BOTANICAL METHODS
FOR
MINERAL EXPLORATION
IN
WESTERN AUSTRALIA

A thesis presented in partial fulfilment
of the requirements for the degree
of Doctor of Philosophy
at
Massey University

Barry Charles Severne

1972

ABSTRACT

The application of vegetation to mineral exploration was investigated in the semi-desert mulga zone of Western Australia. Acacia aneura (mulga) dominated the vegetation and was employed in several biogeochemical surveys to locate subsurface copper and nickel mineralisation after successful orientation surveys over outcropping areas.

Copper concentrations in A. aneura leaf were adequate for locating cupriferous zones in the Murchison Region. In the Kurrajong Region, A. aneura was employed to locate nickel sulphide mineralisation in a terrain of serpentinised and lateritised ultrabasics, characterised by high and variable nickel levels. It was possible to distinguish sulphide mineralisation from lateritic areas by consideration of coincident nickel and manganese biogeochemical anomalies.

A nickel-accumulating variety of the shrub, Hybanthus floribundus, was discovered in the Kurrajong Region. Other Hybanthus varieties were also found to accumulate nickel, in more southern parts of Western Australia. Plant chemistry studies indicated that nickel was concentrated in the leaf epidermis as a small, water-soluble positively-charged complex. The value of these nickel-accumulating shrubs in locating nickeliferous areas was demonstrated. Preliminary attempts to detect this shrub, from the air, using colour infrared photography were unsuccessful, although the potential of colour film to take advantage of the anomalous yellow colour during the summer season was realised.

Three tree species, Acacia coolgardiensis, A. resinomarginea, and A. burkittii, exhibited pronounced geobotanical relationships. The first two species were restricted to metabasalt and metagabbro ridges, whilst A. burkittii characterised calcareous serpentinised pyroxenites. It was found that a usable colour infrared image could not be obtained by vertical aerial photography because of the infundibular growth-form exhibited by this xerophytic vegetation. However the application of this film to photogeology was confirmed.

The possibility of using selenium as a path finder for sulphide mineralisation was investigated. A suitably-rapid instrumental method for the determination of selenium and tellurium was developed and a selenium accumulating tree, Acacia oswaldii, was subsequently discovered. A known toxic shrub, Swainsona canescens, also accumulated selenium, and the potential of this seleniferous flora in locating sulphides has yet to be demonstrated.

It was concluded that the research embodied in this thesis has indicated the application of botanical methods to mineral exploration in the Eremean Province of Western Australia, and has outlined promising avenues for further investigations.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

INTRODUCTION

1. THE OBJECTIVES AND SCOPE OF THIS STUDY.

Australia and in particular, Western Australia is witnessing a massive exploration effort by numerous mining companies both large and small. This activity was catalysed by the spectacular discovery of the Kambalda nickel ore-bodies in 1966 by Western Mining Corporation.

During the next five to six years many mineralised outcrops or gossans in association with ultrabasic rocks were discovered or rediscovered and led to the establishment of several nickel - copper mines. More recently the mineral search has been diversified to seek copper and zinc in acid-volcanic and metasedimentary terrains and various other metals in the vast tracts of granitoid rocks which constitute most of the Western Australian Archaean.

Throughout this period of intense activity, the successful exploration techniques included geological and aeromagnetic reconnaissance, detailed geological mapping (with a prime object of locating gossans) and follow-up soil geochemistry and magnetometer surveys. The final phase was the evaluation of mineralised zones by deep drilling programmes. During this period several companies carried out orientation biogeochemical surveys over mineralised areas but were discouraged, by analytical difficulties which led to high costs and, more important, by erratic results. Therefore, vegetation methods of prospecting have not played a prominent role in this mineral search to the present day.

It was in this atmosphere that the present study was planned and initiated under the auspices of Western Mining Corporation. This company had previously supported geobotanical studies (Elkington, 1969) in the Eucalpyt woodland, south of Kalgoorlie.

The fundamental aim of this work was to eveluate the potential role that vegetation might play in the search for economic minerals in Western Australia. Study regions were largely restricted to the Mulga shrub zone, north of Kalgoorli and initial investigations were concerned only with seeking nickel and copper mineralisation essentially in outcropping areas. The scope of the thesis was rapidly broadened to include the search for buried, non-outcropping mineralisation embracing nickel, copper, zinc, arsenic, selenium, tellurium and uranium.

2. DEFINITION OF BIOGEOCHEMISTRY AND GEOBOTANY.

The terms biogeochemistry and geobotany, in connection with mineral exploration, are well established in geochemical literature. However it is perhaps only a coincidence that in some countries one term is used to the virtual exclusion of the other. Biogeochemistry in mineral exploration was introduced into the literature at about the same time in Russia (Tkalich, 1938), and in Canada (Warren, 1944). This term is usually taken to mean that branch of geochemistry which involves the chemical analysis of vegetation in order to infer some property of the underlying substrate.

Geobotany, on the other hand, is narrowly defined as the study of the spatial relationship between vegetation and geology (Brooks, 1972).

However it has been the practise of the United States Geological Survey to combine geobotanical and biogeochemical prospecting methods under botanical methods of prospecting (Cannon, 1957; Froelich and Kleinhampl, 1960; Kleinhampl and Koteff, 1960).

Apparently the logic behind this semantic approach is based on the previously-established geochemical terminology whereby a geochemical soil anomaly would include both anomalous chemical (metal content) and physical properties, similarly a botanical anomaly would include biogeochemical and geobotanical anomalies.

Geobotany was first used in Australia in 1895, when a "copper plant" was discovered in Queensland (Skertchly, 1897) and, in Australia at least, appears to offer greater application than biogeochemistry (Warren, 1948). This statement has been substantiated in recent years (Cole, 1964; Nicolls et al, 1965; Cole et al, 1968) and accordingly, these authors use "geobotanical investigations" in a broad sense, to include both geobotany and biogeochemistry as defined above. Apparently, Miyake (1965) also employs this terminology.

It has also been the author's experience that informed exploration geologists and geochemists in Australia similarly use the term "geobotany" to include all aspects of vegetation prospecting (Aust. Inst. Min. Metal. 1972).

However, it has been decided, for the purposes of this thesis only, to adopt the nomenclature of Helen Cannon and her co-workers.

Accordingly this thesis, which is concerned with all botanical methods of mineral exploration, is titled "Botanical Methods for Mineral Exploration in Western Australia".

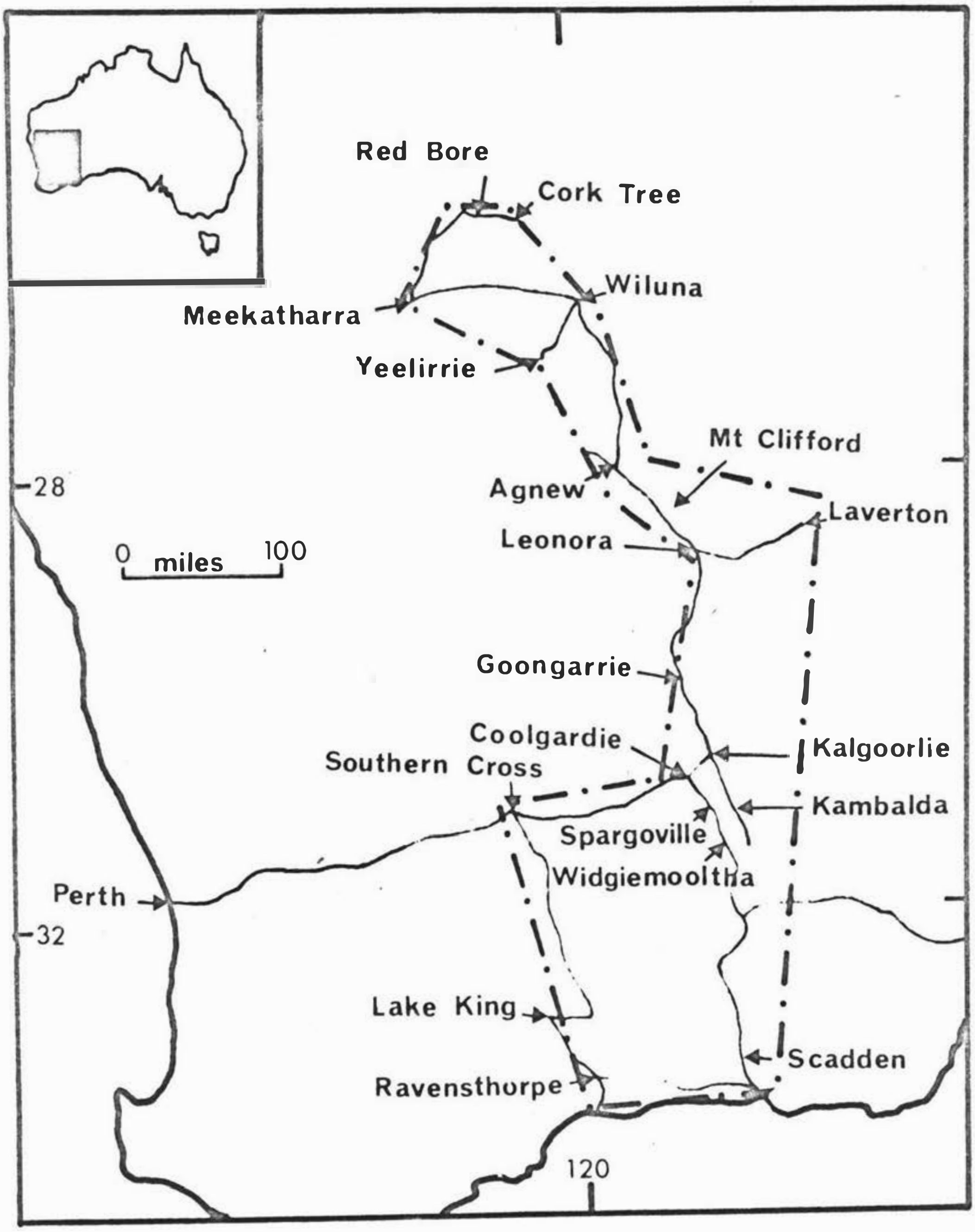


Fig. I-1. Location of the study region in the south western part of Western Australia. The roads are shown which were used to gain access to the various field areas and for reconnaissance surveys.

3. THE PHYSICAL ENVIRONMENT.

(a) Climate.

The study region (Fig I -1) is located within the Eremean Botanical Province (Fig. I -2) which has a typical desert climate with very hot summers, cool winters and a limited rainfall.

July is usually the coldest month with an average maximum daily temperature of about 65°F. By late Spring (November) warm days are experienced with average temperatures of 85° to 90°F. January is the hottest month with average temperatures of 100°F or more. The diurnal variation can be as high as 30°F.

The wind system seems to be quite variable, but the writer has an indelible impression of penetratingly cold winds in the winter months. Annual rainfall is low, averaging about 8 inches in the Mulga zone, 10 to 15 inches in the Eucalypt zone and increasing towards the south coast. This rain is brought in by sporadic maritime air masses which are generally derived from tropical cyclones from the north in summer, and from the extensions of southerly storms in winter.

The annual evaporation is enormous and generally is about ten times greater than the precipitation.

Fig. I -3 shows climate data for Leonara, which is near the centre of the Mulga Zone. Temperature and rainfall data based on more than 16 years were used to compile the "average" data which are then compared with similar data obtained during the period of this study from January 1970 to October 1971.

The annual temperature graphs show that the summers of 1970 and 1971 were hotter or longer than usual whilst the rainfall records indicate that less than 50% of the average (8.32 inches) rainfall was experienced during this study period. Rainfall records were also kept at Mt. Clifford, which is 42

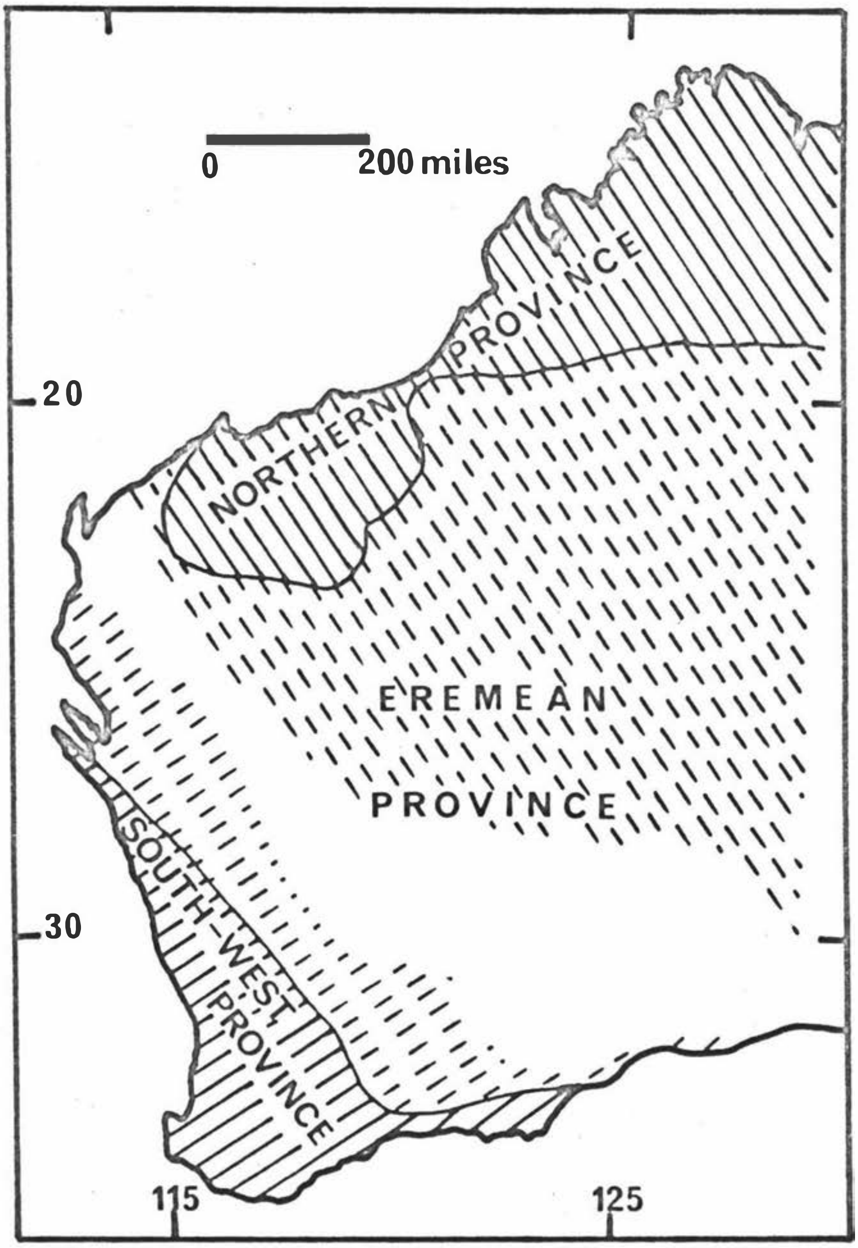


Fig. I-2. The three provinces of vegetation and climate of Western Australia. The Eremean Province is delineated by the rainfall for the four consecutive wettest months being less than 7 in. In the northern part (indicated by broken lines), the four wettest months are January-April. In the southern part the four wettest months are May-August. The middle region (unhatched) has its maximum precipitation between March and June, the two wettest months being March and June. (After Gardner 1942).

miles north of Leonora, and showed that this station received considerably more rain than Leonora. The actual figures for Mt. Clifford/Leonora (in points) were 1970 - 478/363 and 1971 - 548/305. These data give some indication of the extreme variability of the rainfall and emphasises the semi-desert characteristics of this region. It is an unfortunate fact that this study was carried out at the beginning of a drought period which to this day has shown no sign of termination.

This brief account was based on data supplied by the Commonwealth of Australia Bureau of Meteorology and was supplemented by company records.

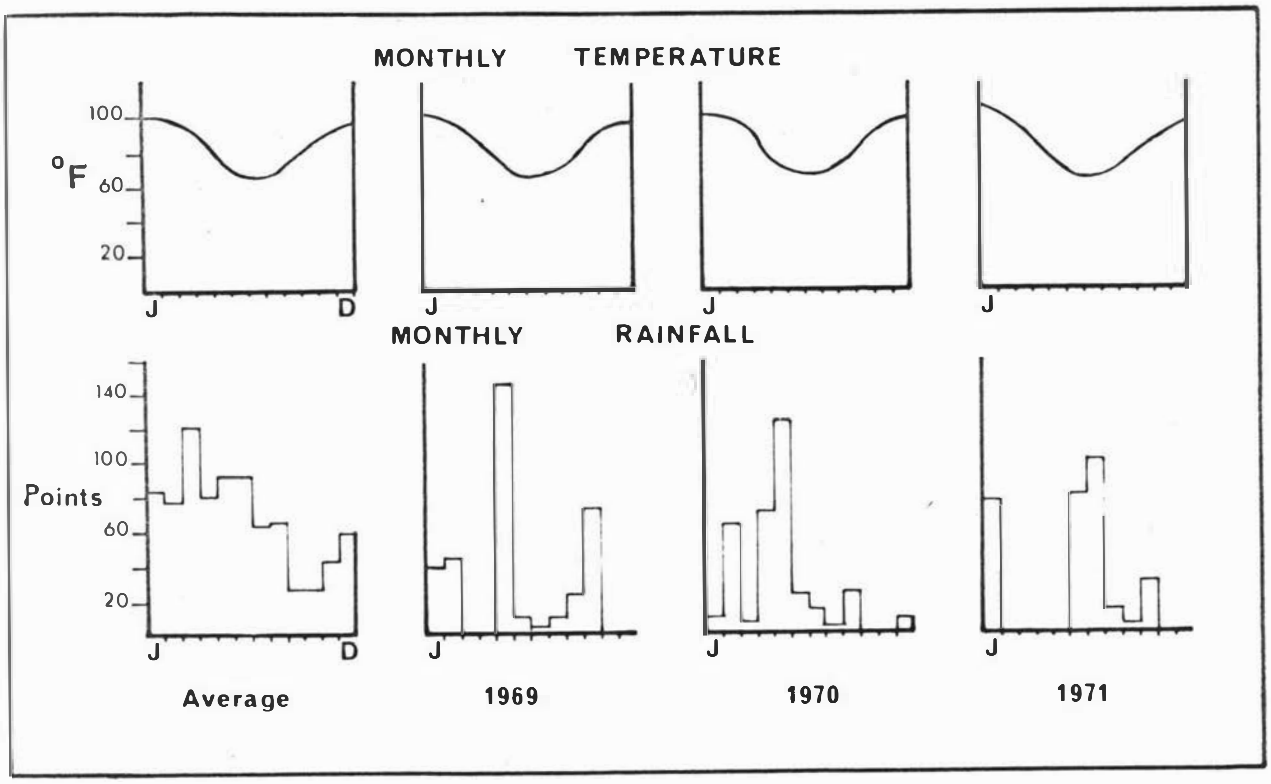


Fig. I-3. Climate data for Leonora. The field studies were carried out during a drought period as illustrated by the rainfall graphs.

(b) Geology.

The study region is situated practically entirely within the Archaean Yilgarn Block which constitutes most of the south-western corner of Western Australia. This block contains approximately 240,000 square miles of Archaean, the greater part of which is granite and granite gneiss enclosing north-northwest trending belts of meta-volcanics and meta-sediments. These areas have become known locally as the 'greenstone belts'. See Fig. I -4.

The 'greenstone belts' have been studied for more than half a century and it is only in the last decade that the nature and origin of these rocks has been understood and analogies drawn with some recent island arc environments (Williams, 1968; Windley and Bridgwater, 1971). Previous workers (Prider, 1961) have compared the Archaean of Canada and Southern Rhodesia with Western Australia and noted the ubiquitous association of basic, often pillowed lavas and serpentinised peridotites.

The greenstone assemblages are metamorphised usually to a Greenschist facies, although higher metamorphic grades are observed in thin belts or towards the margins of larger belts (Prider, 1961; Sofoulis and Mabbutt, 1958).

Detailed studies have recently been carried out on the Yilmia greenstones (McCall and Doepel, 1969), which are located between Spargoville and Kambalda (Fig. I -1).

These authors outlined the following model to explain the association of layered ultramafic or ultrabasic sills with pillowed metavolcanics. Submarine lava flows in a eugeosynclinal environment formed thick lenses and capped their conduits. Later magma pulses resulted in lateral intrusions along suitable horizontal parings to form penecontemporaneous sills. These sills often display layered internal structure and in this case resembled the Stillwater Intrusion, Montana.

The association of basic volcanics, differentiated

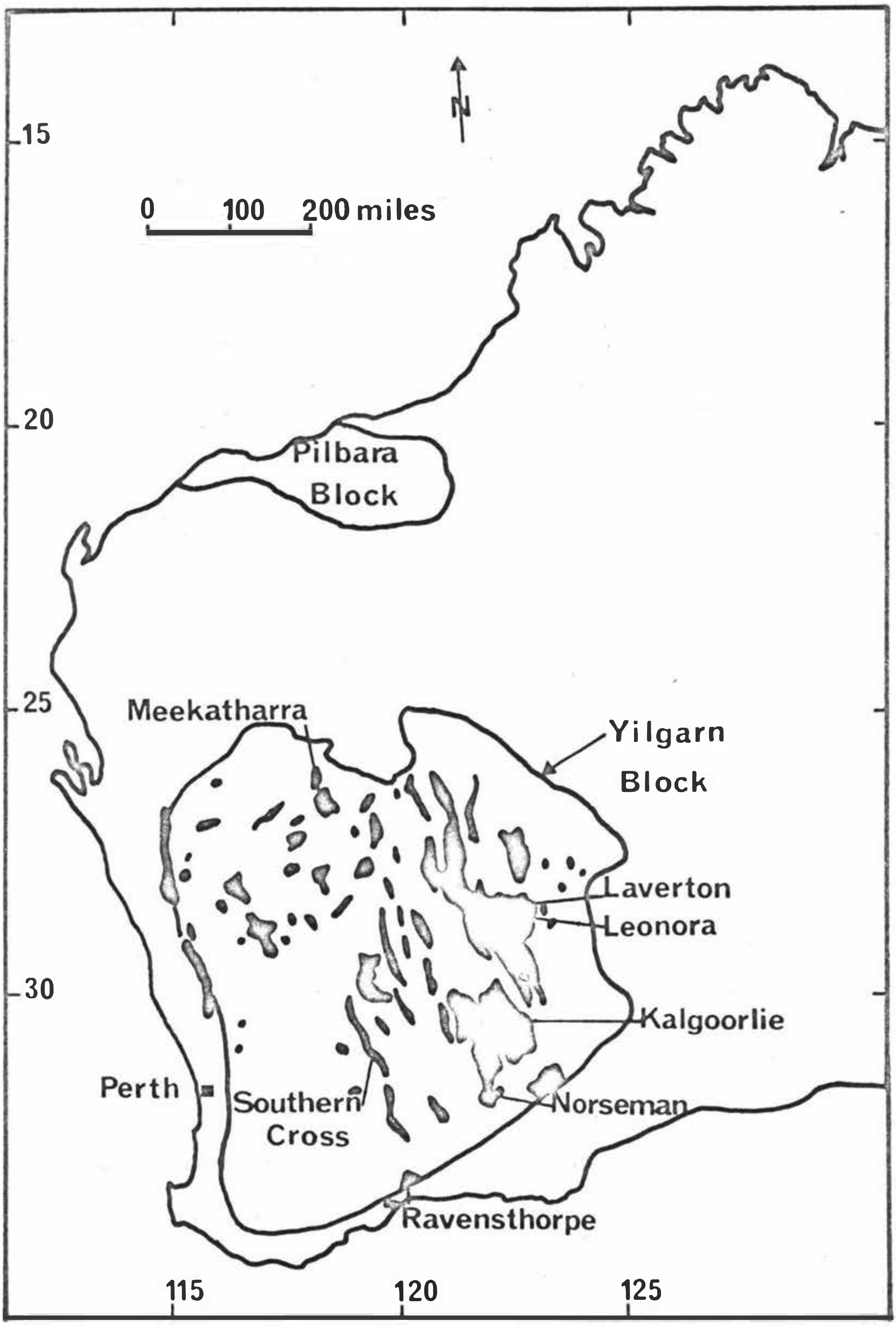


Fig. I-4. Geological map of West Australian Archaean. The 'greenstone belts' are shown blacked-in.

sills and subordinate ultrabasic rocks and pelitic metasediments is repeated several times throughout the stratigraphic sequence of the Kalgoorlie system and suggests an alternation of volcanic eruption with quiescent sedimentation. Radiometric dating (Wilson, et al, 1960; Turek, 1966) indicates a pre-metamorphic age of about 2.6 x 10^9 years for these rocks.

The recognition of layered structure within many sills in the pre-metamorphic eruptive site is recent and was attributed to Western Mining Corp. geologists (Woodall, 1965) by McCall and Doepel (1969).

The granitoid rocks, by comparison, have to date received scant attention. They are usually porphyritic microcline granites but become foliated adjacent to the 'greenstone' belts. In the northern parts of the study region, the Red Bore and Cork Tree areas are situated in the Nullaginian System of Lower Proterozoic Age. This system comprises sediments and volcanics which have age limits of c. 1.8 and c. 2.3 x 10^9 years at the top and base respectively (Dunn et al, 1966).

Over much of the area, the rocks bear remnants of ferruginous and siliceous cappings inherited from a Tertiary (Pliocene) phase of deep weathering (Prescott and Pendleton, 1952). Underlying or exposed bedrock may exhibit extensive kaolinisation and carbonation.

(c) Geomorphology.

The study region embraces several vegetation zones and major geological units, although practically all of the detailed study areas are confined to the areas north of Leonora.

