried Pb	Zn	Cu	ppm, Soil Pb	Zn	Cu	Rock Type
71	Alyxia buxifolia	T 24 335S	Leaves	3.7	0	800	150	0	29.6	5.5				Greenstones
72	Alyxia buxifolia	T 24 335S	Twigs	2.9	0	1300	175	0	37.7	5.0				"
11	Eucalyptus torquata	T 24 390S	Leaves	5.3	0	280	75	0	14.8	3.9				"
28	Eucalyptus torquata	T 24 390S	Fruit	4.0	0	200	110	0	10.4	4.4				"
2	Eucalyptus torquata	T 24 390S	Young twigs	5.0	0	800	155	0	40.0	7.7				"
3	Eucalyptus torquata	T 24 390S	Old twigs	4.3	0	220	95	0	9.4	4.0				"
19	Atriplex paludosa	T 24 500S	Leaves & stems	17.1	0	460	40	0	78.6	6.8	5	80	40	"
57	Atriplex paludosa	T 24 450S	Leaves & stems	14.6	0	160	55	0	23.3	8.0	10	240	75	"
43	Eucalyptus lesouefii	T 24 550S	Leaves	3.5	0	160	70	0	5.6	2.4	5	100	40	"
46	Eucalyptus lesouefii	T 24 550S	Young twigs	3.8	0	220	70	0	8.3	2.6				"
52	Olearia muelleri	T 24 595S	Leaves & stems	3.7	0	400	215	0	14.8	7.9				"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI cont. WIDGIEMOOLTHA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	ppm, Oven-dried Pb	Zn	Cu	ppm, Soil Pb	Zn	Cu	Rock Type
21	Atriplex paludosa	T 24 650S	Leaves & stems	18.3	0	80	20	0	14.6	3.6	5	200	40	Greenstones
23	Olearia muelleri	T 24 733S	Leaves & stems	4.3	0	800	275	0	34.4	11.8				"
34	Eucalyptus lesouefii	T 24 760S	Leaves	3.2	0	260	65	0	8.3	2.0				"
32	Eucalyptus lesouefii	T 24 760S	Young twigs	4.0	0	220	50	0	8.8	2.0				"
74	Atriplex paludosa	T 24 800S	Leaves & stems	14.4	0	160	50	0	23.0	7.2	0	220	30	"
78	Atriplex paludosa	T 24 900S	Leaves & stems	16.1	0	80	40	0	12.8	6.4	0	200	10	"
8	Eucalyptus torquata	T 18W G55	Leaves	3.7	0	200	50	0	7.4	1.8	0	40	10	"
6	Eucalyptus torquata	T 18W G55	Fruit	3.6	0	160	70	0	5.7	2.5	0	40	10	"
158	Eucalyptus torquata	T 18W G55	Young twigs	4.2	0	280	80	0	11.7	3.3				"
9	Eucalyptus torquata	T 18W G55	Old twigs	2.6	0	160	75	0	4.1	1.9				"
7	Eucalyptus lesouefii	T 18W G56	Leaves	4.1	0	460	50	0	18.8	2.0	5	40	40	"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI cont. WIDGIEMOOLTHA

Sample No	Species	Locality	Organ	% Ash	ppm, Ashed Pb	Zn	Cu	ppm, Oven-dried Pb	Zn	Cu	ppm, Soil Pb	Zn	Cu	Rock Type
46	Eucalyptus lesouefii	T 18W G56	Young twigs	4.5	0	80	70	0	3.6	3.1	5	40	40	Greenstones
47	Eucalyptus lesouefii	T 18W G56	Old twigs	4.1	0	60	70	0	2.4	2.8				"
10	Eucalyptus lesouefii	T 18W G57	Leaves	3.2	0	260	95	0	8.3	3.0	5	90	40	"
44	Eucalyptus lesouefii	T 18W G57	Young twigs	4.0	0	160	70	0	6.4	2.8				"
41	Eucalyptus lesouefii	T 18W G57	Old twigs	3.2	0	120	70	0	3.8	2.2				"

Analyses of unmilled, dry-ashed plant material.
WV series samples.

TABLE XI cont. WIDGIEMOOLTHA

Sample No	Locality	ppm Soil Na	K	Ca	Mg	Rock Type
11	Jimberlana Dyke T 17, 00	2060	1000	100000	15300	Soil covered
15	Jimberlana Dyke T 17, 500S	2130	430	11000	6300	Norite
9	Jimberlana Dyke T 17,3300S	860	260	9600	6300	Soil covered
13	Jimberlana Dyke T 17, 300N	3200	3700	48300	35000	Greenstones
29	Norseman Reef T 14, 00	2200	6530	41600	20000	Pillow lavas
17	Norseman Reef T 14, 200NW	500	2660	16000	6000	Pillow lavas
25	Iron King T 16, 00	560	1660	2500	1600	Laterite
27	Iron King T 16, 300E	600	3060	31000	21300	Metagabbro
31	Iron King T 16, 500E	730	1660	5600	5000	Metadolerite
28	Iron King T 16,1600E	130	1760	2500	1500	Metajaspilite
12	Iron King T 16,2500E	760	2760	2200	2300	Schist and chert
26	South Norseman T 12, 00	660	7360	17600	22300	Greenstones
32	South Norseman T 12, 700N	1930	3630	62300	35000	Greenstones
14	Coolgardie T 1,1100E	1830	3530	60260	14000	Basic lavas
16	Coolgardie T 1,5500E	2430	2100	37000	80000	Ultrabasic rocks
24	Coolgardie T 1,11900E	1030	3230	2600	5600	Soil covered

Analyses of soils for major elements.

TABLE XII Na,K,Ca & Mg IN SOILS

Sample No	Locality			ppm Soil Na	K	Ca	Mg	Rock Type
22	Coolgardie	T	1,17300E	360	2000	10300	4600	Laterite
30	Coolgardie	T	1,21900E	530	2860	8500	14800	Metasediments
19	Coolgardie	T	2, 00	1000	630	6600	2600	Amphibolite
21	Coolgardie	T	5, 00	330	2200	2000	10000	Granite
5	Mt Hunt	T	7, 50W	230	1330	2600	11600	Porphyry
3	Mt Hunt	T	7, 700W	230	2100	7300	20000	Soil covered
2	Mt Hunt	T	7, 2200W	230	1100	60000	35000	Ultrabasic rocks
4	Mt Hunt	T	7, 2600W	200	1330	3600	4600	Variolitic lava
10	Mt Hunt	T	7, 2900W	530	1660	76300	21300	Metadolerite
23	Mt Hunt	T	7, 3200W	260	2000	3300	4200	Metabasalt
15	Mt Hunt	T	8, 00	300	1100	16000	80000	Serpentinite
1	Mt Hunt	T	8, 300W	300	260	50100	80000	Carbonated serpentinite
7	Kambalda	T	23, 600NE	560	1430	2000	9000	Serpentinite
8	Kambalda	T	20, 00	560	2300	16000	12600	Metabasalt
20	Widgiemooltha	T	18, 00	230	2100	12600	13000	Greenstones
6	Widgiemooltha	T	18, 900S	1230	3130	76300	32300	Greenstones

Analyses of soils for major elements.

TABLE XII cont. Na,K,Ca & Mg IN SOILS

PART 6

FACTORS GOVERNING THE DISTRIBUTION OF VEGETATION IN THE EASTERN GOLDFIELDS

1. The analysis of the relative importance of the factors governing the distribution of vegetation associations, plant communities and individual species.

The geographical factors that are involved in plant distributions have been examined in detail in the previous sections concerning the field study areas; the degree of their importance within the region of the Eastern Goldfields will now be analysed.

The control of the distribution of vegetation associations and plant communities within this region does not appear to be influenced primarily by the relief and physiography of the land surface. The vegetation associations change and are demarcated for the most part without apparent reference to the topographical nature of the terrain. The greater part of the Eastern Goldfields comprises a rather flat and undulating landsurface, and any changes observed in the vegetation distribution in such areas can be attributed primarily to other factors, such as the nature of the underlying bedrock. Even where physiography is more marked, as at Mt. Hunt, Kambalda and parts of the Norseman area, the distribution of associations is not greatly influenced by the aspect and relief of the ground. It has been shown that these distributions are controlled and influenced to a much greater extent by other factors in the environment; relief is of secondary importance only, in that it affects such factors as the degree of soil development. Associations and communities succeed each other over hill-slopes and down into valleys and lower-lying ground without reference to the degree of slope.

It must be noted here that one species in particular - Eucalyptus torquata - appears to be influenced in its distribution by relief. It was found upon ridges and hillslopes wherever it occurred within a field study area, and although may grow where the ground is flatter, appears to prefer those areas where the topography is more marked. It is not known how far this distribution pattern is influenced by such related environmental factors as drainage.

The importance of drainage and its degree of influence upon the plant distributions in the Eastern

Goldfields is more difficult to assess. For the greater part of the year most of the soils within this region carry little moisture in their upper horizons. It is only after heavy rainstorms that local depressions may become waterlogged. The ground, however, will usually dry out fairly quickly, particularly in the summer when the rate of evaporation is high and the dry subsoil can soak up excess moisture. It seems unlikely that the distribution of associations will be influenced to any large extent by the waterlogging of small patches of ground at infrequent intervals.

Drainage considerations are linked with other environmental factors, such as the build-up of salts in the soil where local base levels constitute salt lakes or pans, and with the relief; it may be difficult to assess which of these related factors have most influence upon the distribution of the vegetation associations.