Most of the area lies on the interior plateau of Western Australia more than 1,000 feet above sea-level. There are a few permanent streams near the southern coast but inland the drainage is internal with large salt lakes. See Fig. I -5.

The plateau is a broadly undulating surface formed by planation of the Archaean granites and local relief is provided by the low hills of the 'greenstone' belts, and by uplands of younger (Nullaginian) sediments. It was formerly deeply weathered, but the weathering crust has been extensively stripped, leaving a younger surface on relatively fresh rock. These two elements have been termed the old and new plateau (Jutson, 1934) and have been observed to form scarps more than eighty feet high. The lower parts of the area consist of alluvial plains and broad valleys which become saline in their lower parts and which commonly lead to salt lakes (Mabbutt, 1958).

The land surface comprising the Old Plateau surface had been lateritised, under humid Pliocene conditions and weathering to depths in excess of 100 feet was general. This "lateritic duricrust" was recognised by Woolnough (1927) as being of continental extent and as having developed on a plain which was later uplifted to form the interior plateau of Western Australia. Recent studies have indicated that laterite and silcrete exhibit complementary regional distributions and are probably related by a hydrological process. It is envisaged that siliceous waters migrated from lateritic areas to precipitate silica in drier areas of sufficient evaporative capacity (Stephens, 1971).

The drainage pattern was geologically controlled by an east-west and south-east structural grain.

The south-easterly drainage was directed towards a

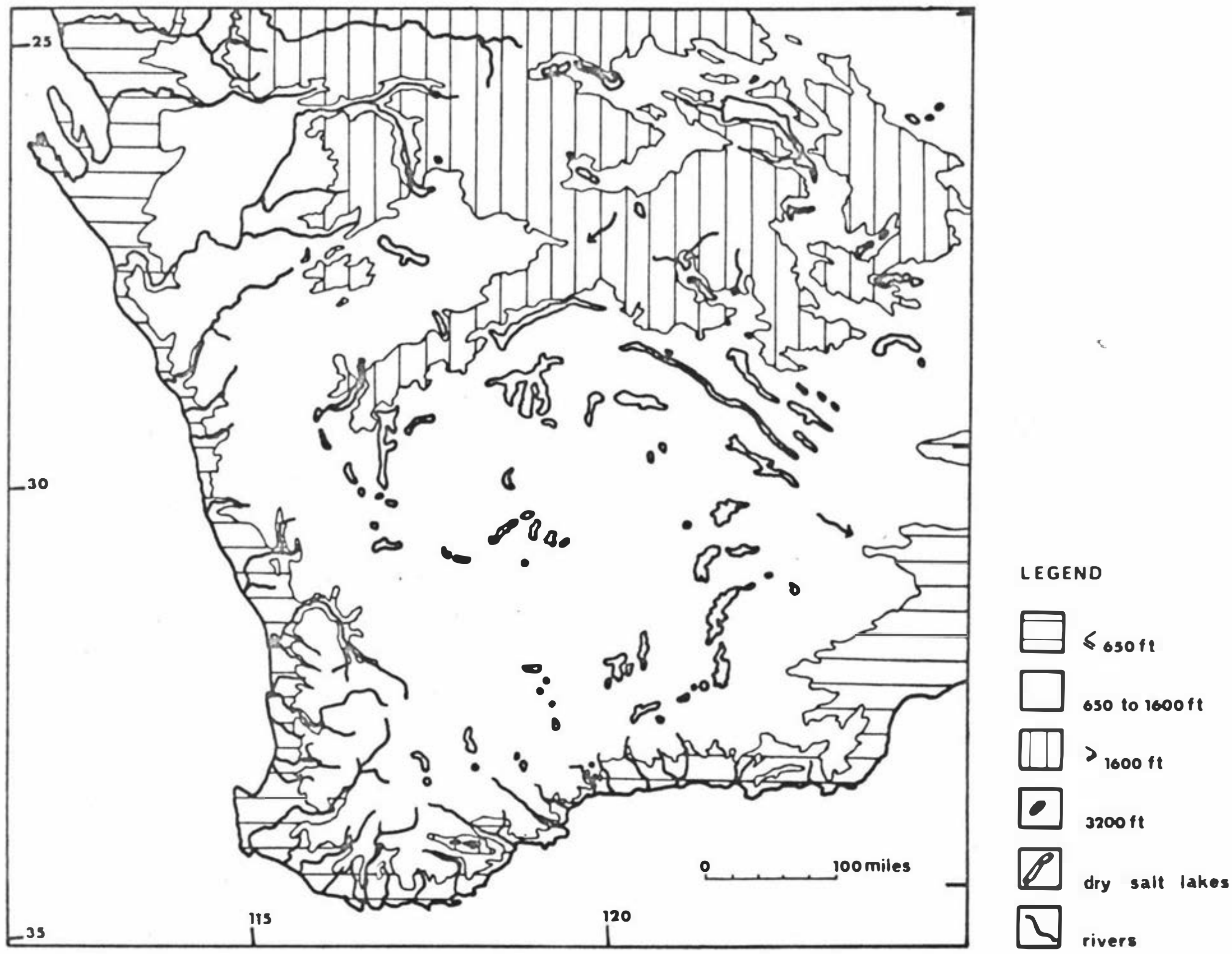


Fig. I-5. Topographic map of Western Australia, showing drainage and dry lakes. The study region is situated on the interior plateau, more than 600 feet above sea-level.

marine gulf on the south coast, and the littoral limestone near Norseman (Clarke, Teichert and McWhae, 1948) may mark a former shoreline and would indicate that the old plateau already existed during the Eocene but that it stood about 1,000 ft. lower relative to sea-level.

Subsequent dissection of the old plateau was probably caused by the uplift of the area to its present altitude, possibly in the late Tertiary (Jutson, 1934). Erosion worked back along the major valleys, eroding the weathering mantle and forming the new plateau. The land forms produced by the advancing younger cycle varied according to the geology and the initial form of the old plateau. On gneiss and granite plains, broad frontal attack on the partially silicified weathering crust, resulted in 'type' breakaway country, and has given rise to "The Terraces" and similar names on regional maps of the Western Australia hinterland.

During the period in which the new plateau was being formed, the climate gradually changed from humid to semi-arid, thus resulting in extensive alluviation in the lower parts of the area. Eventually, the trunk valleys were choked with alluvium and resulted in the formation of "river-lakes". Some of these dry lakes are shown in Fig. I -5. With increasing dessication and lowering of the water-table, the upper layers of the alluvial fills were calcreted.

Much of the alluvium in the region has been cemented to form a siliceous hardpan.

The climate eventually became more arid than at present and widespread wind-sorting of surface deposits took place. Sand movement was generally towards the southeast and resulted in sand plains on the new plateau surface. However, a subsequent increase in rainfall led to the stabilization of sand by vegetation and has caused renewed erosion in the higher parts of the region. The erosion achieved in this latest phase has been very small for sand plains commonly extend to close to the foot of the breakaways, separating the two cyclic surfaces.

The geomorphic processes now at work in this region reflect the semi-arid climate, the low relief, and the low energy of an ephemeral, mainly interior drainage.

Hills and upland comprise 20% of the region and form local watersheds. Run-off is fairly high and hill slopes steeper than 5° are mainly rocky and exhibit pockets of skeletal, residual soil.

The slopes commonly bear remnants of the former weathering mantle and thereby indicate a slow rate of erosion.

The drainage channels of the higher ground give place down-valley to drainage floors which are subject to sheet flow. Such slopes, with gradients between 1 in 100 and 1 in 500, commonly have a contour pattern of vegetation groves. These groves have resulted from an adaptation of vegetation cover to surge patterns of sheet-flow on smooth, gentle slopes, and the associated trapping of alluvium gives rise to a very slight convex slopes separated by longer, concave intergroves.

The extensive stone mantles on the higher parts of these slopes resulted from sheet-flow transport and slight concentration by deflation.

At lower levels in the landscape, with gradient below 1 in 1,000, the alluvium is commonly saline and the fine-textured deposits are liable to severe surface degradation.

The salt lakes are the drainage termini and are subject to flooding after heavy rains.

The sand plain is the most stable environment being restricted mainly to the central eastern areas of the study region. Sufficient vegetation restricts wind movement of sand and run-off is kept to a minimum by the permeable soils.

(d) Vegetation.

The flora of Australia is remarkable for its high degree of endemism of genera and species. This is a result of Australia being the most isolated continent. It is clear that this isolation was provided by continental drift which commenced at the end of the Paleozoic era. However there are strong floral links with other Gondwana countries including South America, India and South Africa.

Several groups of plants were probably of paleotropic origin but they have become so modified that they are no longer recognisable as typical examples. An illustration is provided by the genus Acacia, which comprises over 500 species, of which 400 are indigenous to Australia.

The most primitive form of Acacia is that which possesses compound leaves and *A. farnesiana* is regarded as the archetype and inhabits America, Africa, India and northern Australia. *A. farnesiana*, alone of the Bipinnatae connects the tropical species of this genus with the temperate Bipinnatae in south-western Australia.

From this original stock, a type of Acacia has originated which is characterised by the production of phyllodes, the leaf being represented by the simple flattened leaf-like axis of the compound leaf. It's ontogeny may be observed in any species of the Phyllodineae which number over 300 species in Western Australia. Their highly developed floral economy has enabled them to withstand extreme aridity of the environment.

A general account follows of the vegetation types which occur in the Eremean Province (eremikos (Gr) - Desert). The study region lies entirely within this Province except for Scadden, Ravensthorpe and Hopetown in the south where only brief reconnaissance geobotany was carried out. This account is based largely on Gardner (1942) and is only supplemented where necessary. The Eremean Province (Fig. I -2 covers the vast arid interior of Western Australia and is characterised by an annual rainfall of less than 175 mm which falls mainly between January - April in the north, and March - June in the south.

This province (Gardner, 1942) is the most impoverished, floristically, of the three provinces in Western Australia (Fig. I -6). It is a young flora with its elements derived from the neighbouring provinces, in which the outstanding characteristic is a marked evolutionary epharmonic convergence.

THE FORMATION.

(i) Sclerophyllous Woodland.

In the vicinity of the 225 mm isohyet the loamy soils support a woodland composed entirely of trees about 25 m with an undergrowth of 1 m high shrubs, or there may be a development of shrubby Eucalyptus species known as mallees.

The sclerophyllous woodland forms are everywhere limited by the edaphic factor - nowhere do they occur on sand. The red-sand plains are characterised by *Eucalyptus salmonophloia*, *E. salubris* and *E. longicornis*. In the lake country further to the east, between Widgiemooltha and almost to Balladonia, the number of species increases and includes *E. brockwayi*, *E. leptophylla*, *E. campaspe*, *E. flocktoniae* and *E. oleosa*. Excellent reviews of the Eucalyptus woodlands are given by Elkington (1969) and Gardner (1942).

(ii) Salsolaceous Shrub Steppe.

In the south-east, there is an extensive area of limestone known as the Nullarbor Plain, which supports a vegetation averaging 50 - 100 cm in height and composed chiefly of Chenopodiaceae.

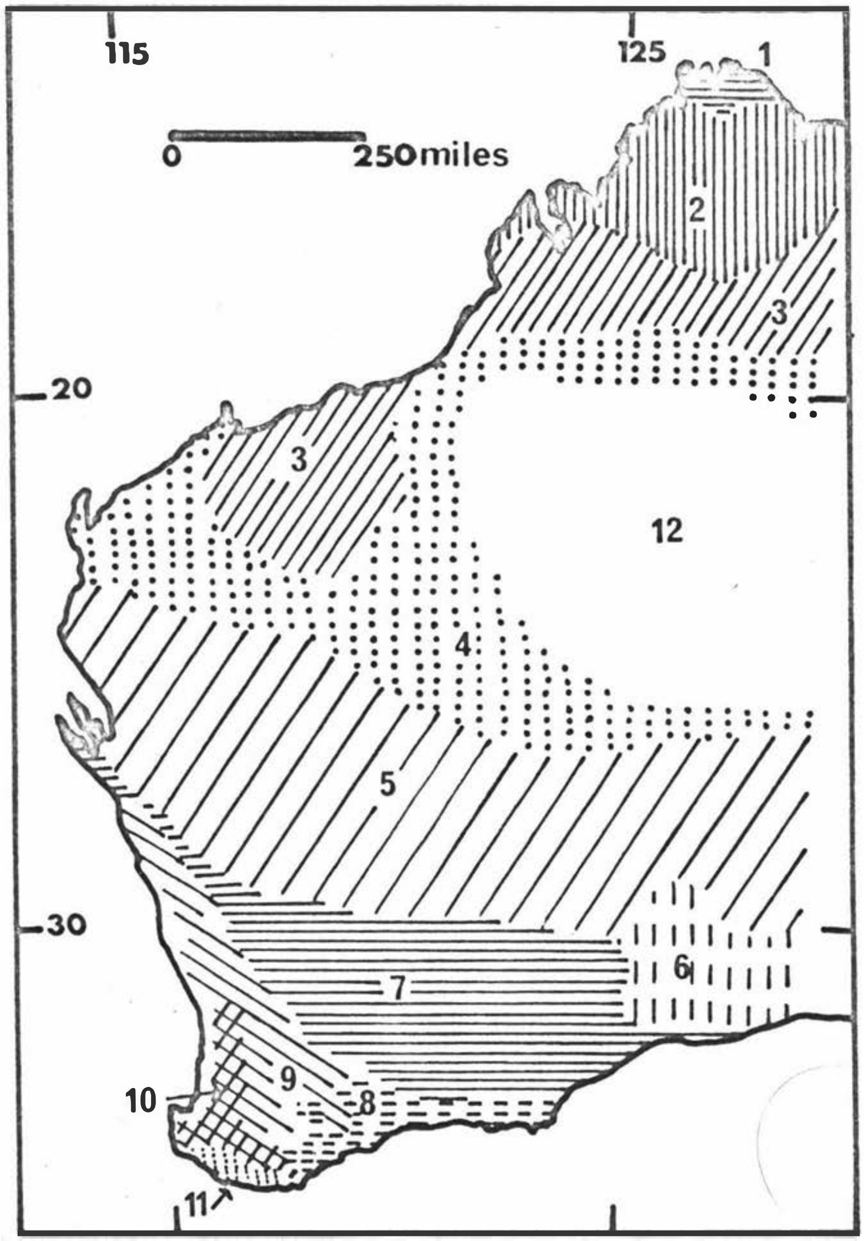


Fig. I-6. The Vegetation Formations of Western Australia.

1. Tropical sclerophyllous woodland.
2. Monsoon woodland, savannah woodland, and riverain forest.
3. Savannah and open savannah woodland.
4. Triodia steppe.
5. Mulga Bush.
6. Salt-bush steppe.
7. Sclerophyllous woodland.
8. Sand-health.
9. Temperate savannah woodland.
10. Sclerophyllous forest ("Jarrah forest")
11. Mesophytic forest (Karri forest).
12. Desert.

(iii) <u>Mulga Bush</u>.

The mulga bush is the most extensive vegetation formation in Australia. The conditions limiting its distribution to the south are not known but are probably related to pluvial-thermal factors. For example the mean temperature for the four wettest months is in excess of $64^{o}F$ whilst for the sclerophyllous woodland to the south, it is less than 64^{o}. Jutson (1934) notes that this line approximates the 10 inch isohyct.

The line of demarcation is remarkably well defined in the field. To the north of Kalgoorlie it is intersected at Goongarrie, a few miles south of Menzies. The Eucalyptus shrubs and trees become more and more scarce and the <u>Acacia</u> species become more dominant, the species being shrubs 3 - 7 metres high with rigid, glaucous phyllodes.

An example of the marked epharmonic development of Eremean species is supplied by <u>Acacia</u>. The common jam tree of the Eucalypt woodland (<u>A</u>. <u>acuminata</u>) has long (7 - 25 cm) flat green phyllodes. On approaching the mulga zone, the phyllodes become narrower, until finally in the mulga bush it merges with <u>A</u>. <u>burkittii</u>, with terete or only slightly flattened phyllodes, and smaller flower spikes. This gradual transition can be observed between Kalgoorlie and Leonora and parallel examples can be observed with <u>Eucalyptus</u> <u>pyriformis</u> and <u>E</u>. <u>kingsmillii</u> and with <u>Eremophila</u> <u>gilesii</u> and <u>E</u>. <u>foliosissima</u>. This epharmonic development is carried out to such an extent in the Mulga country that ultimately only two or three types of growth forms and foliage remain. In general, the broad-leaved plants are either covered with a close indumentum of stellate hairs or are heavily coated with resin. The glabrous leaved shrubs have narrow erect or pendulous leaves which all assume a similar shape.

The <u>Acacia</u> species conform to one of three basic types: those with pinnate leaves inhabiting the watercourses;

those with green pungent phyllodes of "Curara" type with a similar habitat; those with erect or drooping rigid glacous phyllodes - the true "mulga" plants, and those with pendulous flat green phyllodes e.g. A. quadrimarginea.

The Acacias form the tree or tall shrub layer whilst the low shrub layer is usually dominated by the highly diversified species of Eremophila which number about one hundred. Their large blossoms are short-lived but very conspicuous. There is some evidence that this genus originated from a littoral zone, and it is as halophytes that they have adapted to the dry and saline tracts of the Eremea.

The genus Cassia also assumes considerable physiognomic importance in the Eremea and forms part of the low shrub layer. The development of an indumentum of felt has enabled these plants to endure extreme aridity without any loss of leaf surface.

Perhaps the most remarkable tree of the Mulga country, and of the Eremea generally, is the Kurrajong (Brachychiton gregorii). This tree, which attains a height of seven metres, has a spreading crown of large bright-green soft leaves. Its trunk and roots store water which is used in periods of excessive drought; and there is little doubt that this tree is of paleotropic origin.

The seeds of many of the woody elements possess an ability to remain viable for long periods of time, even for a century. In addition some species e.g. Acacia, produce their flowers shortly after rains and thus have no regular flowering season.

The wealth of the ephemeral flora of this region is remarkable. The formation is typically one of widely spaced shrubs with bare exposed soil or rock, but after suitable winter rainfall the whole area is carpeted with an amazing display of annual herbs. These consist mainly of Compositae; with white layers of Helipterum splendidum and Cephalipterum drummondii in alluvial sand, and Eorodia and Velleia in sandy soils.

Other common species include Helipterum battii, Brachycome, Erodiophyllum and vetch-like masses of Swainsona. This brief display of herbaceous floral wealth continues for only a few weeks; two months later only the withered remains of stalks are seen. On the other hand, the summer rains bring an almost equal richness of grasses such as Aristida and Setaria. The mulga-bush formation exhibits this biannual succession to a degree not observed in any other formation in Western Australia. In both cases it is short-lived; without a sufficient rainfall it does not occur and for years no annual species may appear.

The true mulga (Acacia aneura) is the most common species in the mulga bush, and its range extends throughout nearly the entire formation. Over very large areas of flat or undulating country the Acacia species provide a uniformity of physiognomy to which the formation owes its name. The various species so closely resemble each other even when in flower, that it is often impossible to determine accurately the component species, unless pods and seeds are available. It is probable that ultimate research will reduce the number of "species" already described.

The outcropping hills provide a more varied flora. The crimson hop-like fruits of Dodonaea filifolia and D. lobulata, Santalum, and the green-leaved Acacia quadrimarginea provide a strange assembly together with brilliant masses of Eremophila, in an environment so poor in forms.

(iv) The Halophytic Formations.

Throughout the Eremea, salt-lakes and the remains of former ancient river systems are scattered. They are characterised by a distinctive grey vegetation which covers their broad margins. In this vegetation the Chenopodiaceae assume the dominant role. Species of Atriplex, Bassia and Koohia cover the ground with their compact lowly forms. No plant life extends beyond the salt margins which are usually lined with green samphires.

(v) The Triodia Steppe.

Grass steppe occurs on the red sandy soils of the Eremean. It is most typically developed in the areas which receive a summer rainfall. The predominant genus is Triodia, comprising about twelve species. This grass forms dense tussock-like masses which are separated by narrow patches of bare sand. The leaves of all species are pungent-pointed, a characteristic which renders the plants forbidding.

(vi) The Desert.

While, as its name would imply, the whole of the Eremean conforms with the broader definition of what ecologists term desert, there is an area close to the centre of Australia which complies with desert in its more limited sense. This tract however lies beyond the limits of the study region.

A few trees from the Mulga country are found in depressions e.g. Acacia sibirica, A. kempeana, Hakea lorea together with a number of Chenopodiaceae.

EPHARMOSIS AND GROWTH FORMS.

Epharmony (to quote Gardner) is the plant's "growth form" in contradistinction to its systematic form. It reveals itself specially in the habit and in the form and duration of the nutritive organs, but shows to a lesser extent in the reproductive organs. A well-known result of epharmosis is the convergence of systematically removed types; e.g. in Acacia and Hakea, Darwinia and Pimelea. Some species of one genus so closely resemble species of the other genus that, growing together they can only be separated when in flower. The careful climatic grading of the Western Australian flora has resulted in numerous epharmonically moulded species and forms which reach their highest development in the Eremea;

whereby the epharmonic convergence results in the species conforming to a few general growth-form types.

GROWTH FORMS.

(i) Trees and Shrubs.

Trees and shrubs make up most of the vegetation of the Eremea. A growth form becomes dominant in the sclerophyllous woodland and the mulga bush and is common to both trees and shrubs. It is perhaps most typically represented by the jam tree (*Acacia acuminata*), but is consistent both in *Acacia* and *Eucalyptus* throughout the drier areas.

In this growth form, which Gardner (1942) termed the *Infundibular* growth form, the stem, by a system of repeated upward branching, produces a multiplicity of branches and twigs, all attaining more or less the same height, and resulting in a flat or convex dense crown with a light covering of leaves. Whereas in *Eucalyptus* the foliage is pendulous, in *Acacia* it is usually stiff and erect.

This growth form is an adaptation to the desiccating action of dry winds since only a minimum of the leafy area is exposed. It is associated with an erect or pendulous foliage, so that a great number of leaves can be carried without overlapping. This growth form is predominant in the Eremea.

Occasionally in the mulga-bush another growth form is observed. This is the erect-stemmed, horizontally branched form which is typical of acacias of the *A. grasbyi*, and *A. sibirica* type. The simple stem is widely branched with horizontal branches which are again repeatedly horizontally branched to form flat superimposed layers. Thus a series of horizontal planes of leafy twigs bearing short erect pine-like foliage is displayed.

While the infundibular growth form leads ultimately to leaf-reduction or even complete aphylly, the widely-branched plants of the Eremea retain their leaves in an unmodified condition. Such plants rely on a protective layer of hairs or resin on the leaf surfaces, and examples of these growth forms are afforded by the genus Eremophila.

RECENT HISTORY OF THE VEGETATION IN THE GOLDFIELDS.

The history of the sclerophyllous woodland and mulga shrub during the past seventy years has been one of exploitation. Since the discovery of gold some twentyseven million tons of timber have been cut from inland forests, especially around the mining centres, for use in the mines and as firewood (Brockway, 1949). The Eucalypt woodland was characterised by the dominance of E. salmoniophloia but has been largely cut out (Jutson, 1934).

In the Mulga bush zone, the Acacia species have suffered a similar fate.

The sandalwood (Santalum spicatum) has also been severely depleted as it was exported to China. This industry continues at thepresent day on a small scale.

Felling for firewood is no longer allowed. Today all the woodlands are carefully surveyed and are under the protection of the Forests Department at Kalgoorlie.

4. HISTORY OF THE MINERAL SEARCH IN WESTERN AUSTRALIA.

This section outlines the history of the economic mineral search in Western Australia, with particular reference to the areas considered in this thesis.

Gold was first discovered in Western Australia in 1885 and within a decade all the major gold deposits were discovered in an area of one million square miles. Such was the magnitude and success of this mineral search.

The mafic and ultramafic rocks of the greenstone belts, which usually outcrop as low ridges, contain innumerable gold showings. However there were few major orebodies and only six centres produced more than one million ounces.

Gold mineralisation is restricted to the 'greenstone' belts and orebodies are usually localised in favourable structures within 1 mile of the granitic margins. Concentrations of gold were mainly associated with quartz (Sofoulis and Mabbutt, 1958) and usually with accessory amounts of silver, arsenic, antimony, and tellurium.

Up to 1968, 53% of the total gold production of Western Australia was obtained from the "Golden Mile", a small section of ground at Kalgoorlie measuring two miles by one mile (Woodall & Travis, 1969). This pattern of metal distribution implies that the results of systematic exploration for other minerals is likely to result in many uneconomic mineralised areas, a few small mines and a limited number of major deposits.

The extensive gold prospecting activity produced very few indications of base-metal mineralisation. Copper has been mined at Wulamiuna and Ravensthorpe and Meekatharra (Sofoulis and Mabbut, 1958).

Granitic areas, traversed by pegmatitic veins have been reported to contain a large number of minerals including tin, tungsten, tantalum, beryl, mica and even emeralds.

By 1964, gold production in Western Australia fell below one million ounces despite government subsidies. Only four big mining operations remained on the Golden Mile and mining operations are expected to cease by the end of this decade.

The towns on the Archaean Block, and in particular, Kalgoorlie, were given new confidence for the future, when Western Mining Corporation announced the discovery of high-grade nickel sulphide orebodies at Kambalda in February, 1966.

These orebodies were found in ultrabasic units of a 'greenstone' belt and catalysed an intensive exploration effort which rivals the former 'gold-rush' days.

In the years following the Kambalda discovery, several nickel orebodies were discovered and include: Widgiemooltha, Spargoville, Scotia, Nepean, Wildarra, Agnew, Mt. Keith and others. Some of these orebodies have already been brought to the production stage but now an apparent (short-term?) surplus of nickel on the world markets is presently exerting an adverse effect on the development of the West. Australian nickel-mining industry.

Although the greater part of the present exploration effort is directed towards nickel mineralisation in the 'greenstone belts', the mineral potential of the sedimentary-acid volcanic and granitic terrains is gradually being realised and will result in the discovery of copper, zinc and uranium orebodies.

5. PREVIOUS BOTANICAL PROSPECTING STUDIES.

In the following account the previous studies have been considered for convenience in two sections; the first deals with indicator plants and the second with biogeochemical studies. The various aspects of botanical prospecting have been ably reviewed by several workers including Malyuga (1964), Cannon (1960), Warren (1972) and Brooks (1972). Accordingly, this account will only briefly survey the field, with emphasis on Australian studies.

(a) Indicator Plants.

Indicator plants have been used in mineral exploration in Australia since 1895 and even earlier in western Europe. For example, Viola calaminaria has been known to be a zinc indicator for more than 100 years (Raymond 1887) and Linstow (1929) reported up to 1.5% zinc in the ash of this shrub.

Many copper indicators have also been recorded. As early as 1857 Henwood reported the indicator value of Armeria maritima in Wales. Similarly a small blue-flowered mint, Acrocephalus robertii is well known to Katangan geologists as the "copper flower", which is restricted entirely to cupriferous outcrops. Duvigneaud and Denaeyer-de Smet (1963) also reported other copper indicator shrubs, Haumaniastrum robertii and Silene cobalticola, both of which accumulated nearly 0.2% Cu (dry weight D.W.). Two cobalt indicators, Crotalaria cobalticola and Silene cobalticola, respectively containing 530 ppm and 32 ppm cobalt (D.W.) were also found by Duvigneaud (1958). In 1949, G.E. Woodward (Anon, 1959) discovered a copper indicator shrub Becium homblei within Rhodesia that grows in areas of relatively deep soil. This plant is perhaps better known as the "copper flower" of the Northern Rhodesian Copper Belt (Mendelsohm, 1961).

Apparently, this shrub also grows in Katanga and was reported (Duvigneaud and Denaeyer-de Smet 1963) to grow on the margins of cupriferous areas where copper soil levels were only slightly above background levels. The Katangan species of Becium which are indicators of high copper soils include B. peschianum, B. empetroides, B. ericoides, B. metallorum and B. aureoviride.

In Rhodesia, specimens of B. homblei were found to accumulate up to 324 ppm Cu (D.W.) (Reilly, 1967) and(Wild, 1968) found this shrub growing on only five of twenty-eight copper prospects which he examined. However geologists of Rhodesian Selection Trust have used this plant successfully since 1949 to locate large reserves of ore (Cannon, 1971).

Another well-known example of indicator plants is the seleniferous flora of the western United States, which includes certain species of Astragalus. Selenium commonly accompanies uranium in the sedimentary carnotite deposits of the Colorado Plateau, and for this reason selenium indicator plants can be used to locate uranium (Cannon, 1957, 1960). The most useful plants are A. preussi and A. pattersoni which can both accumulate selenium up to 4% in their ash.

Indicator plants have been described for many other elements, including manganese, boron and nickel. Recently two small shrubs, Barleria sp. nov. and Celosia trigyna were found (Cole, 1971) to indicate outcropping nickel/copper mineralisation in the savanna woodland of Rhodesia. Another Rhodesian nickel indicator, Dicoma macrocephala was discovered by Wild (1970) who reported its occurrence on 7 of 28 anomalies investigated. This shrub was renamed D. niccolifera Wild sp. nov. (Wild, 1971).

Many indicator plants mostly shrubs, have been described in Australia for several metals. A tree, Xanthostemon paradoxus has been described in the Northern Territories which accumulates uranium (Debnam, 1955) and it may well prove to be a useful indicator plant.

Polycarpea spirostylis has been used with success in prospecting for copper in the northern parts of Australia. This small woody shrub was first reported in 1858 (Skertchly, 1897) and current reports (Nicolls et al, 1965; Cole, 1968) reiterate the usefulness of this plant in prospecting and also of Bulbostylis barbata and Eriachne mucronata.

In South Australia, indicator shrubs have been reported (Cole, 1964) for lead mineralisation in the lower Cambrian limestones. These included Ptilotus obovatus and Prostanthera striatiflora. The former species was also used to locate cupriferous strata at Pernatty and Ediacara.

Plants have been used as indicators of soil conditions from the earliest days of settlement in Western Australia to aid selection of land for agricultural purposes. However it is only recently that indicator plants have been sought for specific metals.

Elkington (1969) carried out extensive geobotanical studies in the Eucalypt woodlands south of Kalgoorlie and suggested that three shrubs Hybanthus floribundus, Trymalium myrtillus and Ricinocarpus stylosus might indicate soils with high levels of nickel and chromium. Her supervisor M. M. Cole (1971) carried out reconnaissance geobotanical studies in 1960 and more detailed surveys between 1965 and 1969. She found one unidentified shrub species at Widgiemooltha which accumulated nickel. However the indicator value of this plant and its role in exploration was not assessed.

More recently, Nielsen (1972) completed an intensive study, also within the Eucalypt woodland, at Spargoville and concluded that no plant indicators or accumulators of nickel or copper occurred in this area.

Concerning the mulga bush zone, it is evident that no geobotanical investigations have been carried out prior to this study.

(b) Biogeochemical Studies.

The accumulation of certain elements by vegetation was reported by Goldschmidt and Vernadsky over 40 years ago but it was not until about 10 years later that the biogeochemical method began to be used in mineral exploration. Pioneering work was carried out independently in Scandinavia, England, the Soviet Union and Canada. Brundin (1939) undertook investigations on tungsten in Cornwall and even took out a patent for the method.

In the West, the most successful and extensive of these early developments in the biogeochemical method was in British Columbia where Warren and his co-workers began their investigations as early as 1944 (Brooks, 1972). During the following years Warren and Delavault (1950a, 1949, 1955a, 1960) carried out biogeochemical studies on a number of metals including silver, gold, copper, molybdenum, lead, zinc, nickel, cobalt, iron and manganese. Recently, Warren et al, (1964, 1968) showed that the Douglas Fir (Pseudotsuga menziesii) can accumulate arsenic from its substrate. They suggested the possible use of this species to detect arsenic dispersion halos from ore deposits containing minor amounts of this metal. This case illustrates the wider potential of biogeochemical prospecting that may be realised by further investigations. Parallel biogeochemical investigations were carried out in the Soviet Union under Malyuga and Tkalich (Malyuga, 1964; Tkalich, 1959). Official government encouragement has had the result that the Soviet Union has remained pre-eminent in this field in the post-war years. Further research on the biogeochemical method followed by its widespread use in exploration for uranium, was carried out by the U.S. Geological Survey in the 1950s and early 1960s. The work was implemented on the Colorado Plateau, mainly by Cannon and her co-workers (Cannon, 1957, 1960a, 1964) and resulted in the discovery of several uranium orebodies most of which had no surface geochemical expression.

Other investigations carried out in the United States included Harbough (1950) and Keith (1968) for base metals in the Tri-State District; and Bloss and Steiner (1960) who used the biogeochemical method to seek manganese. A recent study (Chaffe and Hessin, 1971) indicated the suitability of this technique for seeking concealed porphyry copper-molybdenum deposits in Arizona.

Webb and Millman (1951) in their studies on the Nigerian lead-zinc belt concluded that this method could assist in the location of buried ore deposits. In Egypt, El Shazly et al, (1971) successfully used Acacia trees to locate lithophile elements including beryllium, lithium and boron and the chalcophile elements, nickel, copper, lead, zinc, and cobalt.

In New Zealand, biogeochemical investigations have been carried out since 1965 by Brooks and his co-workers (Brooks, 1972) on several metals including molybdenum, uranium, copper, lead, zinc, cobalt, nickel, chromium, tungsten and mercury.

Several studies have also been carried out in Australia and include: zinc in Queensland (Nicolls et al, 1965); lead and zinc in the Northern Territories (Cole et al, 1968); and copper in South Australia (Austminex, 1970).

Biogeochemical studies on nickel have been carried out in several countries including Canada (Warren, 1955a), Russia (Malyuga, 1964; Aleskovsky et al, 1959); the United States (Miller, 1961); Finland (Rankama, 1940); and Africa (Cole, 1971a; Wilding, 1965). The results have generally been encouraging.

Similar studies have also been carried out in the Eucalyptus woodland of Western Australia. Cole (1971) and her co-workers undertook detailed investigations which revealed "complex relationships between plant distributions and environmental factors, the understanding of which is prerequisite to the application of geobotanical, geochemical, and biogeochemical techniques in exploration for nickel in this environment".

Cole (1971) also considered that the potential nickel-bearing areas of Western Australia present several major environmental features which might be unfavourable for botanical methods of prospecting. Biogeochemical anomalies were observed over nickel mineralisation but the anomalies were of a low magnitude and were attributed to the sclerophyllous nature of the vegetation.

Elkington (1969) carried out biogeochemical prospecting studies at several localities in these sclerophyllous woodlands and concluded that the usefulness of this technique was limited in the Kambalda area by the apparent unavailability of the substrate nickel, and in other areas did not provide any additional information to that gained by surface soil geochemistry.

Nielsen (1972) concludes from a biogeochemical survey carried out at Spargoville, some 15 miles west of Kambalda, that the nickel content in the bark of several Eucalyptus species was a useful guide to delineating concealed ultrabasic units. More-over, it is apparent that these tree species possess a very unusual ability to accumulate chromium (also in the bark), which characteristically can also be used to locate nickeliferous areas due to the magmatic nickel-chromium relationship.

Several studies on botanical prospecting methods have been carried out in the Eucalypt woodlands of Western Australia. However the present study is the first to be carried out in the Mulga bush zone north of Kalgoorlie where several nickel orebodies have already been discovered.

6. FIELD AND LABORATORY TECHNIQUES.

A. VEGETATION STUDIES.

The distribution of the vegetation was recorded quantitatively in the field by the use of belt transects, which were composed of 100 foot square quadrats. The transects were laid out, either with tapes or using a pre-existing 100 foot grid system and orientated to cross the vegetation associations and the lithologic units of each study area.

Black-and-white aerial photos (1:7200 scale) were used to map vegetation communities over several square miles at some study areas.

All species of trees and shrubs were sample in the orientation surveys. Leaf and twig samples were taken from *Acacia* and shrub species, whilst bark and sapwood chips were taken from *Eucalyptus* and other tree species whose foliage was not readily accessible.

Plant samples were collected with a specially-designed attachment which allowed sampling rates comparable to soils, i.e. about 100 per man-day. Samples were placed in 3 inch x 4 inch kraft bags and oven-dried (50°C) overnight in field camps.

Herbarium specimens were collected of each species for subsequent identification.

B. SOIL STUDIES.

During the initial stages of these investigations soil samples were taken near the base of each plant which was sampled. A -80 mesh (B.S.S.) fraction was obtained usually from a depth of about 6 inches to avoid surface contamination. Sieving was carried out on the site and the sample placed in kraft bags identical to those used for plant samples.

Soil profiles were studied in several areas by means of trenches dug to either 12 feet or bedrock.

pH measurements were made in the field using a C.S.I.R.O. field test-kit. Selected soils were checked in the laboratory using a 1:10 mixture of soil and distilled water which was shaken for 6 hours, allowed to settle overnight and then measured with a separate glass (calomel electrode system).

C. GEOLOGICAL STUDIES.

Much of this work was carried out in previously mapped areas. Where necessary geological mapping was carried out using 1:7200 black-and-white photographs; or in detailed areas using a 100 foot grid system.

Bedrock-chip samples were collected where possible close to sampled plants during the initial stages of this study.

Some highly altered rocks required X-ray diffraction analysis besides trace metal data to confirm identification.

D. GEOCHEMICAL ANALYSIS OF SOIL AND ROCKCHIP SAMPLES.

Soil and rock-chip samples (0.2g) were attacked with nitric/perchloric acids (4:1) in test-tubes suspended over a hot-water bath. The degree of dissolution of the analyte elements was checked on selected samples using concentrated hydrofluoric/nitric acids (1:1) in polypropylene beakers suspended in boiling water. This treatment though slower usually gives improved dissolution of the elements.

Dissolution was adequate for all the metals examined except chromium where it occurred sometimes as spinel which is virtually insoluble under these conditions.

The residue was leached with hot 2M hydrochloric acid for 15 minutes, made to volume (10 ml), and an aliquot was diluted with 0.8% strontium nitrate to allow determination of calcium and magnesium (Elwell and Gidley, 1967).

These solutions were then determined by conventional atomic absorption spectrophotometry using a Varian-Techtron Model AA5 instrument.

E. GEOCHEMICAL ANALYSIS OF PLANT SAMPLES.

Plant samples were ashed at 430°C in a muffle furnace. 0.2g ash was leached with 10 ml 2M hydrochloric acid, mixed, settled and determined by atomic absorption as above.

A rapid method of vegetation analysis (Severne and Brooks, 1972) was developed which involved weighing 1.0g of dry plant material into 60mm x 12mm pyrex test-tubes (Contained in lots of 100 in steel racks) and ashing in a closed muffle furnace overnight at 430°C.

After cooling, 5ml of 2M hydrochloric acid was added to each tube, mixed for 15 minutes on a hot water bath (80°C), allowed to settle (1 hour) and then analysed by atomic absorption as above.

Employing this method plant samples were analysed on a routine basis at the rate of 100 per day per muffle furnace for up to 8 metals.

Specialised techniques, such as selenium analysis are discussed in later sections.

F. ANALYTICAL PRESICION AND ACCURACY.

(i) Precision.

This was considered as the overall reproducibility of the dissolution and analysis scheme. To evaluate this parameter, a set of representative soil and plant samples were selected from areas of varying characteristics and 10 replicate analyses were made on each sample for nickel, copper, cobalt, chromium, zinc, manganese, iron, calcium and magnesium. The precision was adequate as no one value deviated by more than 10% from the mean. Two of these standard samples were incorporated in each batch of unknown samples in order to monitor any inter-batch fluctuations.

Aqueous standards were prepared from Analytical Grade or Spectrographically - pure reagents (Johnson, Matthey & Co. Ltd.) and stored in polythene containers (1000 ppm in 2M HCL) and diluted prior to use.

(ii) Accuracy.

Accuracy is the degree to which the true amount of a substance present in a sample can be determined. Where a set of data is being evaluated on the basis of relative magnitudes of each value within the set, as in this thesis, precision rather than adcuracy is important, assuming that the relative accuracy for each measurement is constant (Meish, 1964).

By analysing the standard diabase W-1 (Fairbairn et al, 1951) a measure of the analytical accuracy was obtained. In common with other workers (Fletcher, 1970; Timperley, 1971), the atomic absorption determinations of the transition metals were too high when compared with accepted values.

This error was almost certainly due in large part to "scattering". This is caused by a high solute concentration in the aspirated solution as the solid particles reflect the incident radiation from the lamp away from the slit causing an apparent absorption. This effect has been studied in some detail (Billings, 1965).

Gidley (1964) showed that scattering was a function of wavelength and that it followed an approximately dependence i.e. at short wavelengths the problem is greatest. It was found that calcium and iron caused the most scattering for all the analyte metals investigated, and the relative accuracies for different samples were dependent on the way in which their calcium and iron contents were varied.

Scattering was most important for analyte metals whose absorption lines lie in the wavelength region less than 3000Å. The analytical lines (Å) used for the various metals were:- nickel 2320; cobalt 2407; copper 3247; zinc 2138; chromium 3578; iron 2483; calcium 4227; manganese 2794; and magnesium 2852.

The accuracy of the analytical data presented in this thesis was considered adequate for all the metals at the usual concentrations encountered, except cobalt. Plant ash and soil samples contained apparent cobalt concentrations about 20 ppm and 50 ppm respectively. Scattering was shown to account for more than 10 ppm. It seemed that interference from other mechanisms, such as molecular absorption, was also present.

SECTION II

COPPER AND NICKEL IN THE MURCHISON REGION

1. RED BORE COPPER PROSPECT.

A. INTRODUCTION.

(i) Location.

The study area is about 100 miles north of Meekatharra (see Fig. I -1) and is reached by a dirt road which trends eastwards from the Great Northern Highway for some eight miles. The entire area lies within the Govennment 1:50,000 Doolgunna (Zone 2, sheet 278) map sheet. This preliminary survey was carried out in late summer (April) of 1970.

(ii) Climate.

The annual rainfall is nearly 10 inches and the wettest month is usually March.

(iii) Geology.

The Red Bore Prospect lies within the Nullagine "system" of lower Proterozoic age. Dolerites, quartzites and finer grained sediments are the usual lithologies encountered.

In the 1960s the local station owner discovered the Red Bore Gossan; see Plate II -1. This gossan assayed at 0.7% copper, contained visible malachite flecks, and appeared to be at, or near the contact of a dolerite unit with weathered yellow-green shales.

A geological sketch map is shown in Fig. II -1 and was compiled using a 1:7200 aerial photograph.

(iv) Topography.

This area forms part of a broad watershed on the interior plateau of Western Australia. It consists mostly of extensive plains with low hill ranges.

In the immediate environment of the Red Bore Prospect relief is provided by a quartzite ridge, several hundred feet thick, less than a thousand feet south of the gossan.

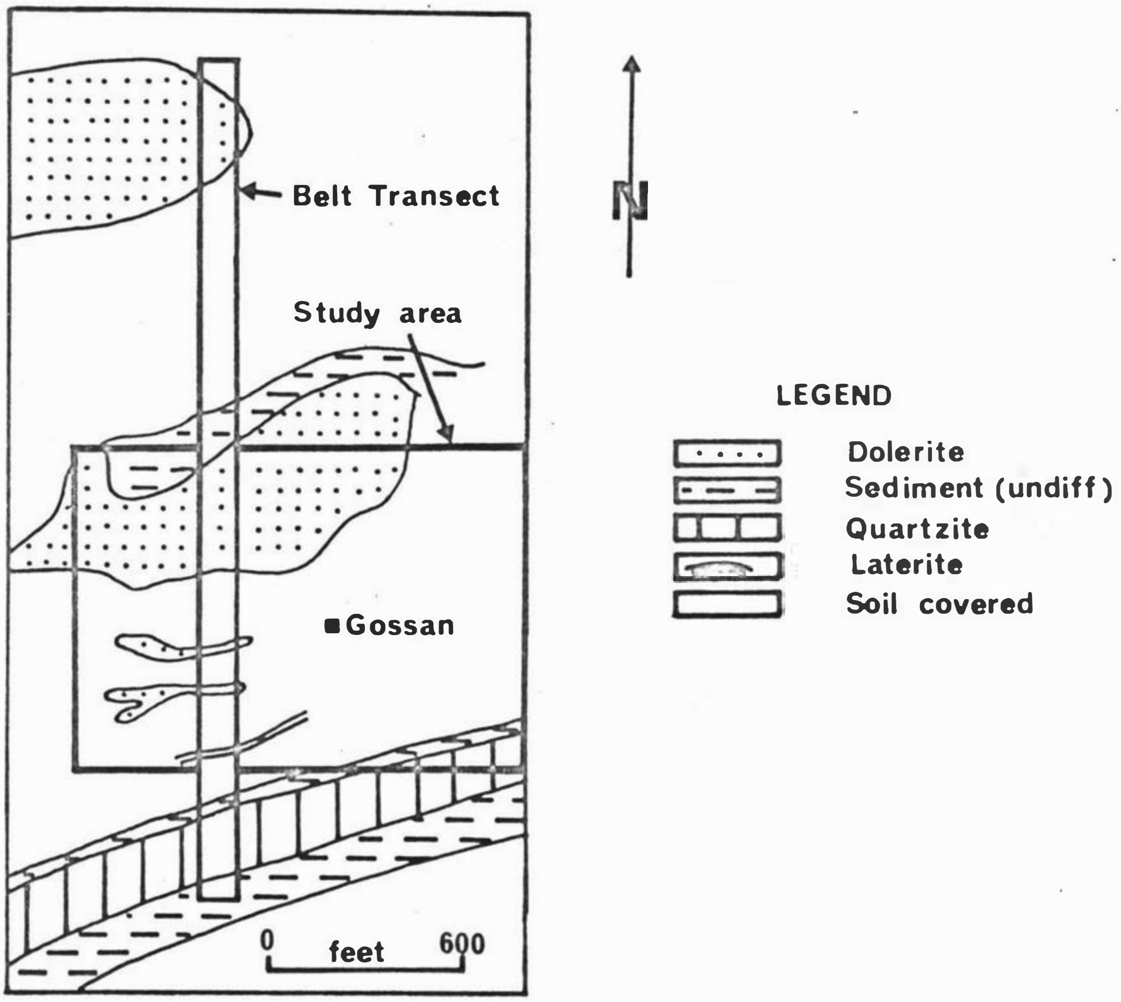


Fig. II-2. Geoligical sketch map of the Red Bore Prospect, showing also the position of the geobotanical belt transect and the geochemical sampling area.

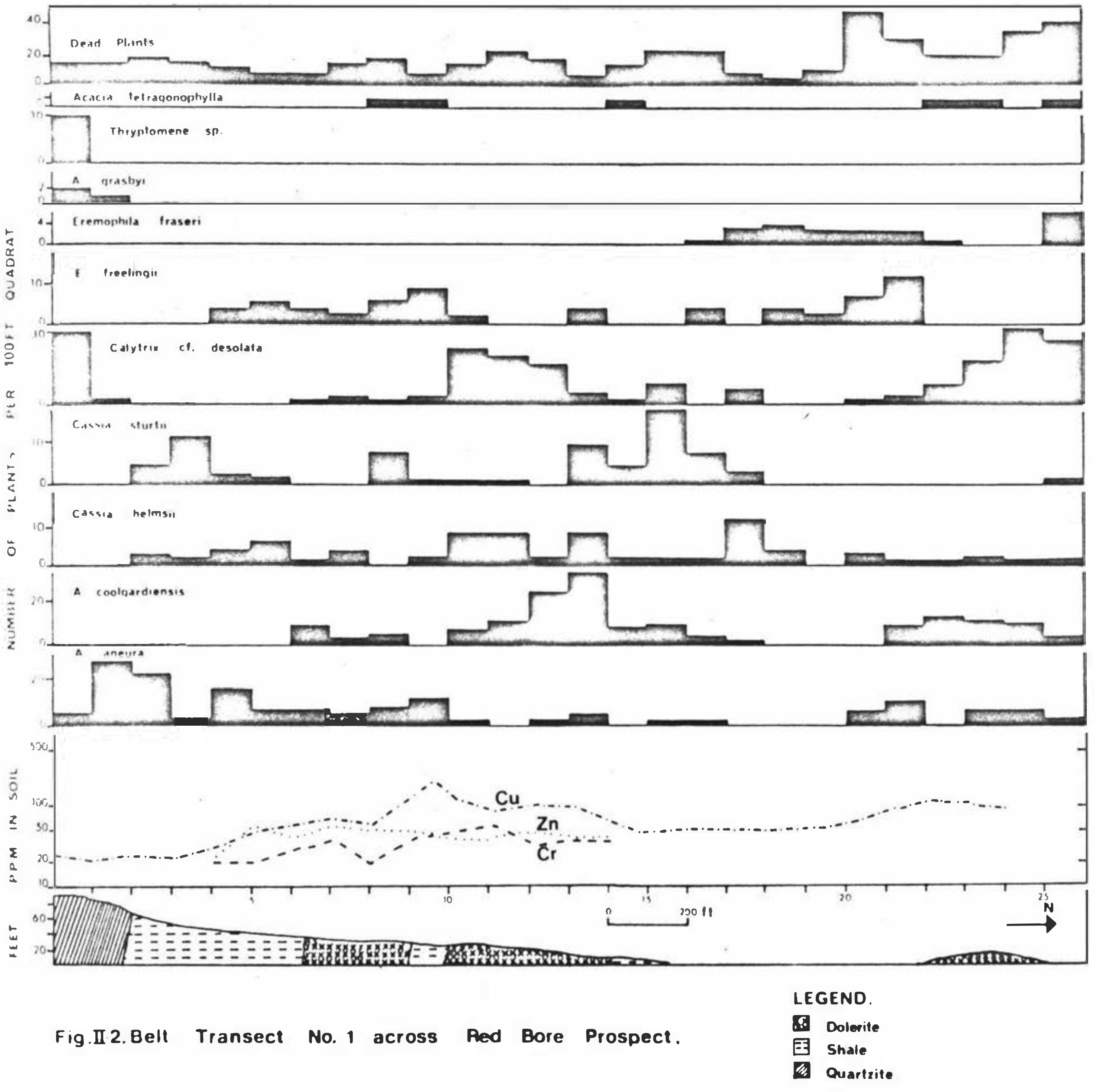


Fig.II 2. Belt Transect No. 1 across Red Bore Prospect.

The density of dead plants was recorded but did not appear to be related to the geochemical environment.

It is apparent from the transect diagram (Fig. II -2) that the tall shrub *Acacia coolgardiensis* is restricted to outcropping dolerites. This finding was confirmed by subsequent reconnaissance over the surrounding terrain. *Acacia aneura* is well distributed throughout this area but has a lower density over dolerite outcrops. Its dominant position in the tree layer is illustrated by Plate II -2 which is a view over the prospect area, looking north from the quartzite ridge.

The overall vegetation density decreased in the alluvial tract between the dolerite outcrops. This effect was considered to be due to the unfavourable physical characteristics of the soil. There was an absence of surface scree and accordingly the surface soil would have lower moisture retention properties than adjacent areas.

Similar belt transects orientated over the actual gossans failed to find any "indicator" plants. However, due to the drought season the ephemeral flora was not observed.

C. BIOGEOCHEMICAL STUDIES.

(i) Soil Geochemistry.