In certain lower-lying areas the effect of drainage upon the vegetation is linked with that of salt concentration in the soil. At Mt. Hunt, for example, part of the run-off following a heavy rainstorm finds its way into the salt pans lying beyond the hill to the east. The concentration of salts within the soil builds up in these areas and the communities and species which can be supported are necessarily halophytic. The frequency of trees in these areas is generally low, becoming greater as the ground rises gently away from the drainage pans. At Mt. Hunt Eucalyptus lesouefii is the only arborescent species which grows over part of the lower-lying saline areas, occurring in small groups at infrequent intervals. As the ground surface rises towards the lower slopes of the Mount and where small hills of serpentinite rise between the salt pans and Hannan's Lake Eucalyptus foecunda becomes prominent in the vegetation association, sometimes accompanied by E. lesouefii.

Similar relationships occur in many parts of the Eastern Goldfields. At Norseman the salt accumulation in the drainage area between the Royal and Princess Royal shafts has resulted in the growth of the common halophytic species Atriplex paludosa, Arthrocnemum halocnemoides, and Disphyma australe. Eucalyptus lesouefii is again the most prominent tree, although its frequency is low, and E. salubris grows here also. Two uncommon tree species in this locality are E. flocktoniae and E. calycogona, both of which become prominent in the tree stratum where the ground is not so saline.

The drainage pattern and the "soaks" which usually occur round granite and gneiss outcrops in this region are important in the establishment of particular associations. Acacia acuminata is the dominant member of the association growing over these granitic outcrops, as it is of many porphyry outcrops also. These areas provide sufficient moisture and run-off after rain to support a characteristically thick growth of annuals in late winter and spring.

On the Jimberlana Dyke at Norseman the distribution of the plant communities appears to be related primarily to factors of drainage and soil depth (see Part 3, A). On the kopjes, where there is little soil and poor water retention, the community is characterised by Casuarina campestris, Melaleuca uncinata, Cryptandra ?glabriflora, Grevillea ?pinifolia, M. elliptica, Eremophila maculata and Lepidosperma brunonianum. The pediments linking the kopjes and flats hold more soil and do not drain quite so rapidly. The community here includes the same species as mentioned above and others which can successfully compete with them, including Eucalyptus Websteriana and Eremophila serrulata. The flatter areas surrounding the kopjes, where soils have built up to a greater degree than elsewhere on the norite, have a better water retaining capacity. Rainwater from kopjes and pediments drains down to these areas. The community in this habitat includes Acacia cochliocarpa and Triodia scariosa as its most important members. In such areas it may not be possible to separate in importance the two environmental factors of drainage and soil depth.

Elsewhere in the Eastern Goldfields it is often difficult to determine the importance of drainage as an environmental factor. For example, Acacia quadrimarginea is frequently found where relief is marked. In such areas the soil is usually skeletal and immature and run-off is rapid. Several factors influence the establishment of A. quadrimarginea and associated shrubs in such localities and it may not always be possible to determine which are the overriding factors and the extent to which drainage considerations are important.

The importance of the underlying bedrock upon vegetation distributions has been considered in each section concerning individual field study areas. It will be examined more thoroughly in the following section (Part 6, section 2). Its influence upon the vegetation is considerable, for ultimately it may be responsible for aspects of both the relief, the drainage and the soil of an area.

The character of a soil within an area, both its physical and chemical nature, may influence the distribution of vegetation associations, plant communities and individual species. Aspects of the chemistry of the soil will be considered later in Part 6, section 3; here the importance of features of its physical nature will be discussed.

Many localities in the Eastern Goldfields are marked by skeletal, shallow soils, particularly in areas of outcrop where relief may be marked. In the Coolgardie area the amphibolite sill near the Three Mile Hill is characterised by scree and a thin soil cover. The vegetation association growing here is Acacia quadrimarginea, Eremophila duttoni, Dodonaea lobulata and Ptilotus obovatus. This same association occurs in several localities at Mt. Hunt, where the physical nature of the soil cover is similarly immature, and the underlying bedrock is metadolerite. A somewhat modified association of A. quadrimarginea, Eremophila sp. J.B./W.A. III, D. boroniaefolia, P. obovatus and Helipterum adpressum grows over outcropping metabasalts at Mt. Hunt, and also at Kambalda where skeletal soils are underlain by either metabasalts or serpentinites. A. quadrimarginea forms associations with a number of shrubs which include E. duttoni, D. lobulata, and P. obovatus, and occasionally H. adpressum. Although not every scree covered locality within an area is occupied by these shrubs (at Mt. Hunt, for example, the skeletal soils over outcrops of metajaspilite do not support this association) the physical nature of the soil appears to have some importance in controlling the distribution of this association, although this distribution may be affected by the composition of the underlying bedrock and the drainage. A. quadrimarginea and D. lobulata are generally associated with a scree covered or rocky terrain. Although other factors must be favourable, the presence of these two species, amongst others, in the association growing over outcrops of metabasalt and serpentinite at Kambalda and their absence from areas where these rock types are covered with deeper soils indicates a preference for such an environment. Alternately, factors of plant competition may be operating more fiercely over the areas of deeper soils; other species, including trees, may be more successful and quicker in establishing themselves here than are such species as *A. quadrimarginea* which are therefore relegated to rockier terrain, less favoured by other plants.

At Norseman certain species are characteristic of some areas of rocky terrain where the soil is skeletal. *Casuarina campestris*, *Acacia cochliocarpa*, *Eremophila maculata*, *Cryptandra ?glabriflora* and *Lepidosperma brunonianum* grow over parts of the Jimberlana Dyke and the Mararoa lava outcrops of the Norseman Reef area. The rocky, scree covered outcrops of the metajaspilites in the Iron King area do not support these same species, but do have shrub species in common with those included in the association on the Mararoa lavas. The shrubs *Grevillea nematophylla*, *Prostanthera aspalathoides* and *Dodonaea boroniaefolia* grow in the last two localities. These plants appear to favour such an environment, although it may be difficult to decide which factors of the environment bear most importance in their establishment. This is true of many of the examples cited, for many factors interact during the establishment and growth of plants. Whereas it is sometimes possible to cite one or two related factors as being most important in the distribution of associations or species, it generally appears that further experimental work is required to determine whether drainage has more or less importance in a particular case than soil depth.

Soil texture may have an effect upon vegetation distributions and is another factor linked with drainage and soil-water retention. Most of the soil types encountered during the field work were of a similar loamy character; some were sandy-clay loams, others silty-clay loams, and often the proportion of clay increased down the profile. In one case only was a relationship observed between soil texture and a particular shrub, the species Eremophila ?dempsteri. In the Coolgardie area a clay soil, characterised by patches of gilgai, was observed over parts of the soil covered area. The gilgai was usually characterised by a community dominated by Eucalyptus salubris and Eremophila ?dempsteri. Wherever this particular Eremophila species was observed in this region it was usual to find gilgai microrelief. Eucalyptus salubris does not appear to be confined to this type of habitat to the same extent. Similar communities over clay soils marked by gilgai were seen west of Kambalda and in other localities of the Eastern Goldfields.

The relationship observed here may be a response to the greater water retaining capacity of the clayey soil rather than to the soil texture *per se*.

To summarise: relief by itself appears to have little importance in the distribution of associations in the Eastern Goldfields where topography, for the most part, is nowhere very marked. Relief may be related, however, to drainage and soil depth, for many of the hills and ridges in the region are associated with outcrops and skeletal soils. In such areas factors of drainage and soil depth will be noted features of the environment. With regard to vegetation distributions, however, it may not be possible to ascribe more importance to a particular factor. Drainage features, such as salinas, are accompanied by the build up of salts in lower-lying areas, introducing a chemical factor and thus influencing the distributions of associations and species. The importance of the underlying bedrock and the chemical nature of the soil are considered in later sections of Part 6.

2. The importance of geological control over vegetation distribution

In several of the field areas studied within the Eastern Goldfields the distribution of the vegetation can be directly related to the underlying bedrock: the boundaries of associations correspond closely with those of the geological formations. Associations and communities may correspond in their distribution with particular features of soil depth, drainage and the metal content of the soil, which owe many aspects of their nature to the geology.

Within the Coolgardie area the changes in the distribution of the vegetation associations correspond with the changes in the underlying bedrock. The boundaries are often remarkably precise so that it is possible to locate oneself geologically with reference to a particular association. For example, the amphibolite dyke or sill, part of which outcrops near the Three Mile Hill, can be traced for several miles as a topographic feature. However, it also has a characteristic vegetation association which, within the Coolgardie area, occurs only here. Although this particular association of *Acacia quadrimarginea*, *Eremophila duttoni*, *Dodonaea lobulata* and *Ptilotus obovatus* is limited to this geological formation, part of the vegetation response may be to the physical environment provided by the sill. These same species are included in associations which occur in other districts where the rock type differs somewhat but the terrain is similarly scree covered and rocky, as over metadolerite at Mt. Hunt and outcropping metabasalt and serpentinite at Kambalda. Within the Coolgardie field area the basic and ultrabasic rocks, metasediments and granites are characterised by specific vegetation associations. The geological control of the vegetation distribution here is apparent, and has been examined closely in Part 4, A.

At Mt. Hunt the distribution of several of the associations is related directly to different bedrocks which are clearly important in delineating their extent. It was observed that, providing the outcrops are sufficiently large, the metadolerites, metabasalts and ultrabasics generally support their own characteristic species. Although some of the genera may remain the same, as metadolerite gives way to metabasalt, the species composition of the associations on each of these rock types is generally characteristic. Areas underlain by metadolerite support an association of Acacia quadrimarginea, Eremophila duttoni, Dodonaea lobulata and Ptilotus obovatus, while over areas of metabasalt, which may abut onto the metadolerite, the species of Eremophila and Dodonaea change so that the association comprises A. quadrimarginea, Eremophila sp. J.B./W.A. III, D. boroniaefolia and P. obovatus. The soil covered ultrabasic rocks can be traced by their association of Eucalyptus foecunda, Acacia leptoneura, A. graffiana, Cassia eremophila and Triodia irritans. This association becomes modified where ultrabasic rocks crop out as serpentinite, different species entering as the physical environment alters. E. foecunda still dominates the tree stratum but A. graffiana is absent and C. eremophila is no longer important. T. irritans persists as a dominant species. Other associations within the Mt. Hunt area are confined to particular rock types; they have been considered in detail in Part 4, (B).

Geological control is similarly important in influencing the vegetation distribution in certain areas at Norseman. The norite outcrop of the Jimberlana Dyke clearly influences the vegetation it supports for it can

be traced by its shrub association which includes
Casuarina campestris, Melaleuca uncinata, Acacia cochliocarpa, Eremophila maculata and Cryptandra ?glabriflora. The outcropping dyke was examined in two areas only and it is not known to what extent this particular association occurs throughout its length. Within the field area this shrub-dominated association is unique to the norite. The feldspathic bronzitite which occupies parts of the periphery of the norite is also marked by its own unique association, dominated by Eucalyptus foecunda, Eremophila drummondii, Ricinocarpus stylosus, Westringia rigida and Triodia scariosa. The underlying bedrock is clearly important in controlling the distribution of these associations.

In the Iron King area at Norseman it is clearly apparent that the distribution of the vegetation associations is controlled by the geology. The metajaspilite bands support an association which includes many species, such as Grevillea nematophylla, Casuarina campestris, Myoporum platycarpum, Alyxia buxifolia, Ricinocarpus stylosus, ?Grevillea didymobotrya, Calothamnus chrysantherus, Prostanthera aspalathoides, Scaevola spinescens, Trymalium myrtillus, Hibbertia ?pungens, Dodonaea stenozyga,

D. boroniaefolia, Acacia erinacea and Westringia rigida. Where the metajaspilites give way to other formations the vegetation is noticeably different, both in species composition and shrub density. The Lady Mary Formation, a sill of metadolerite and metagabbro, and the Marell schist are bounded to their west and east sides by bands of metajaspilite. They support associations which are quite different from that on the metajaspilite. Melaleuca sheathiana, Eremophila dempsteri and Atriplex paludosa grow on both the Lady Mary Formation and the Marell schist, but whereas Eucalyptus torquata, E. flocktoniae and E. lesouefii grow infrequently on the Lady Mary Formation the only tree of importance on the Marell schist is E. Stricklandi. Each geological unit can be traced by its characteristic assemblage of species. The western edge of the Iron King study area is occupied by the Kingswood basalt. Eucalypts become prominent in the vegetation, the most important species being E. leptophylla, and are associated with Melaleuca sheathiana, Eremophila dempsteri and Atriplex paludosa, an association which occurs in this area on this particular rock type only. Open woodland also grows on the Raggedy Formation to the east of this field area. It is somewhat similar to that occurring on the Kingswood basalt but differs in its greater tree and shrub diversity. In addition to those species enumerated above Eucalyptus Stricklandi, E. salubris, Scaevola spinescens, and Olearia muelleri are found growing.

In each of the cases cited above the geological control of the vegetation may be operating in various ways. Some of the rock types mentioned, for example, the metajaspilites of the Iron King area, are more resistant to erosion than the adjacent rock units. They form features of relief and are usually characterised by skeletal, immature soils with large amounts of scree. Such areas are well drained and soils will tend to dry out more rapidly after rain than will the deeper soils occupying the lower, flatter areas. Factors such as the degree of soil development and the rocky nature of the terrain may be partly responsible for the establishment of certain species in these areas of outcrop. Certainly, a number of species, as mentioned in the previous section of Part 6, are largely confined to rocky areas with shallow soils, where the bedrock types may be quite different. For example, Prostanthera aspalathoides was observed on outcropping metajaspilite at the Iron King, outcropping pillow lavas near the Norseman Reef, and on the rocky serpentinite pod at Mt. Hunt. Geological control in such a case as this may well be operating primarily through the factor of the relative hardness and joint frequency of the rocks and their consequent resistance to erosion, producing a habitat suitable to many plants.

Geological control may also operate through the chemical composition of the soil derived from the underlying rock. A suitable chemical environment must be present for normal growth to proceed and by varying this the rock type is influencing the growth of the vegetation. Changes may be seen in the association in localities where the weathering of mineral-rich bedrocks or suboutcropping orebodies has led to high metal contents in the over-lying soils. Species which can tolerate high metal concentrations will thrive and compete more successfully with others which are less tolerant. Analyses for various trace elements in the soils from the various rock units encountered during the field work revealed that the elements studied were nearly always present in amounts which allowed normal plant growth to proceed. Occasionally, the soils from certain localities showed metal enrichment which could be correlated with changes in the vegetation supported. Generally, however, a particular association growing only over a certain rock unit, such as that on the norite outcrop at Norseman, could not be explained by the soil concentration of the elements for which analysis was undertaken. In this case, as in others, it is possible that other elements, which were not determined analytically, are of greater importance in the plant-soil environment. Trace elements and their effects upon plant distributions are considered more fully in the following section (Part 6, section 3).

It is often not possible to establish which particular geological factors are of prime importance in the control of vegetation distributions. Where bedrock is covered by soil geological control must be exercised through the medium of the overlying residual soil, which by reason of its depth, water-holding capacity or chemical composition is favoured or tolerated by certain groups of plants. Where bedrock outcrops relief may be marked and, provided a suitable soil chemical environment is present, any species growing in such areas must be tolerant of thin rocky soils with a low water-holding capacity.

3. The importance of concentration of trace elements on plant distributions and plant morphology

Results of the studies in the field areas of the Eastern Goldfields reveal that most of the plant associations correspond in their distributions with a normal soil content of trace elements; very few of the associations are related to unusually high concentrations of trace elements. Analyses of soil samples from the majority of the study areas gave results which showed that the content of minor elements fell generally within the concentrations which allow normal plant growth to proceed. It is only when the soil content of particular elements, either major or minor, is in excess or is deficient, that the species composition of associations is likely to be affected. The presence of deficiencies and any effects they may have upon the vegetation in the areas of study have not been examined. The presence of toxic or unusually high concentrations of available metals in the soil may be revealed by cut-outs in the distribution of certain species which would normally be expected to grow, and a consequent thinning in the density of the vegetation. In other localities a high soil metal content may result in the replacement of the background vegetation by another association which can tolerate the unusual conditions. These patterns may occur provided that the metal which is present in toxic amounts is available for uptake by the plants.

In the Norseman area the concentration of trace elements within the soils is generally within the limits which allow plants to grow normally. However, in one area, which constitutes a small part of the Jimberlana Dyke, the soil concentration of nickel rises from 86 ppm to a peak of 325 ppm and anomalous values persist for a distance of 900 feet at the southern end of transect 17. The anomaly is closely associated with an east-west belt of woodland which is dominated by _Eucalyptus_ affin. _cylindrocarpa_, with its associated shrubs _Eremophila interstans_ and _E. drummondii_. This vegetation association contrasts sharply with the adjacent, less dense woodland of _E. foecunda_, and the shrub association of the norite outcrop, and appears to be due to the anomalous nickel content in the soil here. The morphology of the Eucalypts composing this belt of dense woodland appears to be affected by the higher nickel concentration. The trees are of uniform height, approximating to twenty feet, and all have similar bushy crowns, giving them the appearance of immaturity. There was no evidence of a fire having been through this area, so accounting for the generally immature appearance. Unfortunately, this particular species of <u>Eucalyptus</u> was found nowhere else so that its habit here cannot be compared with that of the tree elsewhere.

At Mt. Hunt nickel and chromium were the only two elements present in high amounts within the soil, the high quantities corresponding with outcrops of serpentinite and carbonated serpentinite. Peak chromium values occur at the eastern end of transect 8 where carbonated serpentinite outcrops; here the soil chromium content reaches 1200 ppm. The soil nickel content remains fairly uniformly around 575 ppm over both serpentinite and carbonated serpentinite outcrops. While the concentration of nickel is lower than that of chromium, both elements are generally present in higher quantities over these rock types than in soils derived from other bedrocks in the Mt. Hunt area. A low density of vegetation marks the area underlain by carbonated serpentinite at the eastern end of transect 8, <u>Melaleuca</u> <u>lateriflora</u>

being the only important shrub present. This low density and the lack of variety in species present is probably due to the high soil concentration of chromium and nickel. Other species are unable to establish themselves because of the toxic levels of these elements.

High nickel and chromium soil values are also encountered around Kambalda, but over the greater part of the area do not have any noticeable effect upon the vegetation distribution or morphology. However, the geochemical anomaly along transect 22, where maximum soil values are 1040 ppm nickel and 738 ppm chromium, has led to a cut-out in the vegetation over the eastern part of the anomalous high. Eucalypts have been prevented from growing and the shrub diversity drops noticeably, although the density of Atriplex paludosa remains the same as on ground with lower metal concentrations. The western part of this anomaly, however, is not similarly marked geobotanically. Both Eucalyptus lesouefii and E. torquata grow with a diverse shrub stratum of normal density. It appears that the high soil concentration of elements here is not affecting the vegetation because the nickel and chromium are unavailable for uptake by plants. An increase in calcium carbonate was noted in the soil around this particular area of the anomaly. Under a high pH carbonate will remove nickel from solution, and hence less of this metal is available for absorption by plants. Soil over the eastern half of the anomaly did not appear to contain as much calcium carbonate, and in this locality more nickel is available to the plants than is favourable for the normal growth of vegetation.