In order to evaluate the biogeochemical data, it was necessary to observe the secondary dispersion of copper in the soils from the outcropping mineralised zone.

Drilling indicated that the gossan represented a steeply-dipping, narrow (ten feet) mineralised zone, with about 2% copper, 0.04% zinc, and 0.005% lead, on a dolerite-shale contact. Although the gossan averaged about 0.7% copper, the associated surface soils (-80 mesh B.S.S.) contained a maximum of only 0.09% copper. Soils were sampled on a 50 x 200 foot grid at a depth of three to six inches. The acid nature of these soils (pH 6 to 7) resulted in significant lateral dispersion of the copper as seen in Fig. II -3. The dispersion of cold extractable (2.5% acetic acid) copper exhibited a similar but slightly larger pattern and the anomaly contrast was greater. The isoconcentration contours were selected by consideration of the frequency distribution of the data, and interpreted as possibly anomalous and definitely anomalous threshold values.

(ii) Biogeochemistry.

Leaf (phyllode) and twig samples of all tree and shrub species were analysed for copper and cobalt, nickel, chromium, zinc, manganese, calcium and magnesium. The analytical data for soils, rock-chips and plants were examined initially by computor using correlation analysis and, in detail by graphing the significant relationships. Cumulative-frequency plots were examined but provided no additional information.

No copper accumulator plants were found, and this result suggests that none of the observed plant species is a copper indicator plant. Similarly, Brooks (1972) has suggested that an indicator plant may display an unusually high concentration of the metal sought.

Acacia aneura was the only suitable plant for prospecting purposes as other species, especially *A. coolgardiensis* did not have the prerequisite pervasive distribution.

The copper content in the phyllode (leaf) ash of *A. aneura* indicated the substrate distribution of copper with more than adequate precision. Copper values rose from background (120 ppm) to 620 ppm over the gossan. The biogeochemical data are shown in Fig. II -4. The isoconcentration contour values were selected as for the occasional absence of *A. aneura* at a sampling site prevented closure of the isograds.

All other biogeochemical data for *A. aneura*, and for the other species, provided no useful information to aid location of the bedrock mineralisation. It was surprising that the copper content of the twig ash of *A. aneura* gave absolutely no indication of the gossanous zone.

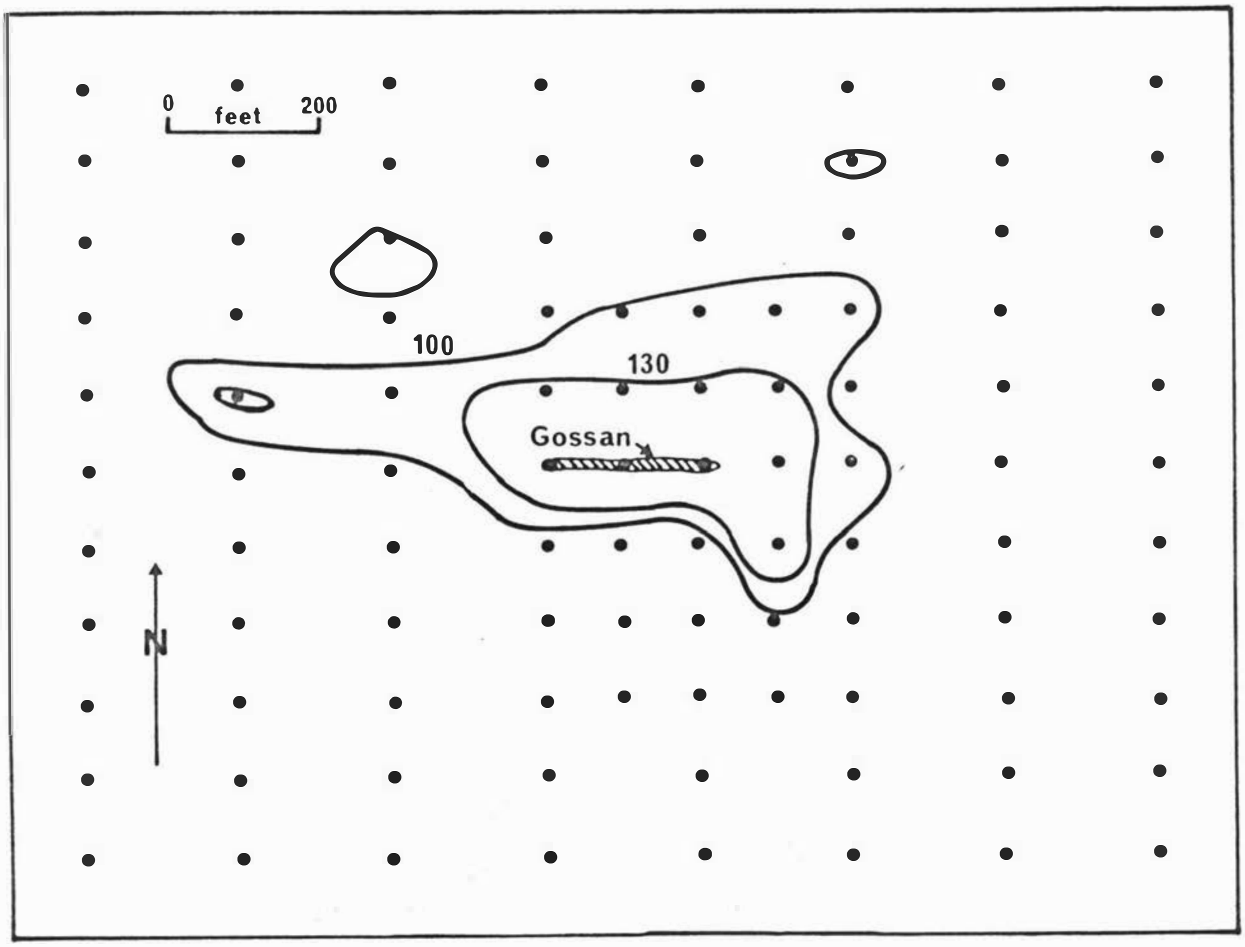


Fig. II-3. Geochemical soil copper plan of Red Bore Prospect. Soils were sampled at 6 inch depth and the -80 mesh fraction analysed for total copper. Iso concentration contours representing thresholds of possibly anomalous (100ppm) and anomalous (130ppm) values are shown. Threshold values were derived from consideration of cummulative frequency and frequency distribution diagrams.

Comparison of the biogeochemical and soil geochemical data (Figs. II -3 and II-4) reveal two important facts. The first is that the biogeochemical anomaly contrast (5) is much lower than the soil copper (total) contrast (18) which is, in turn considerably lower than the cold extractable copper contrast (93). The low magnitude of biogeochemical anomalies has been discussed by other workers (Cole, 1971) and in this environment was attributed to the sclerophyllous nature of the vegetation. A plot of leaf ash copper versus soil copper suggested that a maximum concentration of copper in the phyllode ash was approached at about 500 - 600 ppm. It is apparent that the normal biological restriction of trace metal uptake imposes a definite limitation on the degree of association between plant and substrate metal concentrations.

The second observation is that a small but significant biogeochemical anomaly exists about 500 feet northeast of the gossanous zone. These values initially were not believed. Accordingly, soils and _A. aneura_ were resampled 6 months later only to obtain essentially the same results as before. Bed-rock chip sampling was undertaken, as soils were generally less than 15 inches deep, and subsequent analysis revealed a pronounced bedrock copper anomaly with a maximum (190 ppm) value coinciding with the biogeochemical anomaly. The soil sampling revealed no trace of this bedrock feature. The biogeochemical data provides a preliminary hint as to the potential of this method in locating buried mineralisation.

D. CONCLUSIONS.

In this type of environment with acid, leached soils, it is apparent that soil geochemistry is a very suitable technique for locating similar cupriferous zones.

The biogeochemical method is considered to be comparable to conventional soil geochemistry in this essentially outcropping area.

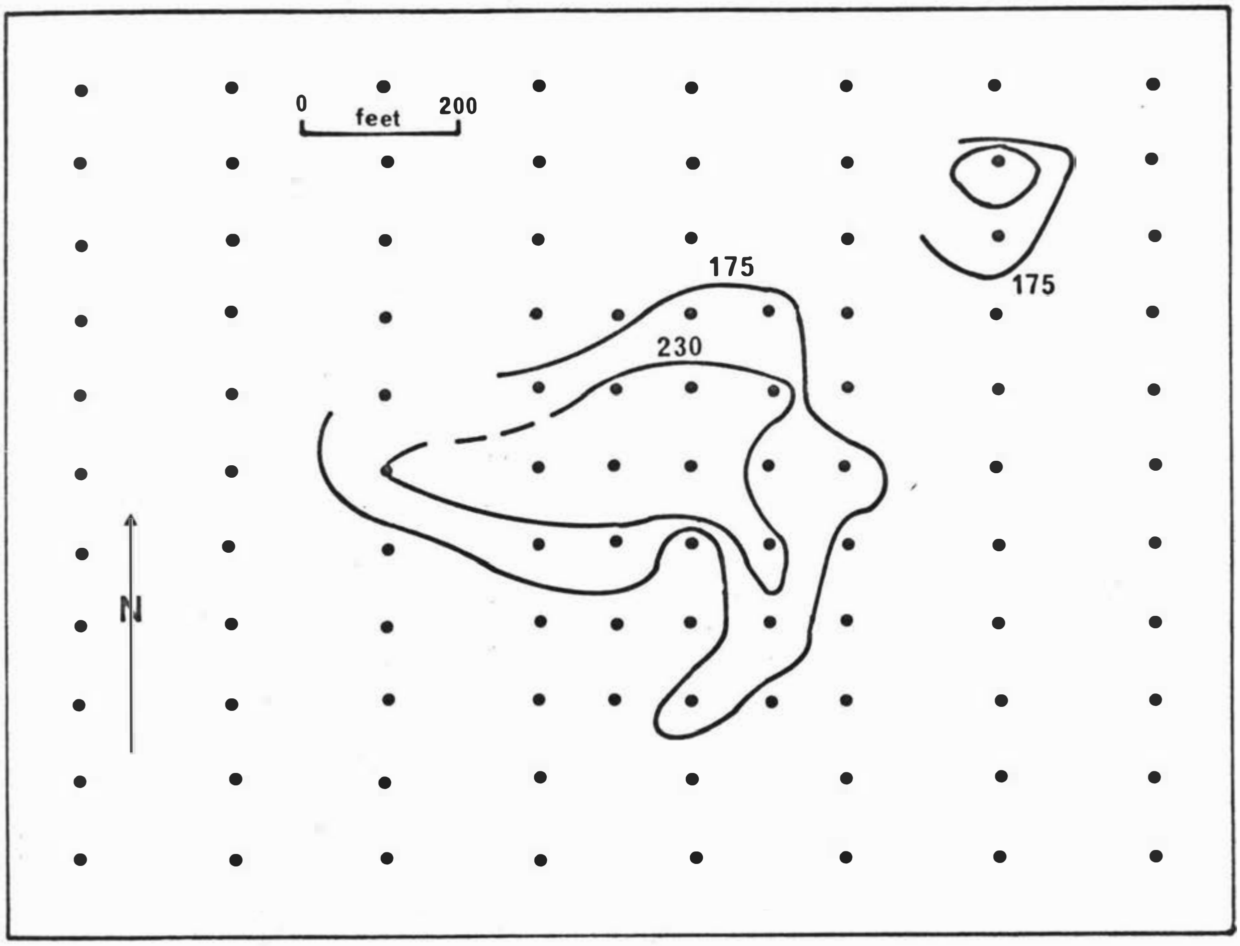


Fig. II-4. Biogeochemical copper plan of Red Bore Prospect. Leaf samples of Acacia aneura were ashed and analysed for total copper. Iso concentration contours representing possibly anomalous (175ppm) and anomalous (230ppm) values are shown.

However, a degree of caution is required in the interpretation of the biogeochemical data. It is apparent from this "case history" that the actual values of the leaf ash copper have little, if any, direct relationship to the bedrock copper concentrations. A biogeochemical anomaly indicates an anomalous metal concentration in the substrate but, at the "present state of the art", does not define its magnitude.

The results obtained at the Red Bore Prospect, being the first obtained in this study, were considered to be highly encouraging. However, it was realised that the value of the biogeochemical method lay in its ability to detect buried mineralisation, which has little if any surface geochemical expression, and where conventional surface techniques would be inadequate.

There is one aspect of the geobotanical survey over this copper prospect which requires further study. It involves evaluating the 'indicator' role of the ephemeral flora. As mentioned in the introductory section these, often colourful, plants may not be seen for upwards of a decade but a survey at the appropriate time may be well rewarded.

2. CORK TREE COPPER PROSPECT.

A. INTRODUCTION.

(i) General.

Following the success obtained with the biogeochemical survey at the Red Bore Copper Prospect it was decided to test the technique in an area containing known subsurface copper mineralisation. The Cork Tree Copper Prospect was the only available area and, although not entirely appropriate for this survey, an investigation was carried out in the Spring (October,) of 1970.

(ii) Location.

The copper prospect is 17 miles east of Red Bore and 18 miles west of Lake Gregory. Abandoned copper workings are seen along the road to the Thaduna Copper mine which is some 12 miles to the north-west of Cork Tree Prospect. The study area measured 4000 feet east-west by 2000 feet north-south and is located on the southern flank of a drainage tract which is characterised by occasional cork trees (Hakea Lorea).

(iii) Geology.

The prospect is situated in an acid-volcanic/sedimentary terrain of probable Nullaginean (Lower Proterozoic Age), and the supergene copper mineralisation is concentrated along fracture planes. It is lower in the landscape than the Red Bore Prospect and is close to the salt-lake drainage termini. As a result the Cork Tree Prospect area is free of laterite and rock outcrop is minimal and usually silicified thus rendering identification of the original rock-type rather tenuous at times. Much of the area is covered by upwards of twenty feet of alluvial-colluvial material.

(iv) Topography.

Topography is very subdued with slopes typically less than 1°. The best indications of slope are provided by vegetation and scree distribution. Very low ridges have rocky crests of silicified volcanics and sediments which are often brecciated. The silicification, especially along breccia zones, is considered to be the causal relief factor.

Due to the low position in the drainage system, the environment is saline and soil pH is close to neutrality.

B. GEOBOTANICAL STUDIES.

A broad water-course, about a half mile wide, trends south-eastwards through the study area as shown in Fig. II -5. It is characterised by a relatively dense vegetation but away from the creek system, which seldom flows with water, the vegetation is sparse. Aerial photographs (1:7200 scale) were used to map the vegetation associations (Fig. II -5).

The alluvial (Creek wash zone) areas are characterised by a dominant tree layer composed of Acacia aneura with occasional specimens of A. tetragonophylla, Hakea arida, H. lorea (the cork tree), Pittosporum phillyraeoides and Grevillea striata. A few low shrubs include the species Kochia pyrmidata and Rhagodia spp.

The flanks of the drainage tract are marked by a fringe zone of tall shrubs comprising Templetonia egena, Eremophila youngii and E. duttoni.

Occasional tree species include Acacia victoriae A. aneura and A. tetragonophylla. The ground layer contains Kochia triptera and K. pyrimidata.

The salt bush zone is comprised wholly of halophytic shrubs usually less than 12 inches high. Deflation has removed the exposed soil between these shrubs so that each plant is now sited on a mount several inches high.

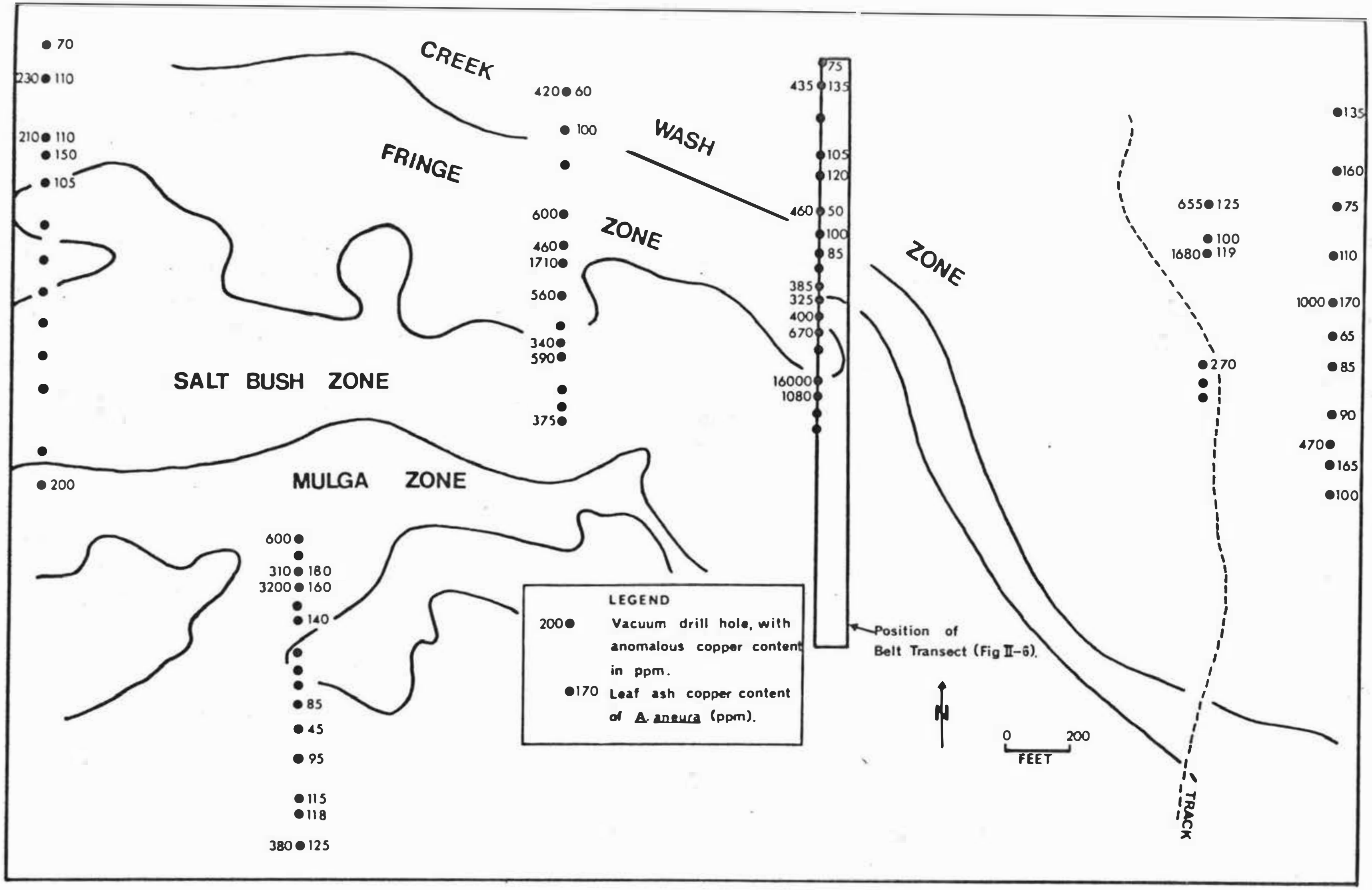


Fig. II-5. Plan of Cork Tree Copper Prospect. The anomalous copper values obtained in drill-holes are shown, along with leaf copper values of <u>Acacia aneura</u>. The vegetation zones and the position of the belt transect are also indicated.

Superficially the salt bushes are very similar in appearance. However several species are present and include _Arthrocnemum halocnemoides_, _Arthrocneumum sp._, _Hemichroa diandra_, _Frankenia setosa_, _Bassia articulata_ and _Kochia triptera_.

The mulga zone is dominated by _Acacia aneura_ with _Kochia triptera_ and _Rhagodia sp._ in the ground layer. The mulga zone, as shown in Fig. II -5, occupies a low ridge crest of rocky ground which slopes gently to north and south. The ground is covered with siliceous scree which decreases in size and density away from the rocky crest zone. The creek wash zone is clearly marked by the brown silt which contrasts sharply with the silicitied pale-coloured colluvial material. Plate II -3 illustrates the low 'saltbush' shrubs with _A. aneura_ of the mulga zone in the background.

Fig. II -6 shows the geobotanical data obtained from a belt transect, the position of which is shown on Fig. II -5. The abrupt northward limit of the halophytic shrubs _Hemichroa diandra_ and _Frankenia setosa_ by the creek wash alluvium is evident. It is also apparent that _Acacia aneura_ has a limited distribution in this environment and these is a large area of the landscape (the saltbush zone) which lies between the ridge crests and the drainage tracts, within which _A. aneura_ and all other tree species are absent.

C. BIOGEOCHEMICAL STUDIES.

This copper prospect was found by a regional geochemical survey measuring cold extractable copper in surface soils. Vacuum drilling was carried out along north-south traverse lines and holes which encountered anomalous copper values are indicated. See Fig. II -5. This drilling revealed erratic secondary copper mineralisation with up to 1.6% copper, generally at about 25 feet below the ground surface.

Plant samples (leaf, twig, of several species) were collected alongside the drill-holes to enable correlation

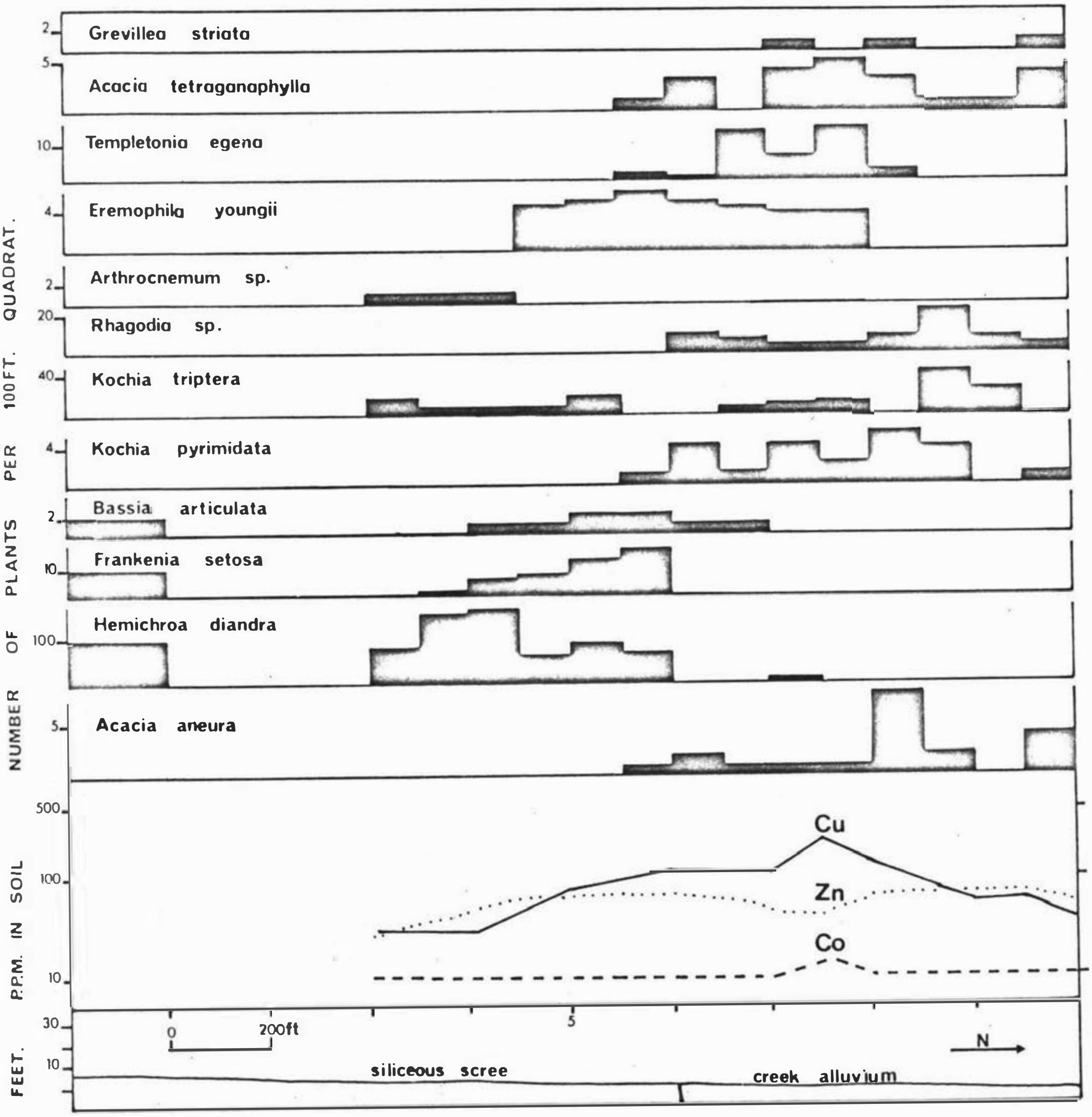


Fig.II-6. Belt Transect No. 1 across Cork Tree Prospect at 137100E.

of plant-drill hole copper data. *Acacia aneura* was sampled wherever possible. All species were analysed to determine whether any copper-accumulating species were present. The analytical data were graphed to determine the distribution of copper values. The drill data were bimodal and skewed. It was interpreted that the sediments averaged 80 ppm, the rhyolites averaged 200 ppm and anomalous (mineralised) values exceeded 260 ppm copper.

Data for the leaf ash of *Acacia aneura* indicated that possibly anomalous copper values exceeded 160 ppm and this result compares well with the figures derived for Red Bore (175 ppm). However the maximum copper value obtained at Cork Tree (280 ppm) is considerably less than the Red Bore maximum value of 620 ppm copper.

Generally, there were insufficient samples of the other plant species to allow firm interpretation of the results. Copper values were at background levels, ranging from 50 to 150 ppm (ash). However the two samples of *Eremophila duttoni* each contained 300 ppm copper in leaf ash and were growing over subsurface copper mineralisation.