In each of the cases cited above it appears that the unusually high concentrations of certain elements within the soil are responsible for abnormal or notably different plant distributions. A soil metal concentration which is too high for most plants will result in cut-outs, or toxicity effects may be evident in those species present. Some plants, which would normally be present in an association, never become established, while others are able to grow but may show toxicity symptons in their habit, such as stunting; the growth form of Eucalyptus affin. cylindrocarpa, described above, may possibly result from the relatively high soil concentration of nickel.

However, a high soil concentration of an element will only produce noted effects on the vegetation if the element is in a form which can be readily absorped by plants. Anomalous concentrations may be present in the soil but may not be available for uptake by the roots so that no toxicity effects or abnormal distributions will occur. This appears to be the case over the western half of the geochemical anomaly on transect 22, Kambalda. Where a high trace element concentration is present in a soil many species may not be able to resist for long the uptake of large amounts of the element which may not be necessary for the plant, and this results in some kind of biological reaction, such as chlorosis (Malyuga 1964). However, it is apparent that, in spite of high concentrations of nickel and particularly chromium in the soils overlying part of the carbonated serpentinite outcrop at Mt. Hunt the shrub Melaleuca lateriflora is able to grow normally. Analysis of plant material from this species did not reveal unusual amounts of either of these elements; although root material was not analysed it seems unlikely that it would contain more nickel than the aerial organs as this metal is usually found in highest quantities in the leaves. Chromium, however, may possibly be precipitated in the roots.

Over the greater part of the field area variations in the concentrations of trace elements did not appear to have any significant effect on plant growth. Analyses were undertaken for a limited number of elements, however, and plant distributions may be influenced to a greater extent by the soil content of other major or minor elements which differ critically in concentration between rock types.

PART 7

THE ROLE OF GEOBOTANY AND BIOGEOCHEMISTRY IN GEOLOGICAL RECONNAISSANCE AND MINERAL EXPLORATION IN THE EASTERN GOLDFIELDS

1. The role of various elements in plant metabolism

It is known that sixteen elements, including both major and minor elements, are needed for the proper growth and development of the higher plants (Fritz 1963). If future research reveals other elements to be essential these will be needed in ultramicro amounts only. In this section the elements which will be considered are those to which some attention has been given in previous sections.

All plants contain copper, for it is one of the essential trace elements. The copper content of plants covers a fairly wide range but this tends to be lower than that for other trace elements. Among other environmental factors, the amount available appears to be affected by the soil pH, the optimum range for availability being approximately 5.5 to 7.0. Exchangeable copper is strongly adsorped by soil colloids, especially by organic matter; adsorption by the latter leads to the formation of stable complex compounds in which the copper becomes non-exchangeable. Copper has some function in chlorophyll formation, although the chlorophyll molecule contains no copper. This function is presumably indirect, since plants may cease growing as a result of a copper deficiency, and yet show no signs of chlorosis. Copper is contained in several plant enzymes: tyrosinase - the best known of the copper enzymes - laccase and ascorbic acid oxidase. Tyrosinase may be taken to include monophenol and polyphenol oxidases. All these enzymes bring about the oxidation of organic compounds by means of molecular oxygen. Copper also plays a role in the oxidation of iron.

Excess concentrations of copper in the soil may result in a number of deleterious symptons in plants, such as purple stems, chlorotic leaves with green veins, stunted roots and the development in some species of creeping sterile forms.

Soils deficient in copper have been reported from localities in a number of countries, where they have been recognised by certain characteristic effects on crops and trees. These effects range from slightly reduced growth to disease symptons so severe that death ensues. Woody plants deficient in copper may suffer from "die-back" or "exanthema" and the effects of this disease on orange trees in Western Australia have been recognised. In herbaceous plants the symptons of deficiency are more severe. "Reclamation disease" of small grains and other crops has been reported from various parts of Europe, commonly occurring on newly cultivated organic soils. The disease has also been found in alkaline calcareous areas.

Deficiency effects have been examined closely only in commercial crops and plants of economic importance so that the effects of copper deficiencies or excesses upon the plants composing the native Australian vegetation are not known.

Leaf analysis of the copper content of plants is not an infallible guide in the diagnosis of copper deficiency. When growth is severely stunted under conditions of severe deficiency the copper content of plant material, as percentage dry matter, may not appear very low (Steenbjerg 1948).

The copper content of plants analysed from field areas in the Eastern Goldfields gave an average of 75 ppm in the ash.

Zinc is another trace element which is essential for proper plant growth and development. This element is probably related to the formation of chlorophyll, as a fairly high proportion may be found in the chloroplasts. The metal is also present in some enzyme systems, for example carbonic anhydrase and triosephosphate dehydrogenase, and, although appearing inessential for some enzymes, may affect them by increasing or decreasing their activity according to its concentration. The auxin content of plants appears to be dependent upon zinc. If zinc is insufficient in quantity auxin is destroyed, and this suggests why a zinc deficiency may result in the retarding or cessation of plant growth. Experimental work on the tomato plant showed more precisely the role of zinc in this connection: the metal is essential for the synthesis of tryptophane, one of the precursors of auxin, so that a deficiency of zinc will prevent its formation (Tsui 1948).

The amount of zinc available for uptake by plants depends, among other factors, upon the pH of the soil, uptake decreasing as pH increases. The critical pH values lie between 5.5 and 6.5; above this figure zinc is converted to a less soluble and less available form. The low availability in highly limed mineral soils is attributed to the formation of insoluble zinc hydroxide and complex zinc compounds. There is some evidence to show that above pH 7.85 zinc may again become more available; it may be included in a soluble form in the anion as zincate. Because of this relation to pH more of the metal tends to be taken up by plants growing on siliceous soils than by those on calcareous or ultrabasic soils.

Deficiency symptons differ in herbaceous and woody plants. In herbs the most outstanding characteristic of zinc deficiency is that of chlorotic leaves with green veins, for chloroplasts are particularly affected. The metal is necessary for seed production in beans and buck-wheat; in Vicia faba insufficient zinc caused the flower buds to fall off. Trees with zinc deficiency show an abnormal growth form known as rosetting; in spring a rosette of small stiff leaves grows instead of the usual elongated shoots. This feature has been noted in Pinus *radiata* plantations in poor soil in Western Australia, but again few observations have been made on the effects of deficiency upon the natural Australian vegetation.

Steward (1963) quotes the work of several authors in connection with the effects of light and season on zinc deficiency. Hoagland noted that deficiency effects were restricted to the summer months in California, not being evident during winter. By contrast, Ferres reported from South Australia that it was during winter that subterranean clover (*Trifolium subterraneum*) showed the most marked deficiency symptoms. From these observations Ozanne concluded that day length and light intensity both play a role in this connection.

While zinc deficiencies are quite common, phyto-toxicity is very rare and few cases have been cited. Some mineral soils near Aachen, Germany, are very rich in zinc. Ordinary plants cannot grow in these "calamine" soils and they support a specialised and peculiar vegetation.

Analyses of plant samples collected from the Eastern Goldfields revealed that most species contain more of this element than of any other trace element for which analysis was undertaken; the average amount in the ash was 330 ppm.

Lead is probably neither necessary nor beneficial to plant growth. It is generally toxic to plants when present in ionic form. A certain amount appears to be absorbed by most plants, being detectable in various organs, although most of it seems to be precipitated in the roots. Soluble lead compounds are toxic to plants except in very low concentrations, the solubility of this metal increasing as the acidity of the soil increases.

Cannon (1955) reported that dried material of Spirogyra growing in drainage water from a mine contained 6600 ppm lead, while the amount of total heavy metals in the water was 16 ppm. She found that lead absorption varied markedly between angiosperm species. From a soil containing 250 ppm lead the amounts in some of the species examined were as follows: ragweed 50 ppm, burdock 58 ppm, pigweed 6 ppm and nettles 2 ppm.

Many of the plant samples collected from the various field study areas were analysed for lead, but very few of the samples revealed this metal to be present. A few of the samples of aerial organs contained 5 ppm lead, but most of the results were below the limits of detection including those from the analysis of root material.

Nickel is not considered to be an essential element in plant metabolism, although most plants probably contain small amounts which are taken up during the course of metal absorption. All the plant samples analysed for nickel showed this element to be present in appreciable amounts. Cannon (1960) gives the average amount in plant ash as 65 ppm, and a visual examination of the nickel content in the ash of plant samples collected from the Eastern Goldfields indicates that their average would approximate to this figure. The amount of this metal in a plant depends upon the species involved, the part of the plant analysed, the soil nickel content, the soil pH, and the age of the plant or organ under consideration.

An excess of nickel in plants will produce chlorosis and necrosis. For example, roots became stunted and secondary root development is suppressed; white dead patches occur on leaves and there is the appearance of apetalous sterile forms. Iron metabolism is upset if the concentration of nickel is too high, as is the case with toxic amounts of other heavy metals; the iron is replaced by the toxic metal and this results in an iron deficiency. It has been shown experimentally that both nickel uptake and symptoms of toxicity are reduced if there is a high concentration of iron in a nutrient solution (Crooke *et al*.

1954). Nickel will also interfere with the uptake of major nutrients and has been found to lower the yield of dry matter. Calcium is one element whose absorption is increased in the presence of nickel, and it has been found to reduce toxicity symptoms produced by nickel. It appears that such a reduction of symptoms is due to a lowering of the availability of nickel following a change in the pH of the soil, rather than an increase in the amount of calcium in the soil per se, for calcium sulphate has not the same beneficial effect as has calcium carbonate (Hunter and Vergnano 1952).

Chromium is present in small quantities in all plants. However, there is no evidence that even minute quantities are useful to plants, and no plant diseases due to lack of this element have been reported. Cannon (1960) gives the average amount present in plant ash as 9 ppm. Analysis of the aerial parts of plants from most of the study areas in the Eastern Goldfields revealed a slightly higher average; while samples collected from parts of the norite dyke at Norseman averaged about 6 ppm chromium, samples from the Mt. Hunt area approximated to 17 ppm. The average from Kambalda plant samples was higher again, approximating to 37 ppm chromium; the average would be expected to be higher here owing to the large amount of this metal in the serpentinite.

Arsenic is non-essential in plant metabolism, and is generally toxic in small quantities. If present in plants it is usually in very small amounts only as, for the most part, plants will die before they accumulate much more than 10 ppm (Robinson and Edgington 1945). It appears that plants tend to solubilise this element for humus tends to be somewhat enriched in arsenic. The amount of arsenic which is available to plants depends on the pH of the soil and the quantity and nature of the clay or colloidal matter. The bulk of this element occurs in the silt and clay fractions of the soil. In acid sandy soils arsenic is readily leached; toxicity occurs at a much lower level of arsenic compared with heavier textured soils, especially if the clay contains an abundance of iron, for there appears to be a close association between arsenic and iron.

A number of plant samples from the South Norseman area was analysed for arsenic, as arsenic geochemical anomalies had been located here, the soil content of this element reaching to 100 ppm. However, none of the plants revealed arsenic present in their tissues; root material also gave negative results.

2. The mechanics of anion and cation absorption by plants

Roots can absorb ions either from the soil solution or from the soil particles with which they come in contact. Some ions are absorped passively, i.e. the process is not dependent upon metabolic energy. Passive absorption involves the free diffusion of ions in or out of part of the tissue, which will thus eventually reach an equilibrium in ion concentration with the external medium. An example of passive absorption is the mass flow of ions through the roots under the pull set up by transpiration; in this theory any increase in the transpiration rate should be reflected in an increase in the absorption of ions.

Most ions are absorped with the aid of metabolic energy, and this is called active absorption. Under this method both anions and cations can be accumulated by plants against concentration gradients, and this accounts for many elements being present within the tissues in a concentration that is often very much higher than that in the surrounding medium.

A number of mechanisms have been suggested to explain how active absorption works, and most of them envisage active transport of an ion into the root cells as taking place with the aid of a carrier compound or molecule present in the cell membranes. According to this theory ions form loose combinations with specific binding compounds and this complex can then move across the cell membrane, dissociating to release the ions inside the cell. The concept provides an explanation for the selective absorption of ions; they are absorped at varying rates and in varying concentrations in the root, although where they have a similar chemical behaviour they may compete with each other for the same carrier and specificity hence becomes low. The nature of the carriers is still unknown, although various suggestions have been made, such as mitochondria and ribonucleoproteins. Of the nutrients entering the roots some will remain within the root cells while the rest are transported to the aerial parts of the plant. The amount remaining in the root partly depends on the concentration there; if it is low more will tend to remain, and less will pass upwards. Precipitation of some of the more toxic elements takes place in the root; for example, uranium and lead both tend to be stored here so that only relatively small amounts of these elements will normally pass into other plant organs.

3. Geobotany as a tool in geological reconnaissance

Vegetation studies, as carried out during the course of the field work, may be used in geological reconnaissance in two ways. First, relationships may be recognised between the distribution of various vegetation associations or plant communities and the underlying rock unit. This may be of assistance during geological mapping. Second, particular species or groups of species may be associated with high soil concentrations of certain metals. Such species occur within certain localities in the field area but because of limited work it is not known to what extent the distribution of these species is controlled by a high soil metal content; the relationship observed may be equally influenced by other factors.

The geobotanical relationships which were noted in each field area have been described in previous sections and will now be summarised. In each field area distinctive associations of trees and shrubs grow over the different rock formations and may serve to delineate the extent of the underlying bedrock. In the Norseman district two of the localities examined revealed distinctive geobotanical relationships. The Jimberlana Dyke is composed predominantly of norite and feldspathic bronzitite. Both rock types can be traced by the vegetation association supported. The norite outcrop carries a particularly distinctive, dense shrub vegetation, dominated by _Melaleuca uncinata_, _Casuarina campestris_, _Acacia cochliocarpa_, and the spinifex grass _Triodia scariosa_. The feldspathic bronzitite, which occurs on peripheral areas of the dyke, is characterised by a low, open woodland in which the dominant tree is a stunted form of _Eucalyptus foecunda_. This species is associated with _Eremophila drummondii_, _Ricinocarpus stylosus_, _Westringia rigida_ and _Triodia scariosa_. Both associations are unique to the dyke and occur nowhere else within the region. A comparatively small area of the dyke was examined. This structure has been traced for a distance of over one hundred miles; it is not known for how great a distance these particular species characterise these rock types, and whether other species gradually become more important in the associations if the vegetation provinces change. Neither is it known to what extent the species change as the norite becomes less rocky with a greater degree of soil cover, and hence a different physical environment. The parts of the dyke studied at Norseman consist of outcropping and predominantly scree covered norite, with soil covered areas of feldspathic bronzitite; where these particular physical conditions are modified it is quite possible that some of the noted species will disappear or become less prominent, while others assume dominance.

In the Iron King area at Norseman similar geobotanical relationships are observable. The Kingswood basalt in the west supports open woodland in which Eucalyptus leptophylla dominates the tree stratum; associated shrubs are Melaleuca sheathiana, Eremophila dempsteri and Atriplex paludosa. The metajaspilite bands to the east of the basalt support a different but characteristic association, composed predominantly of shrubs. Eucalyptus Stricklandi, E. torquata and E. celastroides grow with an overall low density, but the association here is notable for its variety of shrub species. These include Casuarina campestris, Grevillea nematophylla, Myoporum platycarpum, Alyxia buxifolia, Ricinocarpus stylosus, ?Grevillea didymobotrya, Calothamnus chrysantherus, Prostanthera aspalathoides, Scaevola spinescens, Trymalium myrtillus, Hibbertia ?pungens, Dodonaea stenozyga, D. boroniaefolia, Acacia erinacea and Westringia rigida. The Lady Mary Formation and the Marell schist are separated by and lie between the metajaspilite bands. Both have somewhat similar associations which contrast with that growing on the metajaspilite in having a relatively small number of species. Melaleuca sheathiana, Eremophila dempsteri and Atriplex paludosa are the most important shrubs here. Trees are not frequent; Eucalyptus torquata, E. flocktoniae and E. lesouefii occur occasionally on the Lady Mary Formation, and E. Stricklandi on the Marell schist. The Raggedy Formation in the east of this study area supports open woodland. The association is similar to that on the Kingswood basalt, but differs in the wider variety of species present. E. leptophylla dominates the tree stratum and E. salubris and E. Stricklandi also occur. The shrub understorey is dominated by Melaleuca sheathiana, Eremophila dempsteri, Scaevola spinescens and Atriplex paludosa, other species growing with lower frequency.

The two other study areas at Norseman were each located over one geological unit only. The Norseman Reef area occurs within the area underlain by the Mararoa pillow lavas and any changes in the vegetation here appear to be largely the result of changes in the physical nature of the terrain. The South Norseman area lies within the general area of greenstones where outcrop is not common and the vegetation is open woodland.

The Coolgardie area differs from most of the other areas studied in that geobotanical relationships are recognisable over large areas of soil covered bedrock. Geobotany can usefully be employed during the geological mapping of such an area, where outcrop is not common. The basic lavas at the Three Mile Hill form an area of outcrop, characterised by *Eucalyptus campaspe*, *Atriplex paludosa* and *Bassia patenticuspis*. The amphibolite sill, extending beyond the Hill in a north-west to south-east direction, can be traced by its distinctive association of *Acacia quadrimarginea*, *Eremophila duttoni*, *Dodonaea lobulata* and *Ptilotus obovatus*. The association remains constant except where the Dunallen axis crosses the sill and exposes porphyry. The basic lavas abut onto ultra-basic rocks north-east of the Three Mile Hill, and the boundary between the two units is obviously revealed by the change in vegetation associations. The open woodland on the ultrabasics is denser and more varied in its composition. *Eucalyptus foecunda* is the dominant tree, with *E. lesouefii* and *E. torquata* assuming dominance locally. These species are associated most commonly with *Eremophila interstans*, *Cassia eremophila* and *Atriplex paludosa*, although a wide variety of shrub species is encountered, including *Eremophila duttoni*, *Acacia graffiana*, Dodonaea lobulata, Scaevola spinescens, Acacia erinacea, E. weldii and Olearia muelleri. This association persists for approximately 7000 feet across the undulating, soil covered ultrabasic rocks. On the occasional low ridges within the area Eucalyptus torquata is the only tree species growing, associated with Eremophila interstans and Dodonaea stenozyga.

A different woodland association grows on the soil covered area of unknown bedrock adjacent to the ultrabasic rocks. A wide variety of Eucalypts occurs, including E. salmonophloia, E. lesouefii, E. transcontinentalis, E. salubris and E. ?oleosa. By contrast, the shrub layer is poorly represented, both in species variety and in density: Exocarpus aphylla, Eremophila interstans and Atriplex paludosa are the only important members.