Analytical data for all elements in twig ash and metals other than copper in leaf ash were of no aid in locating the subsurface copper mineralisation. It was apparent that the halophytic shrubs of the saltbush zone, which maintained a near constant 50 ppm copper ash, were incapable of indicating 1.6% copper occurring 25 feet below the ground surface.

As expected the leaf ash oopper content of *A. aneura* reflected the substrate mineralisation in the mulga zone (see Fig. II -5). However, in the creekwash zone *A. aneura*, did not appear to reflect faithfully substrate copper values. The drill data revealed that the depth of alluvium varied from 5 to 80 feet over very short distances and the copper mineralisation occurred as isolated irregular blocks or lenses which appear to be related to the subsurface bedrock topography.

The data did suggest however, that anomalous copper values at a depth of 20 feet or more could be reflected by anomalous values in *A. aneura*.

D. CONCLUSION.

No copper indicator plant was found in this area and this is not surprising as surface soil values rarely exceed 200 ppm copper.

The biogeochemical survey was based primarily on *Acacia aneura* as its distribution was greater than other plant species. However in this environment the distribution was too limited to be of practical value in exploration for subsurface copper.

This copper prospect did provide confirmation of *A. aneura's* ability to reflect buried copper mineralisation but such mineralisation would have to be of substantial thickness (greater than 10 feet) to ensure a biogeochemical anomaly. It was considered in some cases at Cork Tree that the tree roots were passing through narrow mineralised lenses. If these mineralised areas were sited above the absorbing zone of the roots (which is generally close to the root tips) it is possible that a biogeochemical anomaly would not be observed. This interpretation is based only on the Cork Tree Prospect where mineralised zones were taken to include mere geochemical concentrations of a few hundred ppm copper.

Photo-interpretation would have indicated the inadequate distribution of *Acacia aneura*. The Cork Tree Copper Prospect was the only area known to contain subsurface copper mineralisation and despite the unfavourable environment the biogeochemical investigations confirmed the potential of *Acacia aneura* in copper exploration.

3. SHERWOOD NICKEL PROSPECT.

A. INTRODUCTION.

(i) Location.

This prospect straddles the Great Northern Highway three to four miles north of Meekatharra.

(ii) Climate.

Detailed climatic data are available for Meekatharra. The average annual rainfall is 9.17 in. and the wettest months are in the late summer. Mean monthly maximum temperatures range from 100°F to 70°F and frosts are very rare. Humidity is generally low but evaporation is high (100 inches per year).

Rainfall effective for initiating plant growth occurs on average three times per year and usually between the months of January and August. The length of the subsequent growth period is usually less than 4 weeks. However vegetation on areas of shallow soil or on steep slopes would have a comparatively shorter growth period whilst that on deeper soils or on areas which receive frun-on would have rather longer growth periods.

Drought years are experienced frequently and can last for 5 years or more.

(iii) Geology.

Meekatharra is a former gold-mining centre and is sited on a greenstone belt. The Sherwood area is underlain by: ultrabasic units which are represented by talc-carbonate rocks; acid volcanic tuffs and fine-grained sediments. The geology (1:7200 scale) is shown in Fig. II -7.

Occasional small granitoid outcrops are seen but most of the area is blanketed with alluvial-colluvial material. The striking feature of the area is the presence of

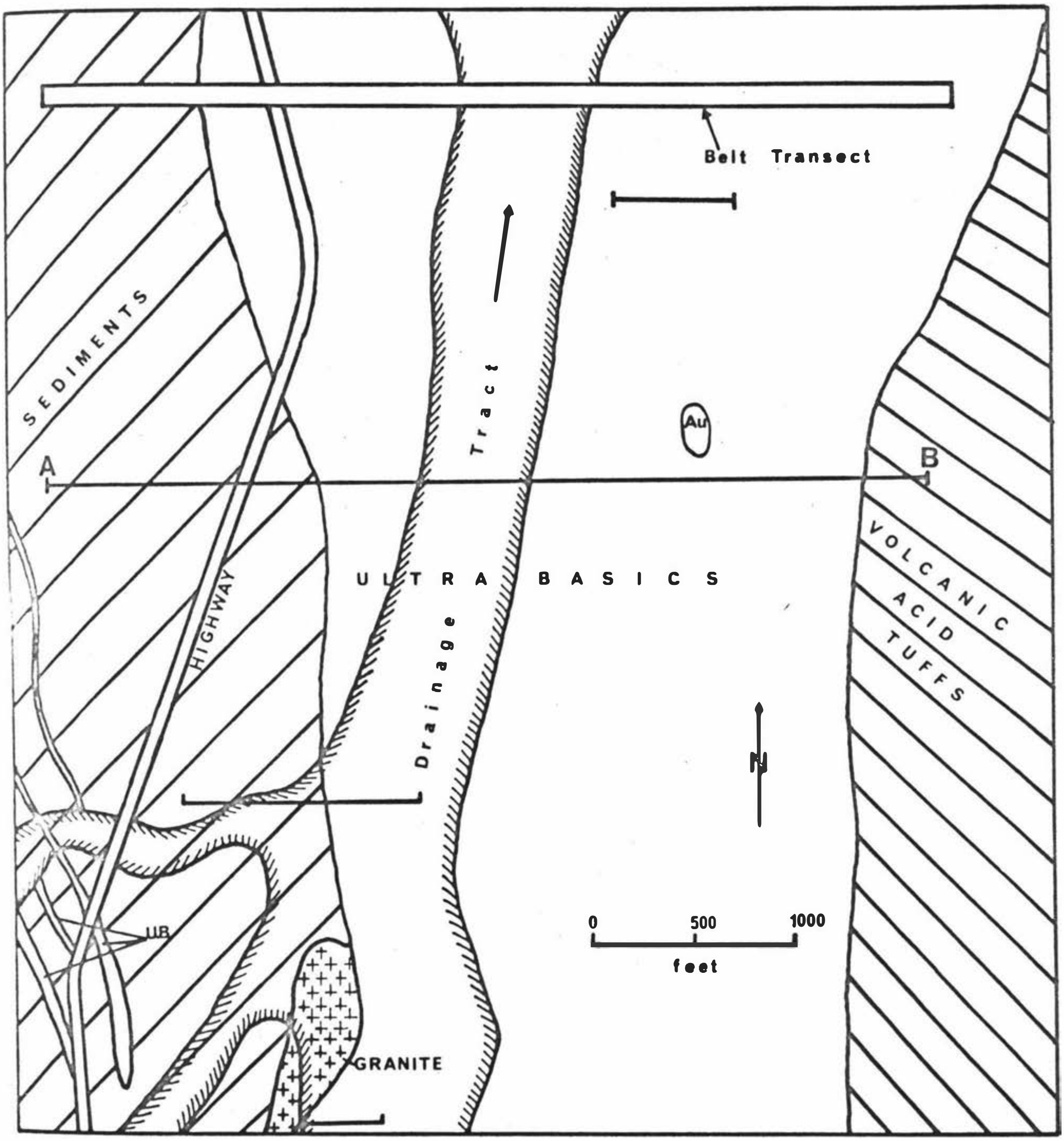


Fig. II-7. Location plan of Serwood Nickel Prospect. The geology is shown together with the positions of the abandoned gold workings (Au), the belt transect and the main drainage tracts. Vacuum drill-hole traverses are shown, orientated east-west across the strike and the major traverse is labelled A-B.

a siliceous 'hardpan' layer in the soil profile.

Abandoned gold workings are seen in the outcropping ultrabasics (see Plate II -4). This area was examined for nickel mineralisation but to date no significantly mineralised zones have been located.

(iv) Topography.

Topography is generally very subdued. Relief is provided by a rocky sediment ridge near the western margin of the study area shown in Fig. II-7. Elsewhere gentle slopes of 2° or less are scree-covered and a dry drainage channel runs northwards through the area. It is marked by alluvial reaches up to 800 feet wide and is demarcated by relatively dense vegetation (see Plate II -4).

B. GEOBOTANICAL STUDIES.

A belt transect was sited across the lithological trends (Fig. II -7) and revealed several plant-habitat associations.

It was immediately apparent that *Acacia aneura* dominated the tree layer and enjoyed a wide non-specific range of habitats. *A. aff. aneura*, *A. ramulosa* and *A. cuthbertsonii* are closely related species and could be distinguished only by their pods and flowers.

A. sclerosperma and *A. victoriae* were confined to the drainage tracts where *A. tetragonophylla* and *A. craspedocarpa* locally became dominant.

A. pruinocarpa, *A. quadrimarginea* and an occasional *Canthium attenuatum* were observed on the higher sediment scree slopes, together with *Hakea aff. arida*.

In the shrub layer the genus *Eremophila* was dominant. *Eremophila macmillaniana*, *E. aff. freelingii*, *E. leucophylla* and *E. fraseri* are observed in lower areas with relatively deep soil whilst *E. latrobei*, with its brilliant-red flowers, is restricted to the skeletal scree soils.

E. spathulata was observed only on outcropping talc-carbonate rocks.

The Cassia genus was represented by C. chatelainiana, C. sturtii and C. helmsii. Occasional specimens of Exocarpus aphyllus, Scaevola spinescens, Grevillea sp., Kochia sp., and Sida aff. calyxhymenia were also recorded but their distribution was quite random.

The ephemeral ground layer presented a very attractive display due to recent winter rains. These plants were typically two inches high and comprised Brachycome ciliocarpa with pink flowers; the yellow flowers of Menkea villosula and Chenopodium rhadinost·chyum. However, no plant-substrate relationship was discernible.

Reconnaissance over the ultrabasic rocks revealed a small shrub of anomalous appearance. Its distribution was restricted to talc-carbonate rocks. It was an unidentified Calytrix sp., (quite distrinct from C. aff. desolata) whose bright lime-green phyllodes contrasted with the general dull grey-green appearance of the vegetation in this environment.

C. BIOGEOCHEMICAL STUDIES.

The Sherwood area, comprising about four square miles, was covered by a soil geochemical survey which revealed several soil anomalies containing more than 400 ppm nickel in areas of outcropping talc-carbonate rocks. Over the alluvial flats nickel soil values were generally low.

Vacuum drilling was carried out on east-west traverses over a strike interval of about one mile. A part of this area is shown in Fig. II -7 and drill traverse A-B was taken as a representative case. It is examined in detail in profile form in Fig. II -8, where drill data is compared with surface soil nickel data.

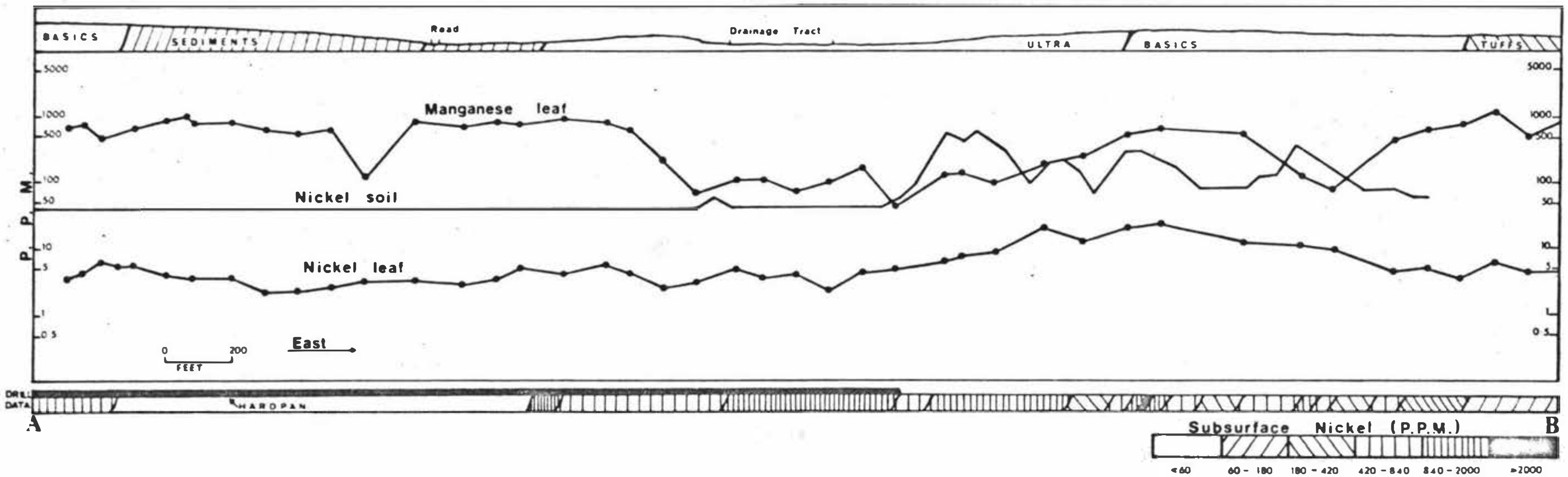


Fig. II-8. Comparison of surface geochemical and biogeochemical data (based on leaf of Acacia aneura) for nickel with substrate nickel values obtained by vacuum drill, along Traverse A-B (see Fig. II-7). Biogeochemical manganese values are very low in the drainage tract, the position of which is shown in the topographic geologic profile.

Biogeochemical sampling was carried out on all drill traverses. Leaves and twigs of *A. aneura* were sampled wherever possible at 100 goot intervals. These samples were analysed by a modified rapid procedure whereby analytical data was expressed on a dry-weight basis with a reproducibility of ± 0.25 ppm.

Vacuum drilling revealed the presence of a subsurface siliceous 'hardpan' layer which had the result that surface soil nickel values did not reflect variations in the bedrock. In outcropping areas, however, soil geochemistry did indicate nickeliferous zones which in the talc-carbonate rocks exceeded 0.2% nickel.

Fig. II -8 illustrates diagrammatically the effect of 'hardpan' on the efficiency of surface soil geochemistry in this environment.

The phyllodes and twigs of *Acacia aneura* were analysed for nickel, copper, chromium, zinc, manganese, and iron. Only the nickel content of the phyllode samples (dry weight), provided useful indication of the subsurface bedrock variation as seen in Fig. II -8.

Manganese, and to a lesser extent iron, exhibited markedly low levels in the phyllode samples in the vicinity of the drainage tract.

A. aneura gave a similar positive response to nickel on the other drill traverses where 'hardpan' was present. In actual fact several species of the *Acacia aneura* Complex were sampled, but analysis of several adjacent samples at various localities indicated that their nickel uptake was sufficiently alike to allow these species to be treated as one.

Several samples of the anomalous *Calytrix* shrub were analysed and revealed that this plant accumulates cobalt. Its average cobalt concentration is 200 ppm (ash) as compared to normal plant levels of 9 ppm cobalt (Brooks, 1972).

Nickel and chromium values were only slightly above background values in Calytrix. Eremophila spathulata which was also restricted to the talc-carbonate rocks, exhibited no unusual elemental concentrations.

D. CONCLUSIONS.

It is apparent that conventional soil geochemistry for nickel in the Sherwood environment is inadequate for non-outcropping areas. However the biogeochemical data, as illustrated in Fig. II -8 show that this technique can be used successfully to detect anomalous bedrock nickel values buried beneath more than 10 feet of overburden.

The results obtained in this survey with Acacia ancura are considered to be conservative as no economic concentrations of nickel have been located in this area. Such nickel mineralisation could be expected to contain significant amounts of cobalt and copper and accordingly these elements should also be analysed in the plant samples to detect coincident biogeochemical anomalies.

The indicator shrub Calytrix sp. was shown to have an affinity for cobalt and further investigations on its field occurrence are required.

4. GENERAL DISCUSSION:- MURCHISON REGION.

In this section the potential role of vegetation in exploration within the Murchison Region was examined. The preceding case studies have shown that geobotanical and biogeochemical surveys are best employed when used together. In the West Australian environment it generally seems necessary to carry out a geobotanical survey prior to the biogeochemical survey. The following paragraphs discuss each in turn.

(i) Geobotany.

No copper indicator plants were observed at the Red Bore or Cork Tree Prospects. However several abandoned copper workings north-east of Cork Tree were examined. On several ore-heaps containing about 2% copper, Ptilotus obovatus (200 ppm copper in ash) flourished. See Plate II -5. This shrub has been reported as a copper indicator in Queensland (Nicolls et al, 1965) and South Australia (Cole, 1964). In Western Australia P. obovatus is a ubiquitous shrub species which, the author feels, includes several subspecies or ecotypes and only some of these variants are cuprophytes. Analogy is drawn with the Becium homblei situation in Rhodesia (Howard-Williams, 1971).

Detailed botanical research on P. obovatus is considered to be a prerequisite to allow the use of this shrub for geobotanical prospecting in the West Australian Eremean.

At Sherwood, the outcropping talc-carbonate indicator shrub, Calytrix sp. is a rather rare species but its conspicuous colour allows its field recognition at considerable distances, measured in hundreds of feet.

Of the tree species Acacia coolgardiensis appears to be the most useful as it can be used for photogeological interpretation of black/white 1:7200 photographs. This species grows only on outcropping dolerites and basalts and exhibits a very distinctive photographic pattern.

Other trees also exhibit a degree of substrate selectivity, e.g. *A. quadrimarginea* on quartzite ridges, but their frequency is usually too low to be useful.

(ii) Biogeochemistry.

The results of a biogeochemical survey are influenced by factors which can be broadly classified into three groups:-

1. the plant species sampled
2. the organ of the plant which is analysed
3. the factors which influence the movement of metal ions from the bedrock source, into the plant organ which is taken for analysis.

There is ample evidence to illustrate the necessity of choosing carefully the species and organ for a particular sampling programme (Shacklette, 1962; Warren et al, 1955) but very little work has been carried out to understand the various mechanisms in the third category.

In the areas studied so far, the choice of species was limited to *Acacia aneura* as it alone possessed the necessary pervasive distribution. On the various organs, only leaves (phyllodes) and twigs are easily obtained. The flowering season is brief and as irregular as the rains and root samples are not feasible to obtain on a routine basis.

Twig (branchlet) samples generally gave no biogeochemical response whereas phyllodes were shown to be quite adequate.

It is apparent that *A. aneura* has an annual growing season of about 12 weeks or less, which takes the form of a short burst of activity immediately after a thunderstorm. The phyllodes are perennial and it would appear that a biogeochemical survey can be carried out throughout the year but perhaps not soon after a period of high rainfall.

A feature of the Murchison region is the frequent occurrence of a subsurface siliceous hardpan. It is absent in most areas high in the landscape as at Red Bore, but where it is present it often renders surface exploration techniques ineffectual. The hardpan is thickest in valleys on lower parts of the new plateau, where the shallow woils may be underlain by 30 feet or more of hardpan. It thins out on the slopes to a discontinuous crust, a few inches thick, covering the rock on gradients of 2 or 3% (Litchfield, 1958). Plant roots are considered (Litchfield, 1958) to be largely confined to the shallow uncemented soils above the hardpan in apparent contradiction to the biogeochemical results obtained in this region.

In this environment it is apparent that Acacia aneura can be used in a biogeochemical survey to delineate anomalous nickel or copper concentrations in subsurface bedrock, even when the siliceous hardpan is present.

SECTION III

BOTANICAL STUDIES IN THE KURRAJONG REGION

1. INTRODUCTION.

Botanical investigations were carried out over a large area of "greenstones" between Agnew and Leonora. This area is referred to as the Kurrajong Region, after a former gold-mining town which was sited 20 miles north of Leonora on the main road to Agnew.

A temporary Reserve covering many hundreds of square miles was taken out by Western Mining Corp. and prospected for several metals including nickel. The geobotanical studies were carried out from a base camp established about two miles north-west of Mt. Clifford beside Clifford Creek. Mt. Clifford has become a well-known locality within Australia and is a small quartz hill injected into sheared metabasalts and the surrounding area is pitted with abandoned gold-workings.

(i) Location.

The base-camp is reached by graded track which trends north-eastwards from the main Agnew-Leonora road at Doyle well. Field studies were carried out at many scattered areas and most are shown in Fig. III -1. Reconnaissance was carried out as far north as Yandal which is 50 miles north-east of Agnew; to the east as far as Laverton; and to Leonora in the south. Only three areas to the west of the main road were visited, and included the Pinnacles nickel prospect 12 miles south of Agnew, the Bannockburn gold mine 10 miles north of Doyle Well and a Zinc prospect at Doyle Well itself.

Detailed botanical studies were carried out over several nickel prospects close to the Mt. Clifford base camp and included the Marriott, '880', '107' and Mt. Newman Prospects. Further north, detailed studies were carried out at the Marshall Pool and Wildara areas. Access throughout this region is by dirt track most of which is passable by four-wheel-drive vehicle.

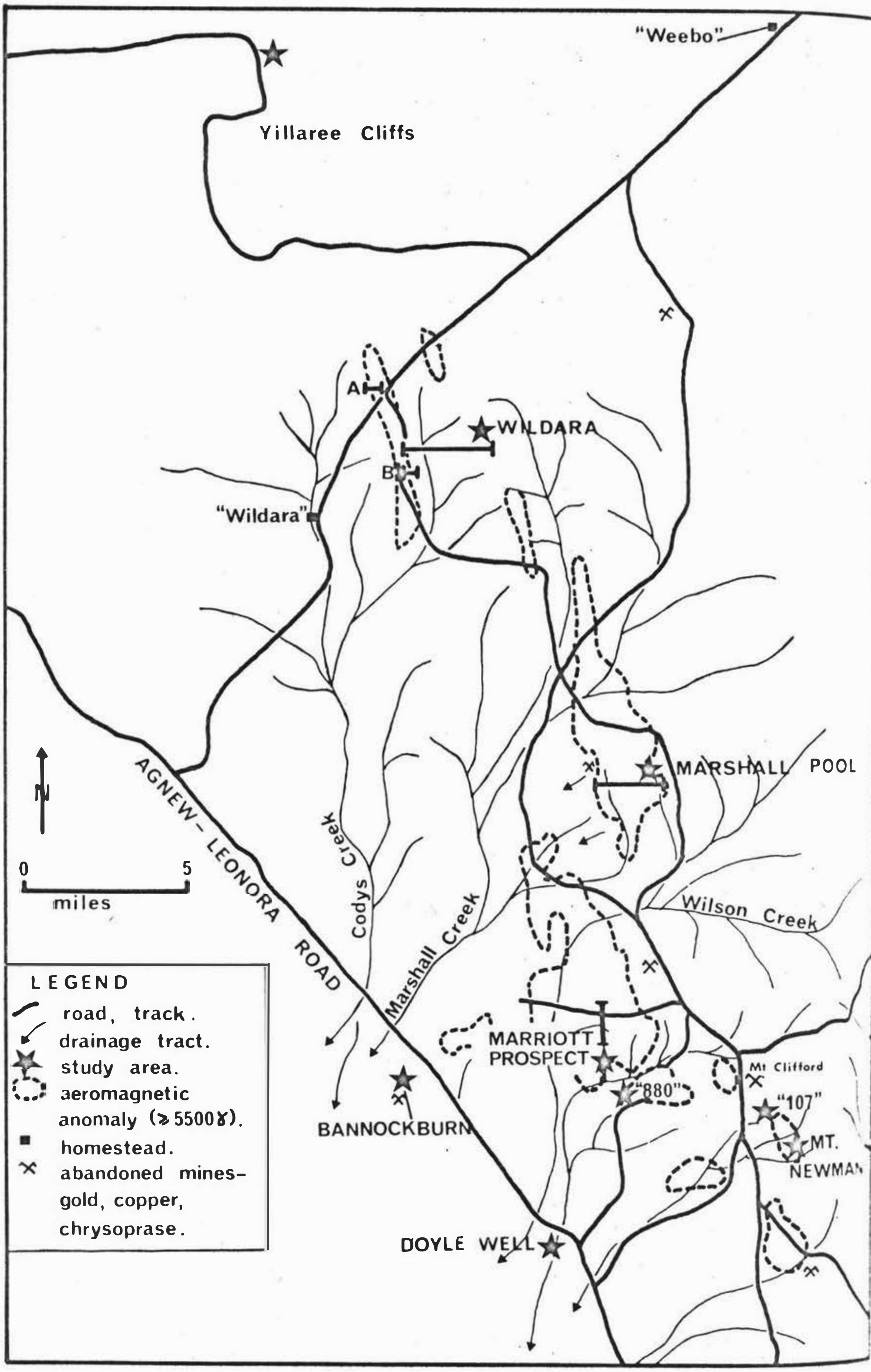


Fig. III–1 Location Map of Kurrajong Region. Ultrabasic areas are indicated by aeromagnetic anomalies, and the three regional geological/geobotanical traverses are also shown.

(ii) Climate.

Climatic data was obtained for the Mt. Clifford base camp and was discussed in a previous section. The rainfall is characterised by its intensity and in summer by its limited distribution. Often it is heralded by dust storms which travel on very wide fronts and turn the day into night. The average annual rainfall for this region is about 8 inches but during the study period drought years with 4 to 5 inches were experienced.

(iii) Geology.

The entire Kurrajong area is shown on regional geology maps as archaean "greenstones". These "greenstones" are predominantly metabasalts and metadolerites. Occasional fresh outcrops are found, but generally the rocks are extensively chloritised. Ultramafic and ultrabasic units are seen in several large structures and one is impressed by the general concordance and degree of layering of these sequences. Generally the ultramafites are serpentinised and in some areas are also lateritised and silicified. However, in some outcrops and drill-cores completely fresh dunites, peridotites and pyroxenites are seen.

Thin, often discontinuous, sediment bands often mark boundaries between some of the basic and ultramafic units. These sediments are fine-grained and are occasionally observed to grade into acid-volcanic tuffs. They seem to indicate a continental rather than the eugeosynclinal environment envisaged by other workers.