The geology is represented by the metasedimentary series of rocks beyond the breakaways, seven miles north-east of Coolgardie. Outcrop again tends to be rather poor and most of the area examined is soil covered. Eucalyptus campaspe, E. salubris and E. lesouefii grow here, often in monospecific copses separated from each other by less vegetated areas. Atriplex paludosa is widely spread, but other shrubs occur only occasionally: these include Eremophila interstans, Cassia eremophila, Acacia erinacea and Olearia muelleri. The soil is saline over part of this area. This has led to the replacement of the typical metasedimentary association by halophytic species, such as Arthrocnemum halocnemoides.

The vegetation changes again as the metasediments give way to the Mungari granite. The granite outcrops as low undulating pavements over part of its area, and the vegetation supported by outcropping areas of this rock type is fairly characteristic. Eucalypts are not usually common and the vegetation is composed predominantly of shrubs of which Acacia acuminata is the most important. It is associated with Eremophila ?gibsoni and Ptilotus obovatus.

Once such relationships between geology and vegetation have been established within an area geobotany can provide a useful tool in geological reconnaissance within that area, particularly where outcrops are poorly represented. Again, however, it must be noted that variations in the physical habitat may lead to variations in the association. Such is the case, for example, over the ultrabasic rocks at Coolgaride, where the ridges and the flatter areas each have their own vegetation association.

At Mt. Hunt a number of geobotanical relationships were recognised, these being mainly between the vegetation and outcropping areas of the various rock types. The unknown underlying geology of the soil covered areas could not, with two exceptions, be interpreted with the information gathered from the different outcrops and their related associations. This again seems to indicate that the outcrop of a certain rock type may be characterised by species which differ from those growing on the same rock type when substantially soil covered.

The outcrops of metadolerite are usually distinguished by an association of Acacia quadrimarginea, Eremophila duttoni, Dodonaea lobulata and Ptilotus obovatus. Outcropping metabasalts and variolitic lavas support similar associations but usually show some differences in their species composition, the association consisting of A. quadrimarginea, Eremophila sp. J.B./W.A. III, D. boroniaefolia, Prostanthera wilkieana, Ptilotus obovatus and Helipterum adpressum. The areas of zoisitic lavas again support a similar association, composed of A. quadrimarginea, Eremophila sp. J.B./W.A. III, D. lobulata and P. obovatus.

Ultrabasic rocks are present within the area and over parts of their occurrence are masked by soil cover. They can be distinguished by the species Eucalyptus foecunda, Acacia leptoneura, A. graffiana, Cassia eremophila and Triodia irritans. These are the most characteristic plants on this soil covered rock type although other shrub species, such as Westringia rigida, may be present. Where serpentinite outcrops the association is modified and is composed of E. foecunda, A. leptoneura, Dodonaea stenozyga and T. irritans. It seems that, whereas E. foecunda, A. leptoneura and T. irritans grow equally well on soil covered ground and scree covered outcrop, A. graffiana and C. eremophila prefer a deeper soil; where serpentinite outcrops their place is taken by other species, such as D. stenozyga.

Part of the soil covered area at Mt. Hunt can be inferred as the basic rock, metadolerite, by reference to the geological map, although this cannot be confirmed by outcrop. This area supports an association of A. quadrimarginea, Eremophila duttoni, D. lobulata and Ptilotus obovatus, which is characteristic of the metadolerite outcrops within the area. The ground surface here is liberally covered with scree from the adjacent outcropping band of metajaspilite, and this may help to create the physical conditions of a rocky soil which seems to be favoured by the species of this association. Such a factor may be as important in the establishment of this association as is the provision of a favourable soil chemical environment by the underlying metadolerite. This is an example in which the use of geobotany has helped to confirm the geological interpretation in areas where bedrock is masked by soil cover.

It was noted at Mt. Hunt that where outcrops are particularly small geobotanical relationships may be misleading. This was observed at the serpentinite pod along transect 7, where the association supported is that of the adjacent variolitic lavas, and differs completely from the association characterising the large serpentinite outcrop further to the east. A similar situation exists along transect 8 over the small metadolerite outcrop. The use of geobotany is limited in cases such as these.

Certain geobotanical relationships can be recognised at Kambalda, although the physical conditions of the environment again show their influence upon the species composition of an association. The higher parts of the hills here are generally composed of outcropping metabasalt, and support an association of Acacia quadrimarginea, A. tetragonophylla, Eremophila duttoni, Santalum spicatum, Dodonaea lobulata, Scaevola spinescens and Ptilotus obovatus. Prostanthera wilkieana, Eremophila sp. J.B./W.A. III and Helipterum adpressum occur on the highest parts of the metabasalt hills, and it is interesting to note that the metabasalt association here is very similar to that on the metabasalt at Mt. Hunt. However, this particular association does not grow where the metabasalt is masked by soil cover, as along part of transect 22. The association here is dominated by Eucalyptus lesouefii, Eremophila interstans, Atriplex paludosa and Olearia muelleri; other shrubs present include Eremophila duttoni, Scaevola spinescens, Dodonaea lobulata and Ptilotus obovatus.

A similar situation to that described above exists in areas of serpentinite. This rock type forms a more subdued relief than does the metabasalt, and is generally characterised by a substantial soil cover. The vegetation growing in these areas includes Eucalyptus lesouefii, E. torquata, E. foecunda, Eremophila interstans, Dodonaea lobulata, Scaevola spinescens, Olearia muelleri, Atriplex paludosa and Westringia rigida. Outcrops of this rock type occur occasionally, as at the north-east end of transect 23. The vegetation differs over such rocky and scree covered areas, and includes *Eremophila duttoni*, *Acacia tetragonophylla*, *Scaevola spinescens*, *Trymalium myrtillus*, *Dodonaea lobulata*, *Hybanthus floribundus*, *Ricinocarpus stylosus* and *Ptilotus obovatus*. This species list includes plants which grow on the metabasalt outcrops, and it appears that the physical conditions of the habitat are of prime importance in their establishment.

The second use of geobotany in geological reconnaissance concerns the relationship between a particular species, or groups of species, and a high soil metal content. In certain localities within the field area where the soil metal content exhibits a high background or values rise above background, forming geochemical anomalies, certain species may appear in the vegetation association. At Norseman the noted example of such a relationship occurs over part of the Jimberlana Dyke. The growth of open woodland, dominated by *Eucalyptus* affin. *cylindrocarpa*, corresponds with the soil nickel anomaly at the southern end of transect 17. Another example occurs at Mt. Hunt, where the high background concentration of nickel, and particularly chromium, in the soil overlying the carbonated serpentinite outcrop at the eastern end of transect 8 appears to prevent the establishment of many species. Melaleuca lateriflora is the only widespread species here, apparently withstanding the uptake of large quantities of these metals.

At Kambalda the three shrubs Hybanthus floribundus, Trymalium myrtillus and Ricinocarpus stylosus grow only on the serpentinite outcrops along transect 23, where the soil nickel and chromium contents are high; nickel reaches a maximum of 1230 ppm and chromium a maximum of 970 ppm. The restriction of these shrubs to a rocky habitat suggests that this type of physical environment is an important factor in their establishment. If these species also favour a high soil metal content their absence from other anomalous areas where the soil is deeper may be due to competition from other species: however, these shrubs may prefer a rocky habitat where the nickel and chromium soil contents are high.

Any conclusions concerning these relationships must remain tentative at present. The restricted number of observations and lack of similar, comparable localities make it impossible to say how far such relationships are consistent. The extent to which these plants are affected or controlled by a high soil metal content can only be determined by further work. However, geobotanical relationships such as these provide part of the preliminary work in the geological reconnaissance of an area, and may help in locating mineral deposits.

In each field area of the Eastern Goldfields geobotanical relationships have been established, indicating the potential use of the geobotanical method in geological reconnaissance. These relationships depend upon the creation of suitable physical and chemical environments by a rock type for the particular plant assemblage supported. The nature of the physical environment obviously plays an important role, for a different or modified form of an association may occur where bedrock outcrops and where it is soil covered. This was noted at Kambalda and Mt. Hunt; it is probably the case in other areas but could not be established because soil covered and outcropping areas of the same rock type were not always available for study within a particular locality. In any use of geobotany in geological reconnaissance, especially where the area under surveillance is of large extent, cognizance must be taken of changes in the physical environment and of possible changes in the vegetation provinces. Geobotanical relationships established in the Coolgardie-Kalgoorlie area, for example, could not be used in the Norseman district due to the many changes in genera and species distributions between the two regions: for use in geological reconnaissance new relationships must be establshed for each new region.

4. Geobotany and biogeochemistry as prospecting techniques in mineral exploration, with particular reference to the search for nickel, copper and gold.

Geobotanical and biogeochemical methods were employed over areas of the Eastern Goldfields where mineral enrichment was known or suspected.

At Norseman field studies were carried out to investigate the extent to which the unique shrub association of the norite outcrop was due to a possibly higher soil concentration of nickel and chromium in the norite as compared with the soil content of these metals on the adjacent greenstones. At the southern end of transect 17, one of the dyke transects, another unique association of limited occurrence grows, contrasting physiognomically and specifically with that growing over the rest of the norite. Instead of the very low frequency of tree species and the predominance of the shrub layer, as over the greater part of the dyke, this southerly association is one of Eucalyptus woodland. The tree stratum is dominated by E. affin. cylindrocarpa, and shrubs in the understorey include Eremophila interstans and E. drummondii.