A major lineament (Leinster Lineament) is considered to have given rise to the general north-nor-west strike of the metavolcanic belts in this region, and field observations show that they dip steeply to the east. The location of most, if not all, ultrabasic units is indicated by aeromagnetic maps published by the Bureau of Mineral Resources. The 1:126,720 sheet (H51/B1-91-2) covering the

Kurrajong region shows that the ultrabasics exhibit total magnetic intensities of 5500 gammas or more. See Fig. III-1. Moreover the magnetic trends and anomalies suggest that the Kurrajong ultrabasics can be correlated with the Agnew ultramafics, within which Australian Selection recently discovered a major nickel orebody. In fact a record 1200 foot drill intersection through nickel sulphide mineralisation was obtained.

Interest was aroused in the Kurrajong Region, well before the Agnew discovery, during the 1960's when Mr. Frank Marriott, a prospector employed by N.M.C., found nickeliferous gossan fragments and traced them upslope to their source which is now known as Marriott Prospect. Other nickel prospects in the vicinity of Mt. Clifford, viz the '880', '107' and Mt. Newman prospects were similarly discovered, and all are situated in serpentinised peridotite units.

(iv) Soils.

The nature and distribution of soils in the shield areas of Western Australia have been influenced to a great extent by its relatively stable history. There has been no recent glaciation and there are few permanent rivers to constitute effective agents of erosion. The soils seen today can date back to the Tertiary and bear the imprints of a previous and different climatic environment.

Four main types of soils occur within the study region; these are lateritic soils; solonised brown soils; skeletal soils and sandplain soils. Lateritic soils are restricted to isolated hills of the Old Plateau whereas solonised brown soils are widespread on the lower ground throughout the Gold fields. Skeletal soils are the youngest soils and are associated with outcropping or near-surface bedrock. Sandplain soils cover large but scattered expanses of country especially in the north and eastern areas.

(a) Laterite.

The profile of this soil-type is characterised by the 3 zones of eluviation, illuviation and weathered bed-rock. Most of the present-day laterites are thought to date back to the Pliocene when the climate was more tropical and humid than that prevailing today (Prescott and Pendleton, 1952). At the surface there is a veneer, usually only a few inches thick, of lateritic gravel which is in a red-brown loamy matrix of acid reaction. Below this gravel, a massive indurated ferruginous horizon (laterite) is usually present. This horizon, which may be up to 10 feet thick, has a vescicular structure, is resistant to weathering and therefore gives rise to characteristic buttes and scarps. The indurated laterite horizon passes fairly abruptly, with depth, into a 'mottled' zone consisting essentially of kaolinised bedrock which may be up to 200 feet thick. This horizon then grades through weathered and finally into unweathered bedrock.

A modification in the normal lateritic profile, as a result of increasing aridity, is the extensive calcification of the profile. It has also been indicated that the introduction of calcium carbonate is an important factor in the disintegration of the upper part of the indurated laterite or duricrust.

(b) Solonised Brown Soils.

Solonised brown soils are characterised by extensive lime accumulation and an alkaline soil reaction. The typical profile shows 3 horizons. The A horizon varies up to 6 inches in depth and is a red-brown sand-silt loam. The B horizon ranges in depth up to 36 inches, is marked by its powdery texture, travertine-coated pebbles and pale brown-white colour due to the abundance of fine calcium carbonate. In some low-lying areas a solonised brown soil containing less apparent lime occurs and it is also characterised by a higher proportion of clay which often becomes very sticky when wet.

The origin of the calcareous material in these soils is the subject of a number of hypotheses and it is probable that in different areas different origins are involved. In the arid regions of Western Australia it is generally attributed either to wind-borne calcareous loess or to deposition of rising calcareous ground waters (Mazzucchelli & James (1966). Elkington (1969) considered the effect of cyclic calcium and sodium in rainwater over geological time in an arid environment. She suggested that the excess of sodium resulted in the leaching and replacement of calcium absorbed to clay partides and the relative solubilities resulted in the concentrations of calcium in carbonates.

This soil type often masks ultramafic bedrocks away from the low rolling hills. Therefore the trace metal distributions were studied in a representative soil profile immediately east of Marriott Prospect. A costean or trench was dug to bedrock and revealed a thin black shale band within serpentinised pyroxenites. The soil was alkaline and pH varied from 7.2 to 7.5. Samples were collected at 10 inch intervals down to bedrock and were analysed for nickel, copper, cobalt, zinc, chromium, manganese, iron, calcium and magnesium. The transition metals displayed a pattern typified by nickel, whereas magnesium followed calcium. Fig. III -2 illustrates the inverse relationship between nickel and calcium and indicates the effect of the carbonate horizon on distribution of nickel and the other trace metals. It is clear that whereas the metal content of the red-brown A horizon bears no relationship to the bedrock the metal content of the whiteish B horizon can be indicative.

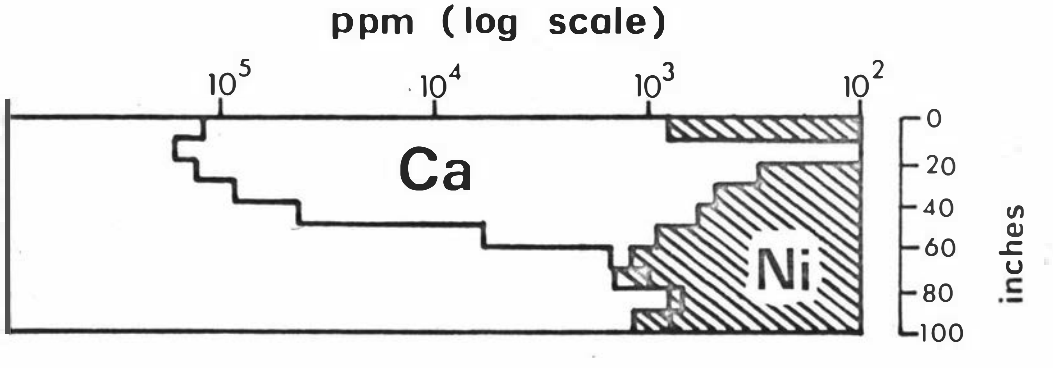


FIG. III-2. Distribution of nickel and calcium in solonised brown soil profile.

(c) Skeletal Soils.

These soils occur wherever the underlying rock outcropped or was close to the surface. Soils developed in such areas are usually very shallow, being only a few inches deep and show no profile development. They are usually red-brown sandy silts and the pH varies from 6 to 8.

(d) Sandplain Soils.

Sandplains cover vast areas and may attain considerable depths. They 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. Textures increase with depth and pH values are slightly acid to neutral. These soils are considered (Mulcahy, 1960) to be locally derived from weathered lateritic material which has undergone colluvial transport. They were encountered east of Leonora and Agnew and are found overlying a range of materials, and often include the pallid zones of Lateritic soils.

(v) Vegetation.

This region lies within the mulga bush zone where the Acacia aneura Complex dominates the tree layer. Several closely allied species or subspecies constitute this Complex and they have not yet been formally resolved into distinct varieties. This is a direct consequence of epharmonic development within the Acacia genus, and it is commonly necessary to have both pod and flower material to enable identification of a species to be made. The genus Acacia gives way to completely different vegetation in saline areas and over the vast tracts of sand-plain. On the salt flats and fringing the dry lakes the halophytic shrubs, e.g. Atriplex, Anthrocnemum and Kochia genera dominate the scene. On the sand-plains, spinifex grass (Triodia spp.) forms a hummocky landscape with occasional spinifex gums (Eucalyptus kingsmillii) as the sole tree representative.

In the "greenstone" belts which are usually quite hilly, the Acacia tree layer is some 20 feet high. The shrub layer is dominated by the genera Eremophila, Dodonaea, Scaevola and Cassia, which are typically about three feet high.

The ground between the scattered shrubs and trees is generally quite bare of perennials. However, in good seasons the ephemeral ground flora provides a spectacular carpet of colour.

The bare ground may be only a short-term effect of the present drought, but it is more probably the result of the impact of grazing animals, viz. goats, kangaroos and especially the sheep which were introduced several decades ago and are now stocked at a density of about five per square mile. The sheep and indigenous fauna are maintained in this semi-desert environment by subsurface water which is tapped by bores. There has been little effort to come to erms with the environment and there are trends in the ground vegetation towards deterioration and degradation (Wilcox, 1963). Unfortunately the tree layer is also affected as changes in the microenvironment have stifled regeneration of *Acacia aneura* (Collins, 1924; Christian and Slatyer, 1958; Jessup, 1948; Moore, 1960). It is therefore apparent that the impact of man has upset the delicate ecological balance that existed in this arid region and may well result in another man-made desert.

(iv) Previous Work.

Prior to commencement of the geobotanical studies, the geology of the prospect areas had been carefully mapped (1:1200) and detailed geophysical and soil geochemical studies were undertaken. The results of this work served as a base on which to plan the present study.

Drilling had indicated that the gossanous zone on Marriott Prospect was the surface expression of significant nickel sulphide mineralisation which occurred as several lenses within peridotitic host rocks. This mineralisation was not considered to be of either sufficient grade or tonnage to support a viable mining operation at this time. However, it did provide a suitable environment in which to carry out orientation biogeochemical and geobotanical studies for nickel.

2. ORIENTATION STUDIES OF MARRIOTT NICKEL PROSPECT.

A. SUBSTRATE ENVIRONMENT.

(i) Geology.

The Marriott Nickel Prospect was located by the presence of a gossanous zone which outcrops along a rocky ridge crest which strikes east-south-east and disappears under an extensive blanket of colluvial soils to the east. This gossan or zone of oxidised mineralisation is seen as a pitted serpentinite with blobs of limonitic material which occasionally displays violet hues of violarite and green bloom of zaratite. It outcrops discontinuously over a maximum width of 50 feet and a strike of several hundred feet, and appears to represent disseminated nickeliferous sulphides at depth (Plate III -2).

The ground falls gently away to the north to a sediment band and to the south to a scarp which marks the footwall contact of the meta-ultramafite sequence with a basic gabbroic sill. The idealised geology of the orientation study area is shown in Fig. III -3. The ground is relatively flat south of the gabbro serpentinite scarp, and laterite forms a thin capping over undifferentiated serpentinites at the southern edge of the area.

North of the main sediment band, amphibolites and serpentinised pyroxenites outcrop. The serpentinites which are the host rocks for the mineralised zone are ex-dunites and peridotites. Outcrop is obscured to the south by laterite and to the east by solonised brown soils (which can attain depths of 10 feet or more), but otherwise is excellent. Drainage in this area is mainly as sheet-wash but there is some concentration of run-off in rills as shown in Fig. III-3.

(ii) Bedrock Geochemistry.

Sample Collection and Analysis.

Bedrock-chips were carefully sampled on a

100 foot square grid system in the study area. Samples were crushed and pulverised (minus 200 mesh B.S.S.) and 0.2g used for chemical analysis. Ten ml. of a 3:1 mixture of nitric/perchloric acid was used for the digestion which was carried out in test-tubes at 80°C. The dry residue was leached with 2M hydrochloric acid and made to volume (20 ml). This solution was used for the atomic absorption determination of nickel, copper, cobalt, chromium, zinc, manganese, iron, calcium and magnesium. The latter three elements required further dilution with 0.8% Sr $(NO_3)_2$ in 2M HCl.

The nitric/perchloric acid digestion mixture has been criticised by some workers. Accordingly, the accuracy was checked by carrying out duplicate digestions using a 1:1 nitric/hydrofluoric acid mixture. Results using this technique were essentially the same for all metals except for chromium, which were two or three times higher. However, interpretation of both sets of results yielded the same information and the more expensive nitric/hydrofluoric acid digestion could not be justified for this study.

Results.

The gossanous outcrops varied widely in their nickel contents from 02. to 1.1% nickel. A channel sample taken across the mineralised zone indicated an average of 0.48% nickel whereas the barren host rocks, serpentinised dunites and peridotites, ranged from 0.1 to 0.2% nickel. Serpentinised pyroxenites generally contained less than 0.1% nickel and the gabbroic intrusion exhibited even lower values of less than 300 ppm.

The effect of the lateritic capping over the serpentinites at the southern part of the study area was to raise the nickel levels from about 0.1% to more than 0.2%. The contoured data are shown in Fig. III-4 and closely reflect the geology. It is apparent from these data that a similar gossan could be obscured by a lateritic environment with an

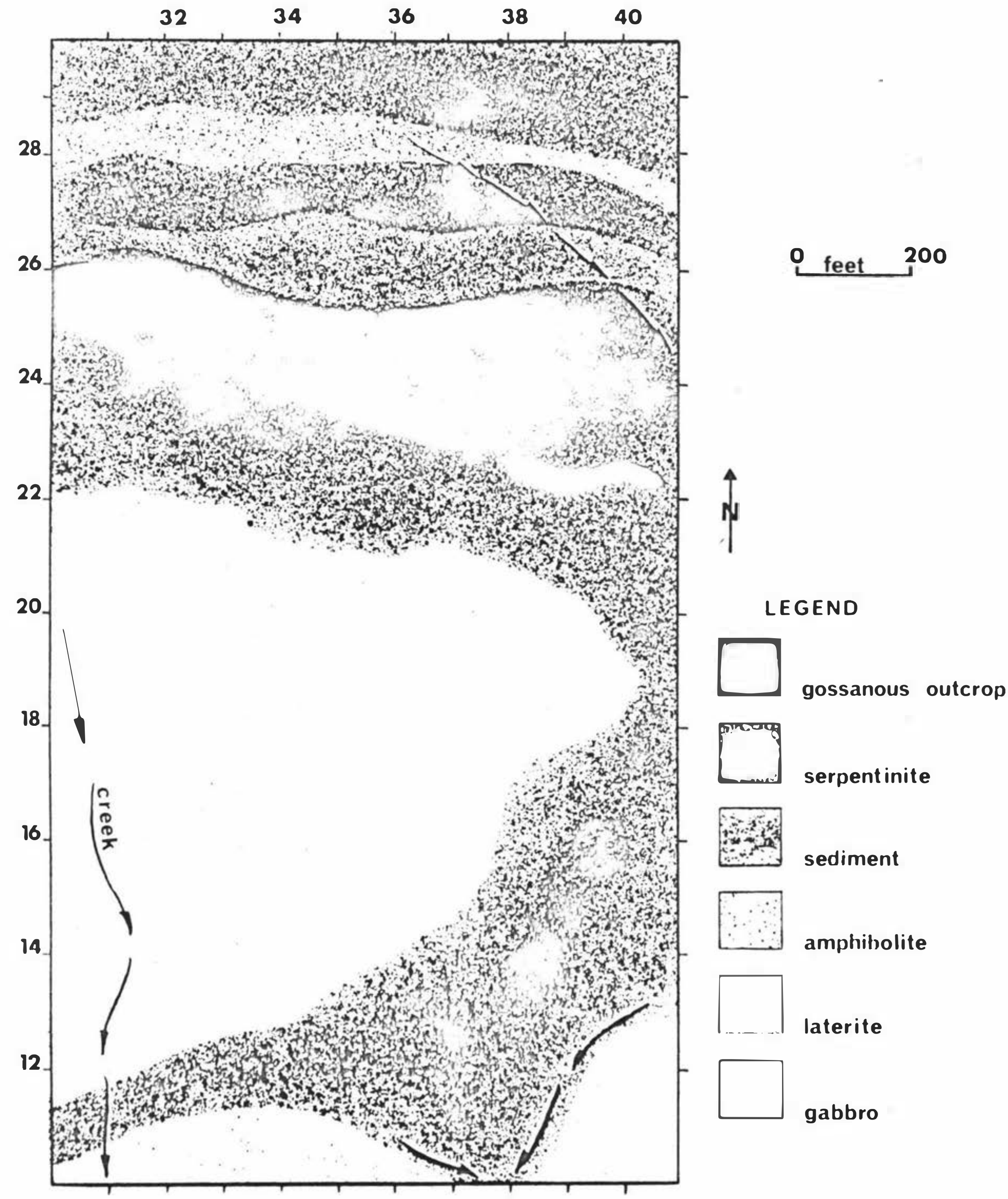


Fig. III–3 Geological plan of the Marriott Prospect study area, showing also the incipient drainage tracts.

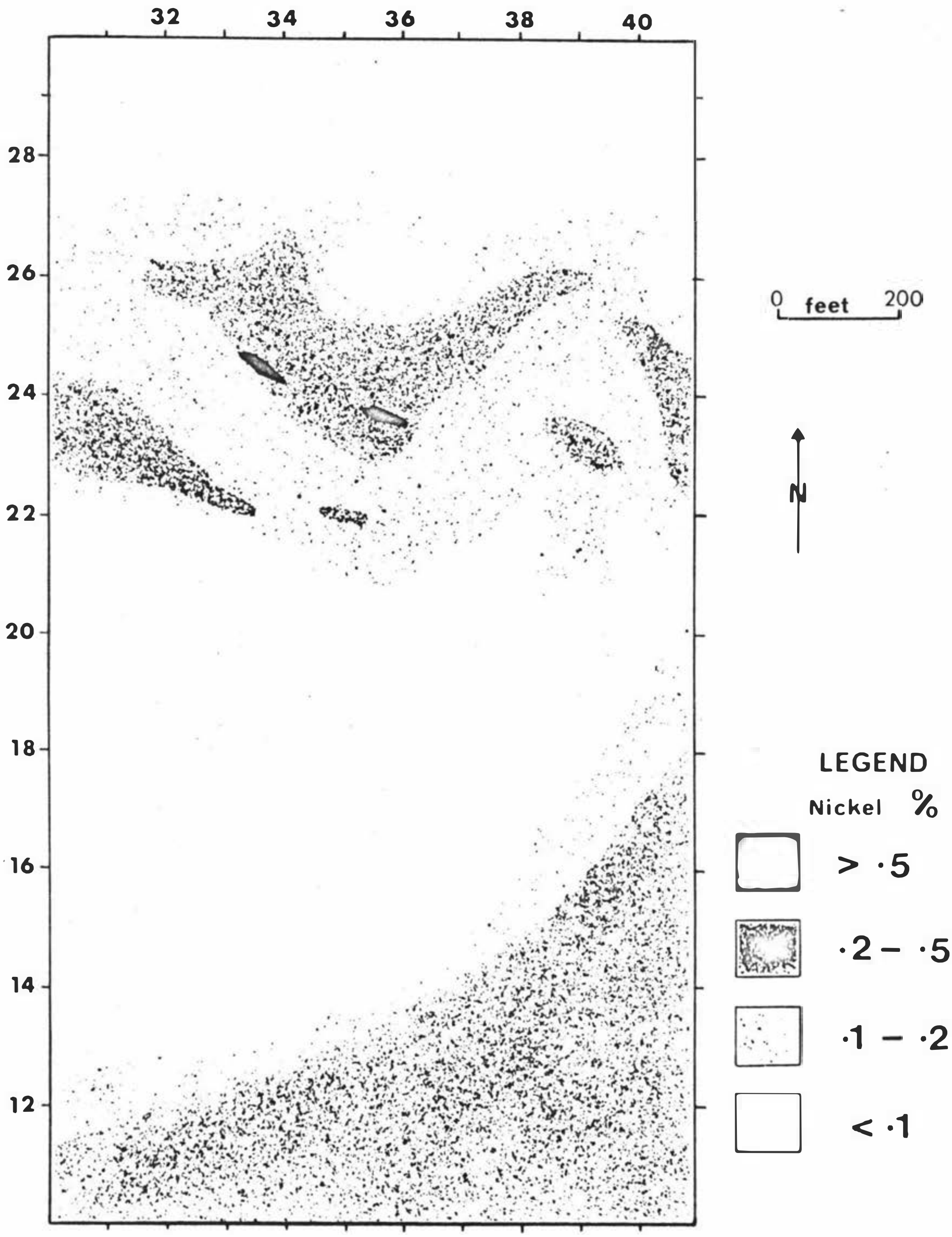


Fig. III–4 Bedrock geochemical nickel plan of the Marriott Prospect study area.

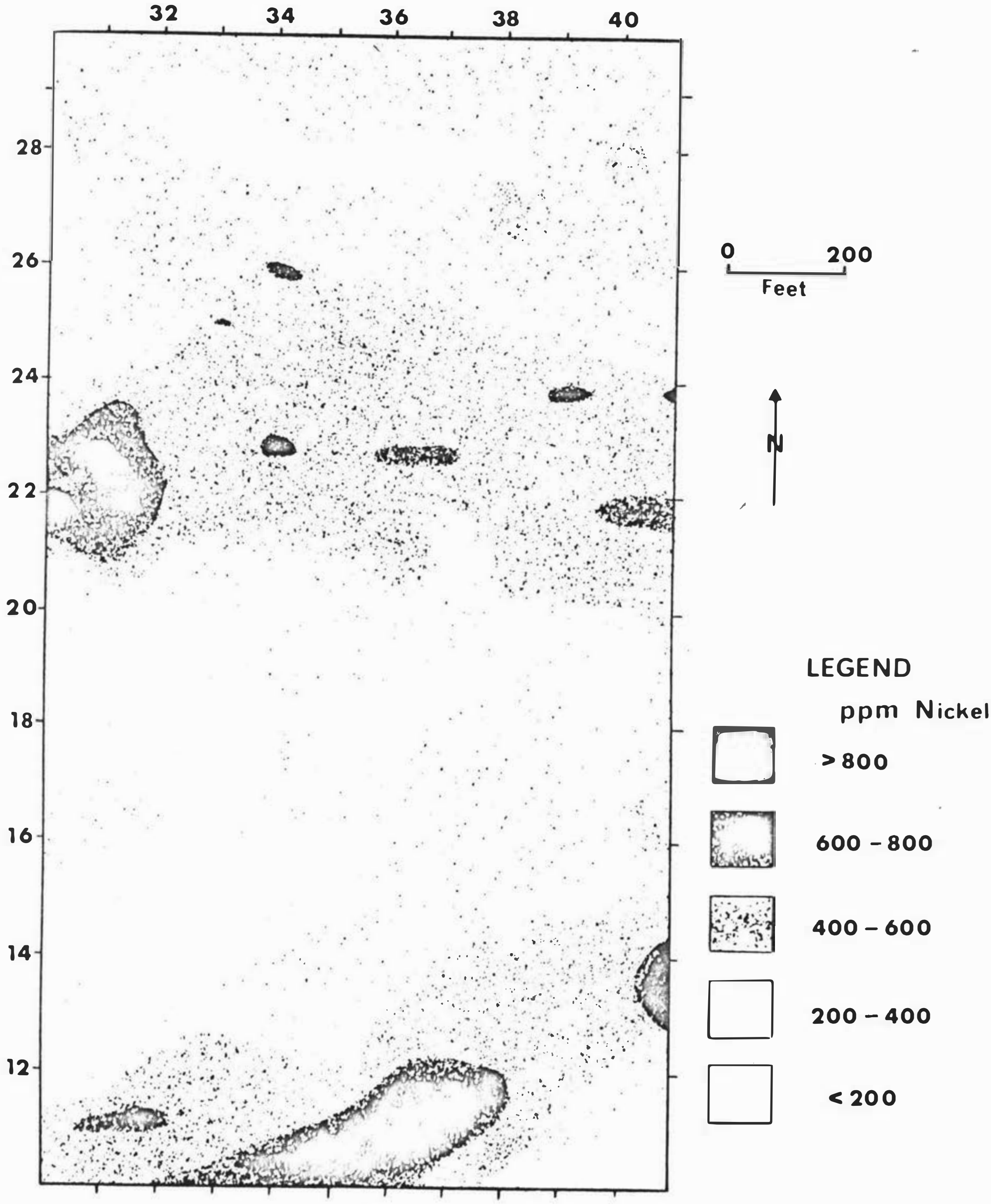


Fig. III-5 Soil geochemical nickel plan of the Marriott Prospect study area.

associated high nickel background and this situation does create a problem for the exploration geochemist.

Copper values were fairly constant around 100 ppm or less. Some, but no all, gossan chips had elevated copper values of about 300 ppm and similar values were also obtained in some laterite samples.

Zinc was generally low in this environment except in sediments which usually contain more than 200 ppm and up to 2600 ppm zinc.

Cobalt contents were less than 50 ppm but occasional high values e.g. 200 ppm were obtained in some lateritic and gossan chips.

Manganese levels fluctuated around 600 ppm in the serpentinites, but exceeded 800 ppm in the amphibolites and gabbro samples.

Chromium values were typically less than 100 ppm in sediments and basic rocks. Serpentinites contained from 600 to 1500 ppm whilst lateritised serpentinites contained from 0.3 to 1% chromium.

Calcium levels in serpentinised peridotites were low and always less than 0.1%. Serpentinised pyroxenites contained much higher levels and ranged from 0.8 to 6% whilst basic rocks exhibited a narrow range of 6 to 10%.

Magnesium values attained their maximum values in the metaperidotites with about 20% and the metapyroxenites were lower and ranged from 11 to 20%. The basic igneous rocks contained 6 to 10% magnesium whilst the lateritised serpentinites contained low amounts (less than 0.1%) of both calcium and magnesium.

It is evident that the gossan zone is revealed by high nickel values (about 0.5% nickel) and sometimes by coincident copper or cobalt anomalies. This gossan was shown by diamond-drilling to be surface expression of nickel sulfide mineralisation which at depths of 200 to 500 feet typically graded at 3% nickel, with low copper values (100 to 140 ppm) and relatively high cobalt levels (260 to 830 ppm).

(iii) Soil Geochemistry.

Sample Collection and Analysis.

Soils were collected on a 100 foot grid system at a depth of about 6 inches or at bedrock interface, whichever was encountered first. They were sieved on site and the -80 mesh fraction analysed as for the rock-chips. Soil pH was measured on site using the CSIRO field-kit which allows reliable and rapid determination to ±0.3 pH units.

Results.