Geochemical soil analyses from transect 17 revealed that the concentration of both nickel and chromium remains fairly uniform along the dyke and is in no way anomalous. The soils from the adjacent greenstones contain similar or greater amounts of these metals. At the southern end of the dyke transect, however, the soil concentration of both nickel and chromium rises -- nickel from 86 ppm to a peak of 325 ppm, and chromium from 330 ppm to 1250 ppm -- the anomalous values, particularly those of nickel, corresponding in their occurrence with the belt of Eucalyptus affin. cylindrocarpa woodland. The growth of this particular association here appears to be a direct response to the increased metal content of the soil, particularly to the increase of nickel, whose soil anomaly shows a particular correspondence with the extent of the association.

Once such a geobotanical relationship has been established between a particular vegetation association and a geochemically anomalous area further use may be made of the relationship in mineral prospecting within that same district. During such prospecting, however, regard must be taken of other features of the environment, for unless these are similar to those in the original area, the plant assemblage being sought may not occur, in spite of anomalous soil values. Thus the E. affin. cylindrocarpa woodland may not grow where soils are skeletal even though a high soil nickel content is present in the soil. The areal extent of a species distribution is also an important factor in geobotanical mineral prospecting. E. affin. cylindrocarpa was found only in this locality at Norseman during the field work. It was not seen at Kambalda, another area of soil nickel enrichment, and so may not extend so far north. This species may not, in any case, be uniquely associated with nickel soil anomalies.

Plant samples were collected from Eucalyptus foecunda and various shrub species on the areas of feldspathic bronzitite peripheral to the norite, and from E. affin. cylindrocarpa. Although only a small number of samples was taken, the plant material from the periphery of the dyke, where soil nickel and chromium values are lower, did not contain as much of these metals as did E. affin. cylindrocarpa. Biogeochemical methods are thus indicated to be of use in prospecting such an area.

Part of the field studies at Kambalda was directed towards ascertaining the degree to which geobotany and biogeochemistry could be of assistance in prospecting for nickel. It is noticeable that, along transect 22, which was run where some of the highest soil geochemical values occur, the characteristic association on the soil covered serpentinite becomes lower in density and species variety. Eucalyptus species, including E. lesouefii, E. foecunda and E. torquata, normally prominent in the vegetation, cut out over the eastern part of the anomaly, and the common saltbush, Atriplex paludosa, becomes the only well represented plant. Although geobotanical relationships are apparent here they cannot similarly be seen along the western side of this same anomaly, where nickel soil values are even higher. This appears to be due to the interplay of environmental factors in the soil: large amounts of carbonate in the soil remove nickel from solution under a high pH, thus reducing the amount of this metal which is available for plant uptake. E. lesouefii, E. foecunda, E. torquata and Eucalyptus sp. J.B./W.A. 304 were sampled along transect 22. Eucalyptus sp. J.B./W.A. 304 occurs near the western boundary of the cut-out area, where soil nickel values are unusually high. It contains a much higher quantity of nickel in its tissues than any of the other tree species analysed from elsewhere along the transect, a maximum of 520 ppm nickel occurring in the ash of the leaves (Table XII). The Eucalypts sampled from the western area of the anomaly do not contain unusual amounts of nickel, indicating that the nickel, although present in the soil in anomalous quantities, is not taken up by the plants in amounts which reflect the total amount in the soil.

Geochemical and biogeochemical analyses were also undertaken for chromium and copper in the Kambalda area. Anomalous soil chromium contents occur in conjunction with those of nickel along transect 22. However, in spite of large quantities of this metal in the soil, biogeochemical analyses revealed that plants do not appear to take up this element to any large extent. The chromium content of the Eucalyptus species along this transect averaged 27 ppm in the plant ash. However, it must be noted that a single root specimen was collected from a young unidentifiable Eucalyptus species, and analysis of this material gave a result of 240 ppm chromium in the ash. Another root sample from a dead specimen of E. lesouefii contained 190 ppm chromium in the ash. No definite conclusion can be drawn from two samples only, but it may be that, although such large quantities as this are absorbed by a plant, most of the element is precipitated in the roots. Throughout the Kambalda area the small shrub Ptilotus obovatus invariably contains more chromium than any of the aerial organs of trees.

Copper is present throughout the area in background concentrations only, and biogeochemical analyses did not reveal anything but usual amounts in the plants. The usefulness of biogeochemistry is limited in the Kambalda area. If nickel is present but unavailable for absorption by plants, as appears to be the case along part of transect 22, no anomaly will be revealed by biogeochemical analysis in spite of the occurrence of anomalous amounts in the soils: if biogeochemistry is being used it must be in conjunction with geochemistry. If chromium is being sought biogeochemical analysis of aerial organs will not provide reliable information of anomalous soil contents, as plants in this region, although possibly absorping appreciable quantities, do not transport this element to any great extent. Although the metal is absorbed it appears that most of it remains in the plant roots, so that use must be made of this organ if the biogeochemical method is to be used in prospecting for chromium.

It has been noted in a previous section on Kambalda (Part 5 (A), section 4) that the three shrubs Hybanthus floribundus, Trymalium myrtillus and Ricinocarpus stylosus grow together on the serpentinite outcrop along transect 23 in the Kambalda area. The geochemical soil samples collected from the outcropping serpentinite showed that nickel and chromium are present in high quantities in the soil. The limited occurrence of these three species suggests that both the geochemical and the physical environment must be favourable for their growth. If a high soil content of nickel and/or chromium is necessary, their absence from the eastern side of the anomalous area along transect 22 may be due to competition from Atriplex paludosa on the soil covered serpentinite; alternatively they may prefer a rocky habitat which is also rich in these two elements. This relationship has been examined more fully in Part 5, (A), section 4, and further work would be necessary before any conclusions could be drawn on geochemical controls with respect to these species. However, this indicates the way in which geobotany may be of use in mineral prospecting.

At Widgiemooltha geobotany and biogeochemistry were employed in conjunction with geochemistry in the vicinity of a small copper prospect. An association of limited extent, dominated by Eucalyptus torquata and a variety of shrub species, including Cassia eremophila, Scaevola spinescens, Ptilotus obovatus and Westringia rigida lies to the east of the copper workings and is surrounded by a more widely spread and less dense association of open woodland, dominated by Eucalyptus salmonophloia, E. lesouefii, Eremophila interstans, Cratystylis conocephala and Atriplex paludosa. The area was chosen for investigation for preliminary observations upon the distribution of these two associations suggested that they might be influenced by the dispersion of copper from the copper prospect. It appeared that the association dominated by Eucalyptus torquata, Cassia eremophila, Scaevola spinescens, Ptilotus obovatus and Westringia rigida, lying adjacent to and slightly downslope from the prospect, possibly resulted from the higher copper content of the soil, and had replaced the more widespread association of E. salmonophloia, E. lesouefii, Eremophila interstans, Cratystylis conocephala and A. paludosa because of its preference for or greater ability to withstand the higher concentrations of copper which had dispersed from the workings. However, the results of the geochemical analyses for this area did not substantiate this. The association of E. torquata, C. eremophila, S. spinescens, P. obovatus and W. rigida does not correspond in its extent with the soil anomalies for total copper and zinc, so that these higher soil concentrations cannot be regarded as influencing the distribution of the vegetation associations here to any great extent.

The biogeochemical analyses for this area showed some correspondence with the geochemical analyses. The small shrub, Olearia muelleri, grows throughout the area with only slight variations in its frequency, and it was possible to sample it along the length of transect 18. Those plants of this species growing over the copper and zinc soil anomalies contain greater amounts of these metals than do those plants growing where soil values are lower. The correspondence is often very exact, with maximum values in plant and soil occurring at the same location. Olearia muelleri, however, tends to concentrate these metals, producing much larger anomalies than those present in the soil. This species does not grow so frequently along transect 24, the second transect in this area. The shrub again contains more copper and zinc than is present in the geochemical samples, but any correspondence between soil and plant anomalies cannot be shown here because of the lack of plant samples over the anomalous part of the transect. The shrub, Alyxia buxifolia, is a member of the association dominated by E. torquata, C. eremophila, S. spinescens, P. obovatus and W. rigida. Analyses of its leaves and twigs showed both to contain more copper and zinc in these tissues than is normal in a plant, the higher content of both metals generally occurring in the twigs (Table XII). However, the limited distribution of this species cannot help to substantiate any geobotanical relationship by the biogeochemical information it provides: no precisely comparable biogeochemical information on the area occupied by the more widespread association of E. salmonophloia E. lesouefii, Eremophila interstans, C. conocephala and A. paludosa can be given unless the species being sampled have a wide distribution and preferably grow throughout the area. Unless it is known that two different species behave similarly in their absorption of anions and cations it is not always satisfactory to replace one species by another in a sampling programme due to specific differences in absorption characteristics. For example, O. muelleri at 685 feet south on transect 18 contained 800 ppm zinc and 125 ppm copper in its ash. A. paludosa, sampled at 700 feet south contained 80 ppm zinc and 50 ppm copper in its ash.

Thus geobotanical techniques were found to be limited at the copper prospect south of Widgiemooltha, in that the distribution of the association of E. torquata, C. eremophila, S. spinescens, P. obovatus and W. rigida, lying adjacent to the prospect showed no satisfactory correspondence with the geochemical results. The biogeochemical results substantiated those gained by geochemistry, but did not appear to provide any additional information to that gained by geochemical methods.

The arsenic geochemical anomalies discovered by Central Norseman Gold Corporation at South Norseman were investigated during the course of the field work. Arsenic shows a strong association with gold ore so that any geobotanical observations made in relation to the arsenic might be used to indicate the possible occurrence of gold ore in other localities. In some of the areas with anomalous total arsenic in the soils the appearance of the woodland vegetation is quite different from that growing outside the anomalous areas where the soil arsenic concentration is low or below levels of detection. The unusually spindly nature of the Eucalypts has been described in Part 3 (D), and during preliminary observation was thought to be a biological response to the abnormally high soil concentrations of the arsenic. Many of these spindly patches of woodland correspond in their distribution with the arsenic anomalies, but the relationship is not constant, as field studies within the area later showed. Biogeochemical analyses were carried out for arsenic but all results were negative. None of the plant samples analysed, including root material, revealed the presence of arsenic. It seems that toxic concentrations of this element cannot be responsible for the unusual physiognomic character of the woodland here. High quantities of arsenic in the soil, such as occurs at South Norseman, may be detrimental to plants, but it appears that the element is not absorped by the vegetation at this locality. The cause of the spindliness of the trees at South Norseman has not been established. Within this particular locality no direct geobotanical relationships between the vegetation and the arsenic in the soil could be observed and the biogeochemical technique requires refinement to identify the additional factor which is associated with the arsenic mineralisation but which also has a direct effect on plant growth. However, this does not indicate that these methods cannot be used as prospecting techniques for arsenical mineralisation elsewhere within the Eastern Goldfields, providing that the element is available for plant absorption. Examples have been given in Part 3 (D) of areas of the world where the vegetation contains extremely high concentrations of arsenic.

In conclusion it may be said that the field studies carried out indicated that geobotanical relationships established over part of the Jimberlana Dyke, and over a limited area at Kambalda may provide the basis for subsequent work in mineral prospecting within these areas. At the copper prospect south of Widgiemooltha and also at the area of arsenical mineralisation at South Norseman no satisfactory geobotanical relationships were observed. The biogeochemical method in these four areas varied in its applicability. At the Jimberlana Dyke only a limited number of samples was taken, but correspondence was shown with the geochemical results, the Eucalypts over the nickel anomaly containing more nickel than did those where background concentrations prevailed. At Kambalda the biogeochemical method was of limited use due to the unavailability of nickel over part of the area. A similar situation exists at South Norseman; no arsenic was taken up by plants so that all biogeochemical results were negative. At Horan's copper prospect, south of Widgiemooltha, the biogeochemical method was shown to be as effective as the geochemical method, particularly in the results given by the shrub Olearia muelleri, which reflected the soil anomalies for copper and zinc by absorping these metals. Peaks in the geochemical profile correspond with peaks in the biogeochemical profile of this species along transect 18. However, it was shown here that the irregular distribution of species may hinder biogeochemical sampling, for the replacement of one species by another is not always satisfactory.

PART 8

CONCLUSION

The vegetation studies carried out in parts of the Eastern Goldfields, although limited in space and time, showed to some extent the use and degree of applicability of geobotanical and biogeochemical methods in geological reconnaissance and mineral exploration.

In each field area geobotanical relationships were recognised: varying vegetation associations coincided with the different geological units encountered, while to a lesser extent, associations, or modifications in the species composition of associations, corresponded with certain localities having anomalous soil metal contents.

Many of the boundaries between different vegetation associations coincided with the geological boundaries to a remarkable degree, enabling the extent of the underlying rock to be determined with varying accuracy. Any vegetation association or plant community developing over a particular area must be responding to both the physical and chemical conditions provided by the environment. The relief, drainage and the soils are all influenced to some extent by the geology, these environmental factors tending to vary in their importance upon the vegetation within the area under examination. Relief, by itself, does not generally appear to be of prime importance in this region of Western Australia, for the topography is rather subdued. However, relief is linked with the drainage considerations of an area, and with factors related to soil depth. It was often impossible to separate these factors in the degree of importance which they had upon the development of a particular vegetation association. Some associations, such as that composed of Acacia quadrimarginea, Eremophila duttoni, Dodonaea lobulata and Ptilotus obovatus appear invariably on slopes and areas of higher ground, which is characterised by scree, a thin skeletal soil cover and a relatively rapid run-off of drainage water. The species supported here must either favour this type of environment or be relegated to it by competition from other plants.

The geology and the differential rate of weathering of elements will also influence the chemical constitution of the soil; this, in its turn, influences the development of the vegetation associations. Although the physical nature of varying localities may be similar, if the bedrock is different there are consequently degrees of difference in the chemistry of the soils produced; the vegetation supported may vary accordingly. Trace element analyses did not always reveal significantly different concentration patterns between different rock types. Hence other factors and elements for which no analyses were undertaken must frequently bear more importance in the soil environment in which an association is established. It was also noted, however, that where varying physical conditions exist over an area underlain by one particular rock type the association supported over outcrop differs from that growing where the same rock type is covered by deeper, mature soils: although the chemical composition of the soil could be very similar in two such localities, the physical environment - in particular the increase in cation exchange capacity - serves to modify the associations supported. This kind of relationship is seen, for example, in the Coolgardie area, where variations occur in the associations supported over areas of outcropping granite, and areas where the granite is masked by soil cover.

The anions and cations in the soil are usually present in amounts which allow normal plant growth to proceed. Where unusually high concentrations of an element are present in the soil, either because the background content is unusually high or because of the presence of mineralisation, the vegetation association may show modifications in its usual species composition, or else the normal vegetation may be replaced.

Areas of mineralisation were examined at Kambalda and south of Widgiemooltha for possible geobotanical relationships. At Kambalda part of the largest geochemical anomaly is marked by a cut-out of species, notably Eucalypts. At Horan's copper prospect, south of Widgiemooltha, there is no definite geobotanical relationship with the copper mineralisation. Over part of the Jimberlana Dyke at Norseman a soil nickel anomaly was located: a belt of Eucalyptus affin. cylindrocarpa woodland coincides with the anomaly, this appearing to be a direct geobotanical relationship. Part of the carbonated serpentinite outcrop at Mt. Hunt is marked by a high background concentration of nickel and chromium. This locality is characterised by an extremely sparse vegetation; Melaleuca lateriflora is the only widespread species, although having a low frequency. This low density vegetation appears to be the result of the high background concentration of nickel and chromium in the soil. Other outcrops of carbonated serpentinite in the

Mt. Hunt area do not have such a high background content of these two metals, and support an association of normal density and variety. Further studies need to be carried out on similarly mineralised areas so that the geobotanical relationships noted above can be substantiated and put to use in prospecting for mineral resources within the area.

It was shown that the applicability of the geobotanical method may be limited by the size of an outcrop. If the outcrop is too small and the vegetation sparse the association characteristic of larger outcrops of that rock type may not develop. This is observable at Mt. Hunt, where pods of serpentinite and metadolerite do not support the associations characteristic of the larger outcrops of these rock types.

It is also necessary to establish the limits of a geobotanical province. Relationships established in one part of a region may not be applicable in other parts of the same region, as the special distribution of species varies. In the Eastern Goldfields different species occur between the Kalgoorlie area and the Norseman area. Any vegetation association characteristic of, for example, ultrabasic rocks round Kalgoorlie will not be characteristic of ultrabasic rocks at Norseman. The marked species differences in the vegetation of these two areas necessitates the establishment of new geobotanical relationships.

Biogeochemical methods were carried out in each area under investigation. The availability of a metal for uptake by plants is of prime importance. Although the concentration of the metal in the soil may be very high, unless it is in a readily available form biogeochemical analyses will not give useful results. Over part of the Kambalda area where there is a high nickel anomaly it appears that the nickel is made unavailable by carbonate in the soil removing the element from solution under a high soil pH. Similar observations were made at South Norseman. Here the soil arsenic anomaly finds no reflection in the plant material. Although arsenic is present in quantities up to 100 ppm in some localities, no arsenic was revealed in any part of the Eucalypts or shrubs by biogeochemical analysis. It is concluded that the arsenic is in a form which is not available for uptake.

Where a metal is readily available for absorption by plants there may be a remarkable correspondence between the position of soil geochemical anomalies and biogeochemical anomalies. This is the case at Horan's copper prospect, south of Widgiemooltha. Along one of the transects here the peaks in the copper and zinc anomalies in the soil and in the plant _Olearia muelleri_ correspond in their positions, although not in their relative quantities. The preliminary use of biogeochemistry here suggests that the analysis of a widely spread shrub, such as _O. muelleri_, will give results which are comparable in their usefulness to those obtained by soil geochemical methods.

In other areas the metal content of plants did not reflect that of the soil. At Mt. Hunt the soils from the southerly outcrop of carbonated serpentinite contain a relatively high amount of nickel and chromium; nickel remains fairly uniformly around 575 ppm and chromium reaches a peak of 1200 ppm. Analyses of the aerial parts of _Melaleuca lateriflora_, the dominant shrub growing there, showed that these metals are present in the plant material in normal amounts only, and do not reflect the high background in the soil. However, it must be added that no root material was analysed, and that these metals, particularly chromium, could possibly be absorped in larger quantities and precipitated in the roots.

Much work remains to be carried out upon the physiological behaviour of individual species. Each species behaves in a characteristic way in a given environment, some concentrating metals, others able to reject the uptake of large amounts. Further, where metal anomalies in plants do not correspond with total metal soil anomalies, studies of the available metals in soils by cold extraction techniques, and investigation of the variation in cation exchange capacity from scree and coarse-grained soils to deeper, mature and clayey soils will need to be undertaken before these factors can be put in perspective. The recognition of these variables in the soils and the behaviour of particular species will do much to extend the usefulness of both the geobotanical and the biogeochemical methods in geological reconnaissance and mineral exploration.

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