The soils over serpentinised peridotites were characterised by high nickel levels of 400 to 600 ppm, whereas the metapyroxenites had lower 200 to 400 ppm nickel values. The gabbroic soils have even lower values of less than 200 ppm except near the serpentinite contacts where contamination may increase the levels to nearly 400 ppm nickel. Laterisation had a variable effect on nickel values and sometimes raised them as high as 800 ppm. The gossanous zone was marked by some small areas of 600 to 800 ppm nickel in soil and in one area near the footwall contact of the meta-peridotite, values exceeded 800 ppm nickel. There is clearly a very close relationship between geology (Fig. III-3), bedrock geochemistry (Fig. III-4) and soil geochemistry (Fig. III-5), for nickel. It is apparent that a nickel soil anomaly by itself does not necessarily indicate subsurface nickel sulphide mineralisation and other elemental data are required to interpret such areas.

Cobalt soil values were low, being less than 30 ppm over basics, less than 40 ppm over serpentinites and sometimes attained 50 ppm over mineralised and lateritised areas.

Copper was low over serpentinites being less than 60 ppm but was slightly higher (about 100 ppm) over the basics and sediments, the latter sometimes being indicated by copper values of 90 to 180 ppm.

Zinc values were less than 200 ppm except over the thin sediment bands, where values attained 500 ppm. Values were generally less than 70 ppm over the igneous rocks.

Manganese values were low (400 ppm) over serpentinites but exceeded 1000 ppm over the basic units.

Chromium values were low over basics, metapyroxenites and sediments (less than 200 ppm), but metaperidotites contain 200 to 300 ppm, and attained even higher values over lateritised areas.

Calcium levels reached their lowest levels over lateritised serpentinites (about 0.2%) and metaperidotites contained 0.26 to 0.4% calcium whilst the metapyroxenites were typically 0.4 to 0.5% and basics contained 0.5 to 2.0% calcium.

Magnesium values decreased from metaperidotites (1.0 to 2.6%) through metapyroxenites (about 2.0%) to basics (0.9 to 1.5%) to lateritised serpentinites with less than 0.4%.

Soil pH was high over the serpentinised ultramafites and ranged from 7.0 to 7.9. The gabbroic soils ranged from 6.8 to 7.2 whilst the lateritised soils were acid and the pH was less than 6.7. There was no area of low soil pH around the gossanous zone.

The Marriott gossan represents subsurface nickel mineralisation with relatively high levels of cobalt. However, the soil geochemical data as illustrated by nickel (Fig. III-5), do not reliably indicate the gossanous outcrops, in this environment where lateritic remnants are present.

Sulphide-specific 'pathfinder' elements would facilitate interpretation of geochemical soil surveys, especially regional surveys. Such elements might include arsenic, selenium, tellurium, cadium, and platinum, and they are considered briefly in Section VII.

B. GEOBOTANY.

(i) Data Collection.

Plant distributions were obtained by recording the number of plants per 100 foot square quadrat. These quadrats were sampled as belt transects suitably orientated across the study area which measured 2000 by 1100 feet.

In this instance six belt transects, orientated north-south, were completed on alternate 100 foot wide stripes.

As more than 50% of the ground was covered, the geobotanical data was processed to fairly accurate single species distribution maps as well as the usual profile diagrams. A representative geobotanical profile diagram sited across the middle of the study area, is shown in Fig. III-6. The topographic section was compiled from accurate levelling data. The soil geochemical data (log. scale), soil pH and soil depth were also considered when interpreting plant-lithology. relationships.

(ii) Data Interpretation.

During the course of the field-work several plant-lithology associations were observed and are also revealed in Fig. III-6. Considering the tree layer first, Acacia burkittii was restricted to serpentinised pyroxenites, but did 'spill-over' on to serpentinised peridotites.

A. resinomarginea displayed an inverse distribution to A. burkittii and was confined to the basic gabbroic sill, although again some overlap on to serpentinised peridotites was observed (Plate III-1).

A. aneura occurred on basic and ultrabasic lithologies but at a considerably lower density than the previous two species.

A. linophylla was restricted to the high rocky areas which in this unusual case coincided with a

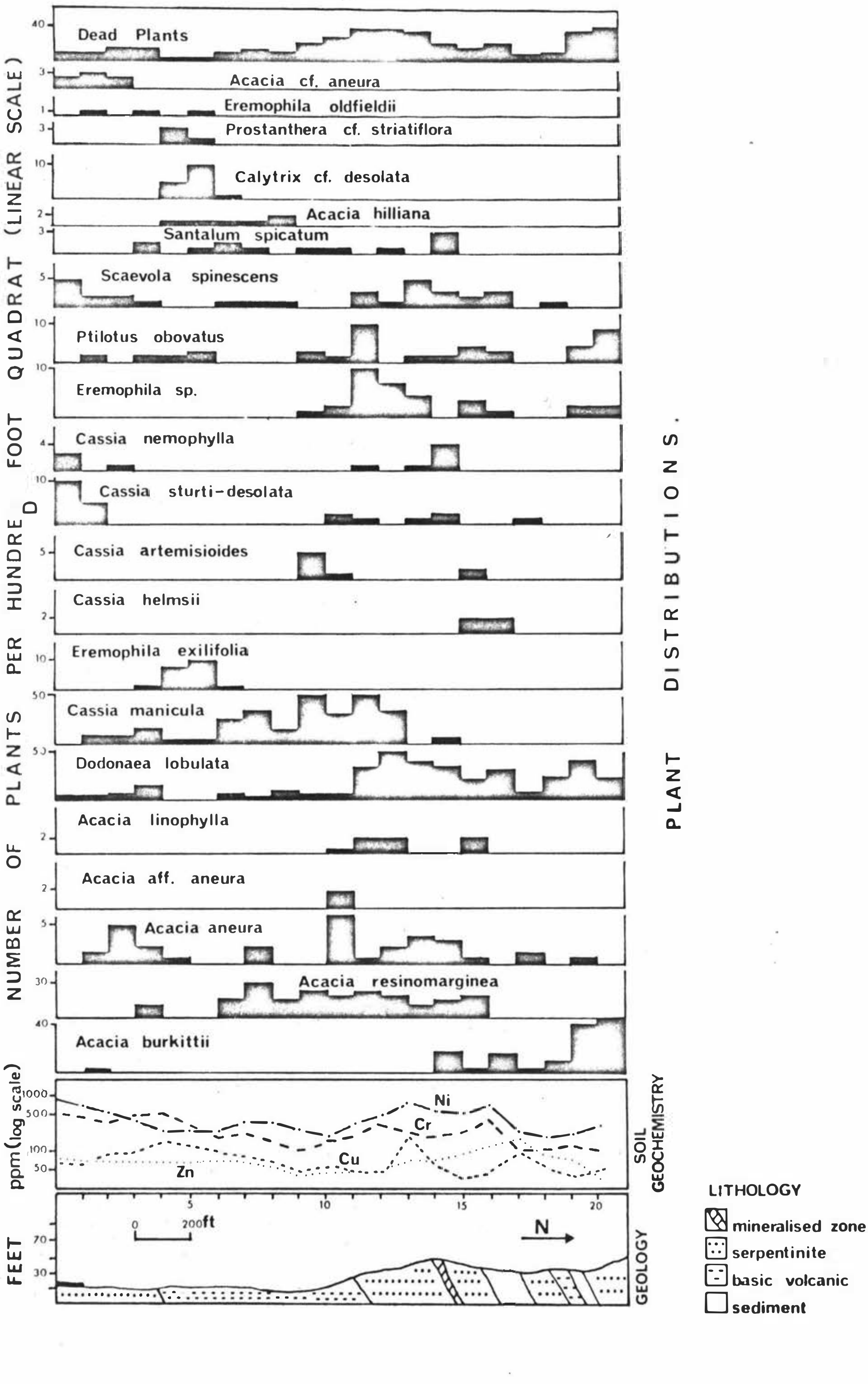


Fig. III–6 Belt transect across Marriott Prospect study area, showing the relationship between plant distributions, geology, and soil geochemistry.

gossanous zone. *Acacia* aff. *aneura* (A and B) are undescribed varieties or subspecies of *A. aneura*. Type A has a low density with some preference for basic rocks whilst Type B with a characteristic long, flat phyllode is confined to laterites.

Other tree species which are only occasionally seen include *Eremophila oldfieldii* and *Santalum spicatum* and they are usually found on low flat ground.

The shrub species generally are less then 4 feet high and exceed the trees in diversity and overall density.

The genus Eremophila includes *E. exilifolia* which is restricted to rockly basic outcrops, *E. sp. nov.* which is restricted to outcropping serpentinites and may be related to *E. exilifolia*.

Dodonaea lobulata is another shrub species which is also restricted to serpentinites. The *Cassia* genus includes *C. artemisioides* which grows in relatively calcarious soils as are found over the sediment bands. *C. sturtii*, *C. desolata*, and *C. helmsii* also exhibit this preference for finely-powdered calcareous soils and such areas often have relatively high metal values in their finer (-200 mesh) fractions.

In fact, *C. sturtii* forms a monospecific geobotanical anomaly near the base of the serpentinised peridotite-dunite unit which corresponds to a calcareous soil with high nickel levels (more than 1000 ppm nickel). This area has co-ordinates 923N 831E Fig. III-5. (Ref. WMC Plan No. 529-513).

C. manicula is strongly restricted to outcropping basic rocks, while *C. nemophila* is found only over serpentinites. The other shrub species, *Scaevola spinescens*, *Ptilotus obovatus*, *Calytrix* cf. *desolata*, *Acacia hilliana* and *Prostanthera* cf. *striatiflora* are of sparse distribution and the latter three species are usually found only on rocky basic outcrops.

C. BIOGEOCHEMISTRY.

(i) Data Collection.

Samples of all plant species growing over or near the gossanous zone were collected to determine whether any species accumulated nickel, copper or cobalt and thus indicated an affinity for these elements. The four main tree species, *Acacia aneura*, *A. burkittii*, *A. linophylla* and *A. resinomarginea* were sampled in preference to the smaller shrub species because it was considered that the tree species would have a bigger root system and ideally might possess the ability to reflect "blind" mineralisation beneath barren bedrock or exotic overburden.

Leaf and twig samples were collected and dry-ashed prior to analysis for nickel, copper, cobalt, chromium, zinc, manganese, calcium and magnesium. Calcium and magnesium analyses were proformed to determine whether the plants indicated ultrabasics by a decrease in the calcium/magnesium ratio.

(ii) Data Interpretation.

An IBM 1620 Computer was employed to calculate means for the various data populations and some of these data are given in Table III-1. Correlation analysis was carried out on plant-soil and plant-bedrock data with a view to screening out rapidly the 'significant' data. It was soon realised, that correlation analysis had little if any practical application in the interpretation of these biogeochemical data.

Table III-1 reveals two important facts. None of the plant species listed accumulated nickel, copper or cobalt to any appreciable extent. Therefore one can postulate (Brooks, 1972), that none of these species has any marked affinity for these three elements and it is unlikely that a nickel indicator plant exists in this study area. Anomalous nickel values were obtained over both the gossanous zone and

TABLE III-1 (Cont.) Analytical Results for Plant Samples obtained during Orientation Study over Marriott Prospect.

Values shown are Geometric means.

PLANT SPECIES	NO. SAMP.	TWIG ASH (PPM)							
		Ni	Cu	Co	Cr	Zn	Mn	Ca%	Mg%
Acacia aneura	117	59	53	-	18	57	319	33.58	0.89
Acacia burkittii	101	55	-	-	11	42	108	36.38	0.66
Acacia resinomarginea	82	46	35	-	20	45	142	35.4	0.72
Acacia linophylla	29	49	52	-	11	56	248	34.07	1.05
Acacia aff. aneura	8	81	52	-	20	76	314	31.58	1.21
Acacia craspedocarpa	6	87	90	3	15	80	1860	31.3	1.90
Acacia grasbyi	9	31	28	-	17	27	63	36.34	0.50
Acacia sowdenii	3	27	82	3	19	125	203	33.3	2.3
Acacia quadrimarginea	5	65	59	4	20	104	712	34.9	3.23
Acacia dempsteri	1	25	67	-	25	82	80	31.50	4.00
Brachychiton gregorii	1	70	53	0	20	50	305	35.0	0.80
Cassia sturtii	10	42	70	-	23	130	139	32.86	1.24
Cassia nemophila	6	52	53	-	26	102	172	33.98	0.86
Cassia helmsii	6	55	85	-	21	165	160	-	-
Cassia artemisiodes	4	103	54	0	22	110	274	31.5	1.20
Calytrix cf. desolata	1	75	127	7	40	240	8000	16.00	2.85
Dodonaea lobulata	8	77	93	-	44	224	226	29.82	0.91
Eremophila exilifolia	8	88	156	-	33	420	652	25.11	1.55
E. aff. exilifolia	2	270	520	0	69	740	1630	17.0	3.75
Eremophila platycalyx	5	88	166	1	33	331	442	23.0	1.30
Eremophila pantoni	3	70	235	0	75	266	503	12.0	2.46
Grevillea sp.	1	210	135	0	12	70	6500	24.0	5.10
Hakea leucoptera	21	108	50	-	14	37	4450	24.72	1.84
Ptilotus obovatus	6	135	153	8	65	700	980	21.3	2.28
Santalum spicatum	1	70	130	0	18	380	210	24.0	2.00
Templetonia egena	1	20	35	2	15	50	260	31.5	2.40

the lateritised serpentinites in the southern part of the study area. However the mineralised samples were readily separated from the lateritic samples by consideration of the manganese levels. Leaf samples collected over the gossan contained more than 200 ppm nickel and less than 1400 ppm manganese. Similar nickel values were occasionally obtained over laterite but were conspicuous by their associated high manganese levels of more than 2000 ppm.

It is also apparent, from the tabulated data, that metal values in the twig ash are significantly lower than in the leaf (phyllode) ash.

Examination of the appropriate frequency distribution plots showed that generally the range of metal values was greater in leaf ash than in twig ash, and this suggested that the leaf would be the superior sampling medium.

Threshold limits for anomalous and possibly anomalous values were obtained by consideration of the frequency distribution graphs. The nickel leaf ash data for A. burkittii and A. resinomarginea were plotted and anomalous values (more than 100 ppm nickel) in a general way indicated the gossanous zone. The gossanous zone was not indicated by any other data, including twig nickel contents, for these two species.

A. linophylla which is confined either on or near the gossanous zones contained anomalous (more than 130 ppm) nickel levels in leaf ash. However the distribution of these three species is generally limited to outcropping areas, whereas the aim of biogeochemical prospecting is to locate mineralisation beneath soil-covered flats where other surface exploration techniques are ineffectual.

A. aneura is often the dominant tree species in such an environment and exhibited a thin but widespread distribution over this outcropping study area. 132 samples of A. aneura were sampled over the Marriott Prospect and embraced areas immediately east of the study area.

Superimposing anomalous and possibly anomalous metal values (obtained by graphical techniques) on geology plans, revealed that nickel, and to a lesser extent copper, values in leaf ash of A. aneura outlined the gossanous zones. The nickel leaf ash plot is shown in Fig. III-7. It includes most of the study area as well as the eastern extensions of Marriott Prospect and the co-ordinates allow correlation with Fig. III-3, -4, and -5.

D. DISCUSSION OF RESULTS.

Perhaps the most striking observation made at Marriott Prospect was the lack of a pronounced geobotanical anomaly over the serpentine areas. Serpentine floras are reputed to be so greatly differentiated from the surrounding vegetation that the serpentine boundaries are readily observed (Brooks, 1972). This statement is certainly true in humid environments as in New Zealand but it is suggested that in arid areas, where extensive calcification of the soil profile occurs, the serpentine soils do not present a markedly hostile environment for the xerophytic vegetetion. For example a typical serpentine soil on Marriott Prospect might contain 1% magnesium and 0.4% calcium whereas a serpentine soil from Dun Mountain, New Zealand would have 8% magnesium and 0.2% calcium. It is apparent that the recognition of ultrabasic host-rocks for nickel mineralisation by geobotanical observations in this arid environment will not be as obvious as in more humid environments. Nevertheless the habitat specifivity of A. burkittii and A. resinomarginea will be of use in mapping basic volcanics/intrusives and serpentinised clinopyroxenites.

The geobotanical anomaly displayed by Cassia sturtii coincides with a soil nickel anomaly at the footwall of the serpentinised peridotite. Topographically, this soil anomaly is situated at most a few hundred feet, downslope

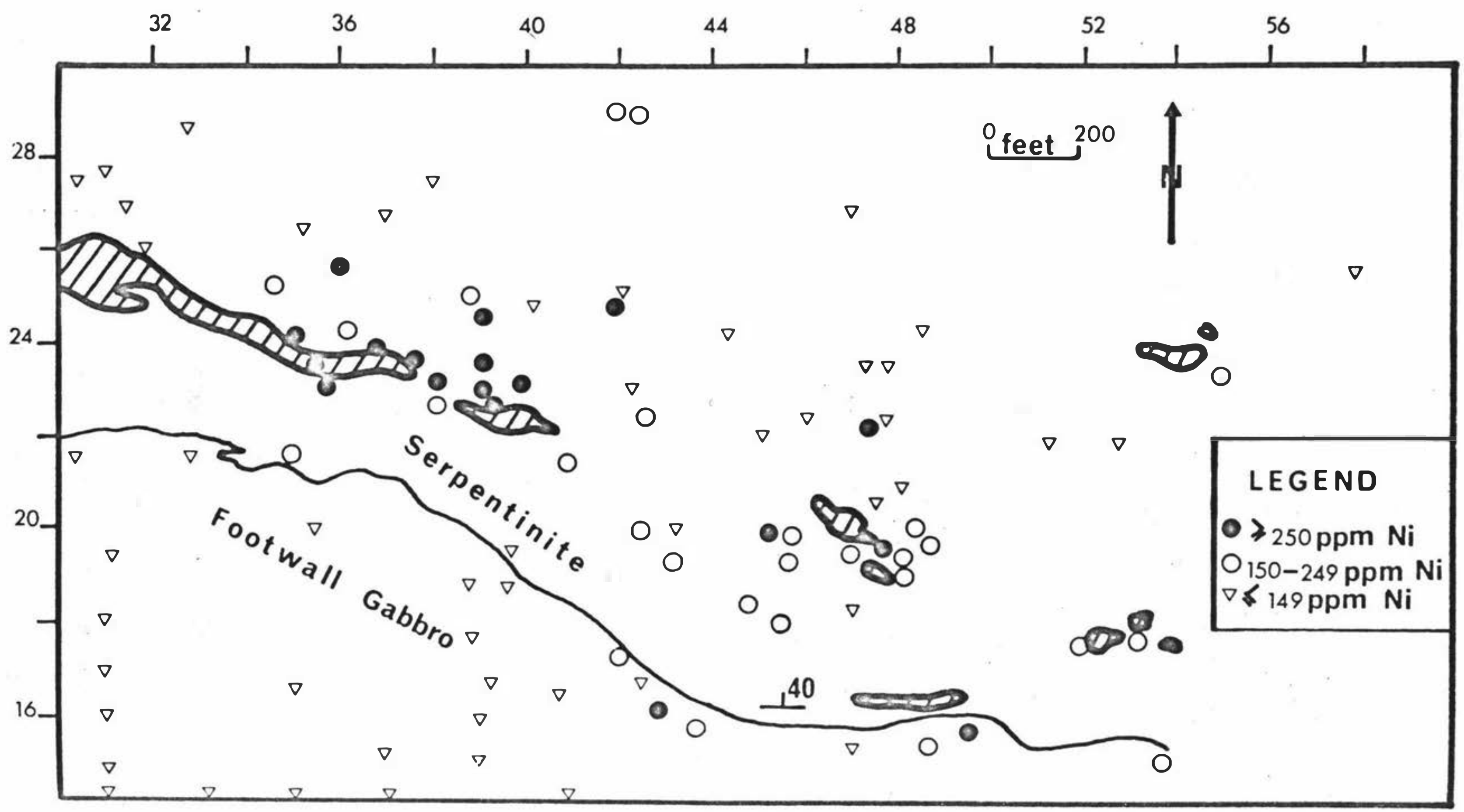


Fig. III 7 Biogeochemical nickel plan of Marriott Prospect, using leaf ash of *Acacia aneura*.

from the gossanous ridge and from a bedrock feature (see Fig. III-3, -4, -5). It is envisaged that nickel weathered from the gossanous zone was leached and winnowed downslope by sheet-wash to the flat ground at the top of the gabbro scarp. Marshall (1970a) considers however, that the chemical mobility of nickel in this alkaline environment is limited. The soil attains thicknesses in excess of six inches and exhibits a finely powdered texture and it is considered that the soil texture and perhaps also the carbonate content are the causal factor for the monospecific C. sturtii community. This interpretation is based on observations made in several areas of the Kurrajong region and it is significant that the biogeochemical nickel analyses were low and fluctuated around 90 ppm. C. sturtii has no affinity for nickel and its coincident distribution with a soil anomaly is misleading as is the distribution of A. linophylla over and around the gossanous zone.

The results of the orientation biogeochemical survey were encouraging and showed that most, if not all of the plant species contained anomalous nickel concentrations over the gossanous zone. The observation that the leaf ash of Acacia aneura can outline such areas (Fig. III-6) suggested the next stage was to test this prospecting tool in an area of poor outcrop or deep exotic overburden (transported soil cover). This work is described later in the section.

It has already been shown that a biogeochemical or soil geochemical nickel anomaly does not necessarily indicate sulphide mineralisation and the present-day trend is to multi-element determination in an attempt to characterise nickel sulphide mineralisation reliably. In this connection, the coincident nickel-copper anomaly is considered to be the most reliable general indicator (Marshall, 1970a). The position regarding biogeochemical anomalies over contact zone nickel sulphide mineralisation is not clear. Marshall, (1970a) obtained "strongly contrasting copper anomalies" yet Nielsen (1972) working over the Spargoville deposits obtained coincident nickel-copper anomalies, in the bark of Eucalypt trees, over lateritised serpentinites rather than the contact gossanous zones. At Marriott Prospect, relatively few coincident nickel-copper biogeochemical anomalies were obtained and as expected, the copper contrast was lower than nickel because of the low copper content of the mineralisation. The copper data did not allow discrimination of laterite from mineralisation or improve the delineation of the mineralised zones; and the cobalt levels in all the plant species tested were too low (less than 20 ppm in ash) to be accurately monitored. It is apparent that for geochemistry and biogeochemistry, a sulphide indicator element is required for reliable discrimination of nickel sulphide mineralisation in this environment.

3. REGIONAL GEOBOTANICAL STUDIES.

A. GENERAL INTRODUCTION.

Most of the ground examined in the Kurrajong Region lies in the relatively narrow greenstone belt which may approach 10 miles in width. Beyond these characteristically hilly areas, the sand-plains and granite outcrops exhibit the usually low relief of the Old and New Plateaux. The sand-plains, which can be seen only 5 miles north of Wildara on the main Weebo road are characterised by Eucalyptus kingsmillii (spinifex gum), Triodia spp. (spinifex grass) and the scarlet-flowered Grevillea sarissa. On the granite hills, a few miles north of the Weebo homestead, Acacia linophylla with unusually long, pendant phyllodes dominates the tree layer, whilst Dodonaea petiolaris is the most common shrub species. The adjacent alluvial flats support Hakea arida, Acacia oswaldii and Eremophila oldfieldii tree species with the sole shrub representative being E. fraseri. The granite ranges, 20 miles south of Wiluna supported markedly different vegetation and included Acacia resinomarginea, Eremophila exilifolia and Ptilotus obovatus.

The sand-plains around the Windarra nickel deposits, a few miles north of Laverton, support the E. kingsmillii - Triodia spp. formation, but on the rocky chert ridges, the character of the vegetation changes abruptly to the tree species A. aneura and A. quadrimarginea, with Cassia sturtii and Dodonaea latrobei as the shrub representatives. The discovery gossans which outcrop at the base of the chert ridge supported only the above-mentioned species and no indicator plants were apparent.

B. MT. CLIFFORD, MARSHALL POOL AND WILDARA TRAVERSES.

(i) Introduction.

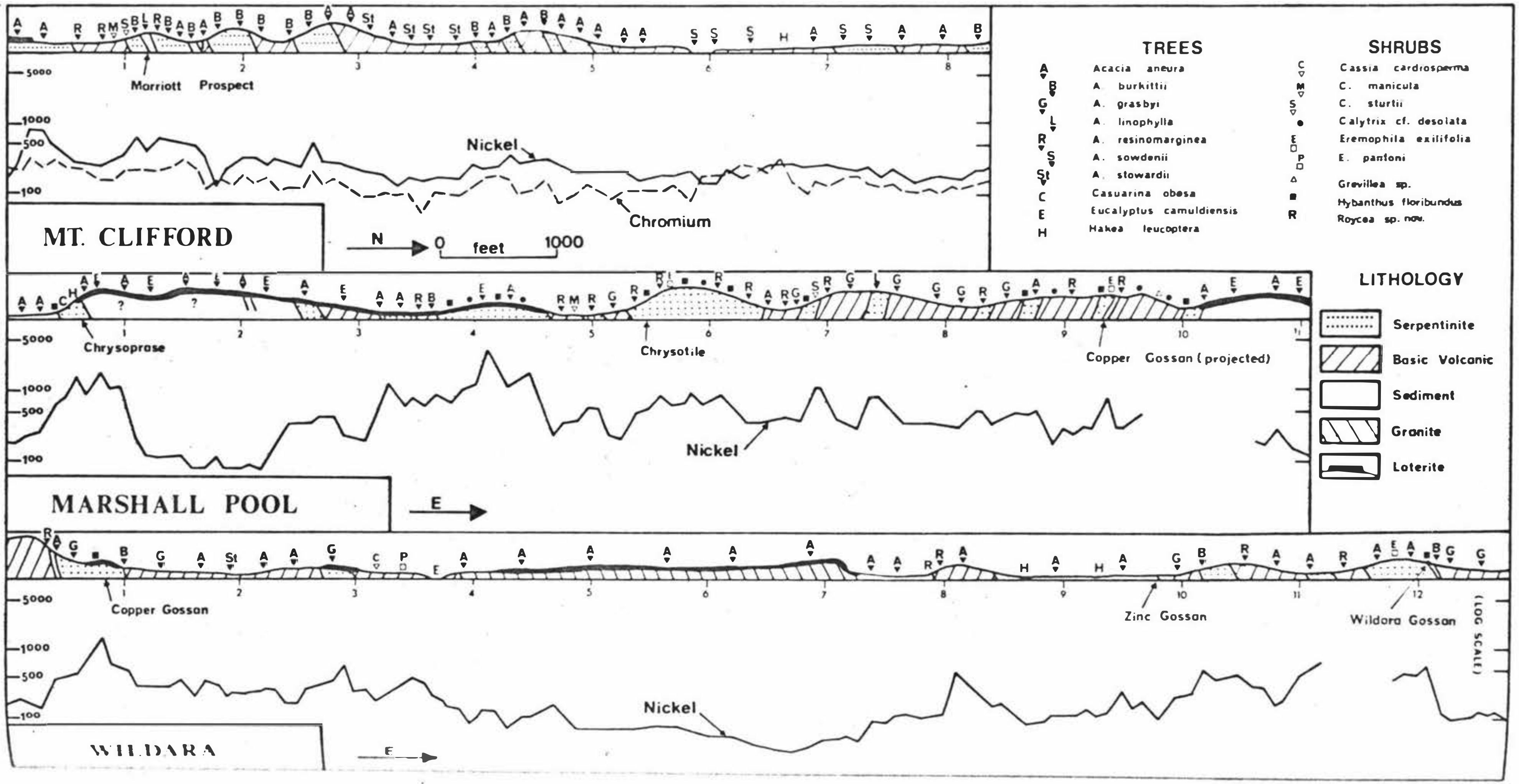
The Kurrajong greenstones were examined in detail at three areas situated at approximately 10 mile intervals along the regional north nor-west strike of this metavolcanic belt. The location of these three areas, Mt. Clifford, Marshall Pool and Wildara are shown in Fig. III-1., and were initially studied by means of belt transects usually 1000 or 2000 feet long by 100 feet wide sited over gossanous zones. However, it was decided to carry out regional geobotanical studies using 1:7200 scale aerial photos to map the vegetation and geology at the same time. In this way, 2000 foot wide strips of ground up to 2 miles long were mapped, and appropriate soil geochemical studies were also undertaken.

The three areas all embrace potential host rocks for nickel sulphide mineralisation, and contain relics of the laterisation process to varying degrees, being least in the Mt. Clifford area and at their maximum in the Marshall Pool area.

(ii) Geological Setting.

Mt. Clifford.

The southern 2000 feet of this traverse were covered previously by the Marriott Prospect study area. In Fig. III-8, the topography, geology soil geochemistry (nickel and chromium) and geobotany are shown diagrammatically and the figure is a synthesis of the mapping of a 2000 foot strip of ground. It is seen that the Mt. Clifford complex embraces the Marriott zone which contains nickel mineralisation in a serpentinised peridotite unit just above the gabbroic sill. The sequence dips and youngs towards the north and magmatic differentiation is witnessed by the trend northwards from metaclinopyroxenites together with an increasing basic volcanic


MT. CLIFFORD
Morriott Prospect
Nickel
Chromium
N
0 feet 1000
MARSHALL POOL
Chrysoprase
Chrysotile
Copper Gossan (projected)
E
WILDARA
Copper Gossan
Zinc Gossan
Wildara Gossan
(LOG SCALE)
5000
1000
500
100
TREES
A Acacia aneura
B A. burkittii
G A. grasbyi
L A. linophylla
R A. resinomarginea
S A. sowdenii
St A. stowardii
C Casuarina obesa
E Eucalyptus camuldiensis
H Hakea leucoptera
SHRUBS
C Cassia cardiosperma
M C. manicula
S C. sturtii
Calytrix cf. desolata
E Eremophila exilifolia
P E. pantoni
Grevillea sp.
Hybanthus floribundus
R Roycea sp. nov.
LITHOLOGY
Serpentinite
Basic Volcanic
Sediment
Granite
Laterite

component. The anomalous east-west strike at the Marriott Prospect is the result of a large complex fold structure (The Mt. Clifford Complex).

Marshall Pool.

The Marshall Pool area has been studied in detail from a petrogenetic viewpoint by McCall and Leishman (1971). It is considered to be a north-plunging syncline flanked to east and west by lateritised terrain which in part obscures the bedrock. Ultrabasic and basic igneous rocks occur as outcrop and rubble and there are minor but persistent metasiltstone intercalations. These sediments bands display abundant convolute laminations, indicative of depositional instability and provide the only reliable facings. The environment was considered to be shallow subvolcanic intrusive, perhaps with analogy to the ultrabasic magmas at present some 4 kilometres beneath the Hawaiian volcanoes. (Eaton, 1962; Malahoff and Woollard, 1966). A chrysotile prospect is situated near the synclinal axis and in the western lateritic scarp, chrysoprase workings can be seen. A minor copper gossan had also been found in a thin sediment band which can be correlated with the sediment at about 9500 feet east in Fig. III-8.

Wildara.

The Wildara area is considered tentatively as an anticlinal structure with a granitic intrusion along the fold axis separating the basic-ultrabasic formations into eastern and western belts. A copper prospect is shown at about 800 feet east and a zinc gossan (sediment) with its projected position is shown at 9800 east. The main Wildara gossan, which will be discussed further, is shown at 12200 east. Lateritisation is most extensive over the granite in the centre of the area. It should be noted that the 3 traverses are shown at the same horizontal scale, and the soil geochemical data is on a logarithmic scale.

(iii) Soil Geochemistry.

Mt. Clifford.

The nickel soil levels reach their maximum values over the lateritised serpentinites in the south; and to the north peaks coincide with the serpentinised peridotites and clinopyroxenites. The chromium soil values follow nickel quite closely, except near the major drainage tract at about 6000 north. Generally they are less than 160 ppm over the basic units, and nickel values are also low being less than 300 ppm.

The iron content in the soils normally fluctuates about 4%. The lateritised area is amarked by higher iron (5.5%) and manganese (600 ppm) levels whereas manganese is usually in the range 300 - 380 ppm. Copper and Zinx values are low being less than 50 and 90 ppm respectively, except for one zinc value of 200 ppm obtained over the sediment band at about 1600 north.

Soil pH is usually alkaline on the low flat ground and may attain values of 8.5. On the basic outcrop areas, pH is close to neutrality (6-7) and over the lateritised areas it drops to 5-6. The serpentinised peridotite outcrops are generally 7-7.5 but the meta-pyroxenite units bear markedly alkaline soils with pH 7.5-8.5.

Marshall Pool.

The nickel soil values were considerably higher than the Mt. Clifford area probably because of the effect of lateritisation. Values of 4000 ppm were obtained over some lateritised serpentinites (e.g. 4100 east).

Copper and zinc values were low being less than 40 and 80 ppm respectively. Manganese values follow iron closely. They were lowest over unlateritised basics, being less than 400 ppm and 4% respectively. They increased slightly over the serpentinite units with typical values of about 5-6% iron and 400-500 ppm manganese. Over lateritic areas values were much higher; iron attained 9% and manganese 800 ppm. Chromium values were very similar to manganese and ranged from less than 300 ppm over basics to more than 800 ppm over lateritised ultrabasics. Soil pH varied from 5 over lateritic areas to 7-7.5 over serpentinites to 8-8.5 over basic amphibolechlorite rocks. The magnetic band bounded by ferruginous lateritic at 600 east also exhibited high pH in the narrow range of 8-8.5.

Wildara.

Nickel soil values varied from 100 or less over the lateritised granite to more than 1000 over lateritised serpentinites at about 800 east. The serpentinites generally exhibited high nickel values of about 1000 ppm, whilst the values in the basic volcanics were commonly less than 500 ppm nickel. Copper and zinc values were again quite low, being less than 90 and 100 ppm respectively. Iron content fluctuated around 3-4% but climbed to 5.8-6.0% over the eastern serpentinite ridge, and over the western lateritised serpentinites iron levels attained 7-8%. Manganese exhibited a similar pattern to iron with soil values less than 300 ppm except over lateritised areas where 700 ppm was common.

Soil pH varied from pH 6-6.5% over the lateritised granites to neutral over the rocky serpentine ridges (7-7.5), but became quite high (pH 8-8.5) on the basic amphibole-chlorite rubble and flats.

(iv) Geobotanical Studies.

In Fig. III-8, only the dominant tree and shrub species are shown which characterise various segments of the environment.

Mt. Clifford.

Acacia aneura inhabited nearly all the ecological niches encompassed by this traverse but A. resinomarginea was often restricted to outcropping rocky basic and metaperidotic areas where soils are skeletal and near neutrality. On the basic amphibole-chlorite flats A. stowardii became dominant, and the soils were markedly alkaline. A. burkittii formed a nearly monospecific community over the metaclinopyroxenites with their relatively calcareous and alkaline soils. A. sowdenii was confined to the colluvial flats (Plate III-3) with Hakea leucoptera where the solonised brown soils predominate. The shrub species such as Dodonaea lobulata and Cassia manicula were locally important in rocky areas as encountered at about 1000 north.

The Marriott zone was further investigated by detailed belt transects. Six transects covered most of the study area as previously described. The gossanous Marriott zone was recogned d as being confined to a basal serpentinised periodotite or dunite unit, which either lensed out to the west or disappeared under colluvial solonised brown soils to the east. Therefore 5 additional belt transects, each being 1200 to 2000 feet long by 100 feet wide, were orientated north-south and sited at 1000 foot intervals along strike. These transects, together with the initial study area, covered some 6000 feet of the potential ore-bearing structure. The geology is well exposed immediately west of Marriott Prospect, and the main sediment band occupies a topographic low. The serpentinised peridotite unit thins and is flanked by metabasalts and metagabbros. These latter rock-types with their neutral soils are characterised by the tree species Acacia hilliana, A. resinomarginea and by the shrubs Eremophila exilifolia, Cassia manicula, Calytrix cf. desolata and the mint, Prostanthera cf. striatiflora. The meta-clinopyroxenites with their calcareous soils suppor A. burkittii which also grows in the zinc rich (200 ppm) soils over the sediment band.

To the east of Marriott Prospect the meta-clino-pyroxenite hills are characterised by A. burkittii. The serpentinised peridotites usually form only low rubbly out-crops separated by areas of solonised brown soils. A. aneura and A. resinomarginea characterise the serpentinite islands, and are joined occasionally by the mustard Lepidium lepto-petalum and Eremophila platycalyx.

The trees Eremophila oldfieldii var. august-ifolia and Santalum spicatum display a low and sporadic occurrence. Acacia oswaldii to the casual observed, has a similar distribution pattern. However, it was recorded only over serpentinised peridotites at a horizon which can be correlated with the mineralised zone, some 3000 feet to the west.

The non-outcropping areas, occupied by the calcareous alkaline soils support Hakea arida and H. leucoptera, with a shrub layer comprising Cassia nemophila, C. artemi-sioides, C. sturtii and Eremophila pantoni.

Marshall Pool.

Acacia aneura was the most widely distributed species, being co-dominant with A. linophylla over the lateritised areas, and extends with low frequency over basic and ultrabasic terrain alike. The lateritised serpentinites at 4000 east were also characterised by the tall shrub Grevillea extorris and two low shrub species Bossiaea walkeri and Hemigenia sp.

On the steep western scarp of laterite (at 600 east), a pronounced geobotanical anomaly was clearly visible both on the ground and on 1:7200 aerial photos. A 200 foot wide band of magnesitic soils with chrysoprase nodules, overlay a metadunite parent and was flanked above and below by ferrug-inous laterite with typically acid (pH 5.0) soils. The magnesitic band supported Casuarina obesa (she-oak) and Hakea arida.

Acacia resinomarginea dominated the metagabbro outcrops at 3700 and 4800 east. It also spread over the chrysotile prospect (5500-6000 east) which was situated in metadunites.

The amphibole-clorite units further to the east with their alkaline soils supported a near monospecific tree layer of A. grasbyi (minnaritchie). This species is remarkable in that its rough, curling bark is bright red and the sap is slightly toxic.

Calytrix cf. desolata often grew in an extremely harsh terrain, where basic and ultrabasic bedrock outcropped strongly and the skeletal soil existed only as small isolated pockets. Eremophila exilifolia, sometimes accompanied by Dodonaea filifolia, was also conspicuous on very rocky outcrops of serpentinite, whereas Grevillea sp. inhabited the basic volcanic outcrops.

Lybanthus floribundus a small compact shrub, was observed on slightly acid soils (pH 6-7) over lateritised serpentinites and over serpentinite ridges which exhibited no visible signs of the lateritic profile.

Detailed studies were made, by belt transect, over a copper gossan in a 12 inch wide sediment band which, although 9000 feet south of the traverse line shown in Fig. III-8 can be correlated with the sediment shown at 9500 east. Chip samples of the gossan contained visible flecks of malachite and assayed at up to 4% copper, 2% zinc and 0.03% silver. The soils reflected this bedrock anomaly with zinc and copper values of up to 500 and 200 ppm respectively. Contrast over background values was in the range of 5-10 times.

The gossanous sediment formed a narrow, discontinuous intercalation on the side of a serpentinite ridge close to the junction with collovial-alluvial soils on the flats. Accordingly most, if not all of the variation in the species distributions could be assigned to the abrupt change from an outcrop to a relatively deep soil environment. Acacia burkittii grew at and below the gossanous zone, probably as a function of soil pH and texture. The most interesting species here was Ptilotus obovatus, the reputed copper indicator, which displayed mauve-coloured flowers, which elsewhere are white.

Wildara.

The ubiquitous distribution of A. aneura was also observed in the Wildara area, and this species form a monospecific community on the lateritised granites. On the basic metadolerite and metabasalt ridges A. resinomarginea dominated the tree layer whereas A. grasbyi, sometimes with Cassia cardiosperma characterised the basic amphibole-chlorite rocks which usually form flat poorly-outcropping areas.

In the large dry Codys Creek, at 3700 east, Eucalyptus camuldensis forms a 40 foot high ribbon of trees, and the only other relatively broad-leaved tree Brachychiton gregorii (Kurrajong tree) occurs as a solitary tree growing on metabasalt hills, amid a low shrub layer. Another unusual form encountered in this area is a flax species Dianella revoluta which is also restricted to drainage tracts.

The shrub Eremophila exilifolia was again observed to be restricted to basic and ultrabasic ridges whilst E. pantoni in this area grew only on the alkaline flats over amphibole-chlorite bedrock.

Hybanthus floribundus was restricted to the lateritised serpentinites around the copper prospect at 700 east and over the serpentinised peridotite unit which contained the Wildara nickel gossan on its eastern contact. At this latter site another native mint, Prosthanthera baxteri var. Crassifolia was noted.

An unusual geobotanical anomaly was observed at a granite-metabasalt contact at 7900 east. Here quartz veining delineated the contact zone which was otherwise obscured by colluvial soils and quartz scree. The tree layer gave way to a monospecific community of Roycea sp. nov. which is a small woody shrub. Trace element contents in the associated soils were very low and suggested extensive leaching in this area.

Detailed geobotanical studies were carried out over the Wildara gossan by means of conventional belt transect. The gossanous zone is several hundred feet long and about 12 inches wide. Although nickel and copper values approach 1% and 0.4% respectively, the soil levels show only a low copper, nickel anomaly barely twice the serpentinite background.

Acacia burkittii together with A. grasbyi and A. resinomarginea flourished over the serpentinite and gossanous zone. The shrub layer included the Cassia, Scaevola, Eremophila and Ptilotus genera but only Hybanthus floribundus exhibited a definitely restricted distribution over the gossanous zone.

C. OTHER MT. CLIFFORD NICKEL PROSPECTS.

(i) Introduction.

The '880', '107' and Mt. Newman nickel prospects all lie within 4 miles of Mt. Clifford itself, and are shown in Fig. III-1. Gossans and pseudo-gossans have been located at these areas and some encouraging nickel intersections have been obtained by deep drilling programmes.

(ii) Geological Setting.

These three prospects are located in serpentinised peridotite and pyroxenite units and probably occupy a common stratigraphic horizon.

The '880' prospect is an east-west trending serpentinite ridge which bears a strong imprint of the laterisation process. The serpentinite unit has an outcrop width measurable in hundreds of feet, and although no definite gossanous zones habe been located, some rock-chip samples assay up to 1% nickel, 0.7% chromium and 0.1% manganese. The high manganese and chromium values suggest a lateritic origin. The '880' Prospect is stratigraphically below Marriott Prospect which is on the other side of Clifford Creek, about amile to the north.

A major shear zone (The Leinster Lineament) is considered to separate the '880' and Marriott's from the eastern prospects which include the '107' and Mt. Newman.

The '107' prospect consists of a serpentinite ridge with a chloritic contact zone against footwall meta-basalts to the west and sediments to the east.

At the Mt. Newman Prospect a small gossan occupies the footwall-sediment serpentinised peridotite contact and contains up to 0.7% nickel, 0.6% copper. The ultrabasic unit outcrops as a nearly circular mass, and is surrounded by sediment scree which sheds off the steep chert ridge immediately to the east of the serpentinite.

(iii) Soil Geochemistry.

Background nickel values in the Mt. Clifford area were high and ranged up to 200 ppm (-80 mesh, 6 inch depth). The serpentinite areas were characterised by nickel values in excess of 400 ppm and lateritised areas contained both high nickel and chromium values, often in excess of 1000 ppm.

The '880', '107' and Mt. Newman Prospects were all delineated by nickel values in excess of 800 ppm.

The '880' Prospect, because of the laterite prescence, had soil chromium values usually twice as high as the nickel levels but the other two prospects had a nickel/ chromium ratio greater than 1.

(iv) Geobotanical Studies.

'880' Prospect.

Three belt transects, each 2000 feet long were orientated north-south at 1000 foot intervals along strike. Considering the tree species firstly, it was apparent that Acacia resinomarginea and A. aneura were widely distributed whereas A. burkittii was limited to small areas at the eastern limits. A. linophylla exhibited its usual rocky high-ground habitat, and was accompanied by A. tetragonophylla and A. hilliana.

Eremophila exilifola and E. aff. exilifolia grew widely over the lateritised areas. Cassia manicula, C. sturtii, C. helmsii and C. nemophylla occur at low frequency over wide areas.

A similar non-spedific distribution was also exhibited by Ptilotus obovatus, Scaevola spinescens, Kochia triptera, Dodonaea latrobie. Calytrix cf. desolata grew over basic rocky outcrops only and Hybanthus floribundus was locally very abundant over high nickel (more than 2000 ppm) soils. A few specimens of Acacia oswaldii were observed in some of the lateritic areas of this large prospect but were **not** **able** to be correlated with the bedrock geology at the time of observation.

'107' Prospect.

The footwall contact zone being on the junction of skeletal and solonised brown soils is an alkaline environment and supported Acacia grasbyi, A. burkittii, and A. aneura. A. resinomarginea was restricted to the serpentinite hills with A. linophylla while the shrub layer comprising Kochia triptera, Cassia sturtii, C. helmsii, Ptilotus obovatus and Eremophila aff. exilifolia extended over the entire prospect area. Hybanthus floribundus was restricted to the serpentinised dunites which lie some 800 feet east of the footwall contact.

Mt. Newman Prospect.

The chert ridge which towers over the serpentinite unit was covered with a distinctive tree layer comprising *Acacia* aff. *aneura* and *A. quadrimarginea*. *A. linophylla* and *A. aneura* extended down over the serpentinites and *A. resinimarginea* was restricted to them. Several shrub species also displayed distributions limited to the serpentinites but this may result from the fact that the serpentinite area is strongly outcropping with only skeletal soils whilst the sedimentary scree surrounds and provides a relatively deep soil. These species included *Eremophila exilifolia*, *Cassia sturtii*, *C. manicula* and *C. nemophila*.

Three shrub species displayed a very small and common distribution over the serpentinised peridotite outcrops and comprised *Hybanthus floribundus*, *Trymalium ledifolium* and *Prostanthera striatiflora*.

D. DISCUSSIONS AND CONCLUSIONS.

The extensive field observations suggested that the dominant influences on plant distributions were soil-type, degree of calcification, pH, major element status and laterisation. The trace elements vary in sympathy with these conditions and can therefore exhibit a degree of correlation with plant distributions. It is only in exceptional circumstances that trace elements in the soil will influence plant distributions and would involve either nutrient deficiencies (Ishizuka, 1971), accumulator plants, or toxic concentrations of heavy metals in the 'available soil solution'.

In Fig. III-9 the plant community-lithology relationships are schematically indicated and the communities are defined by the dominant tree species. An attempt has been made to suggest the specific substrate conditions which generate the geobotanical relationships. Fig. III-9 suggests

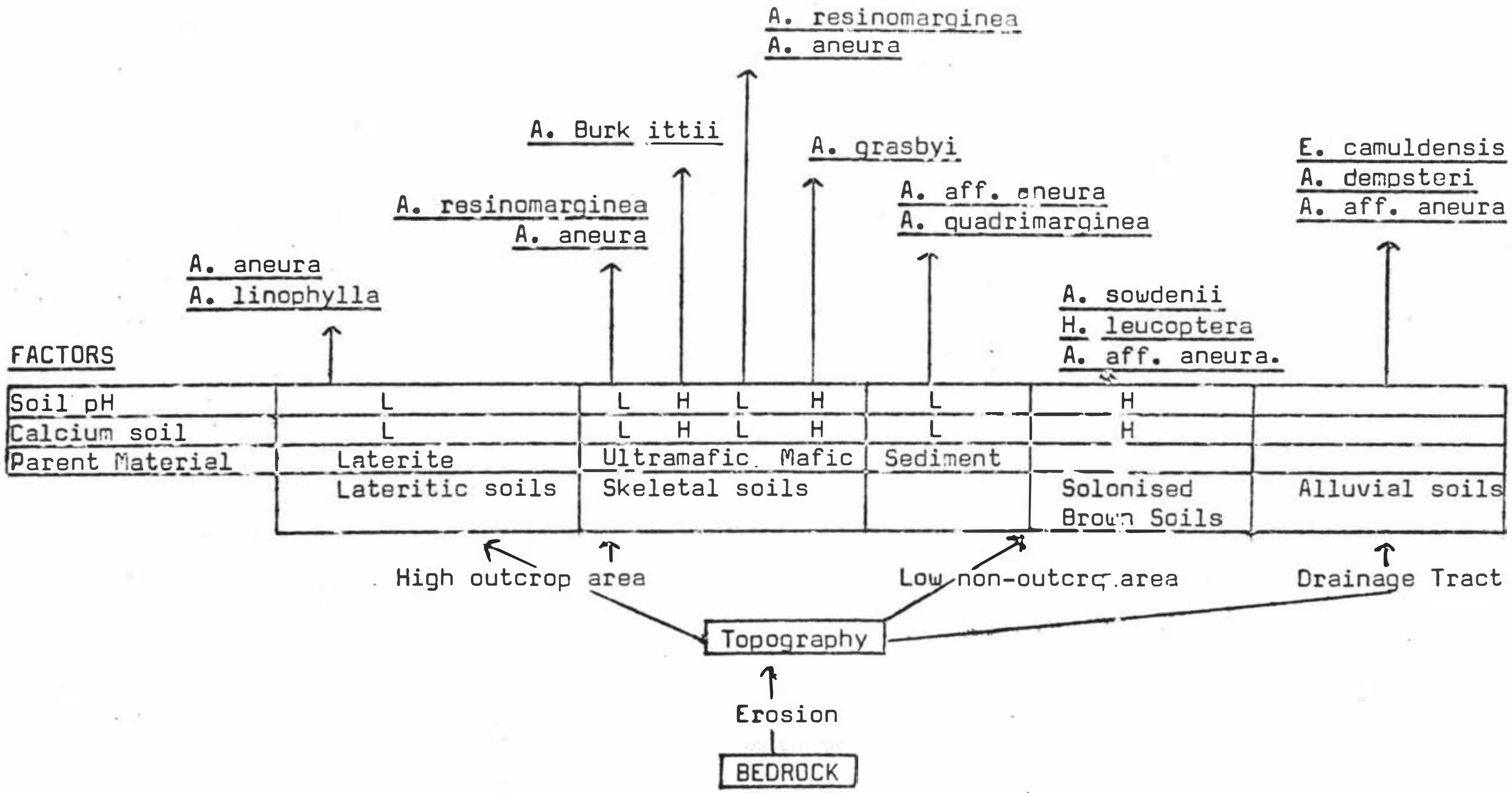


FIG. III-9 Hypothetical classification of plant communities with respect to lithology. (L - low, H - high).

that the soil pH and calcium (carbonate) levels are the prime factors which regulate the plant distributions. Obviously other major elements are involved and to arrive at a more complete explanation must involve chemical analysis of the major soil components as well as an evaluation of the soils physical characteristics. Atomic absorption analysis is suitable for measuring traces of many elements in soils but at percent concentrations, x-ray fluoresence analysis supported by x-ray diffraction studies would be more appropriate. Such facilities were no available for this study.

The geobotanical relationships concerning plant distributions and geology can be used in two general ways. The field prospector or geologist on foot or motorcycle may employ 'indicator' shrub or tree species to locate interesting areas such as gossans. On a larger scale, the tree layer is suitable for remote sensing and regional aero-visual surveys. The remote-sensing aspects of geobotany are discussed in Section VI.

Considering the tree layer firstly, it was observed that certain species exhibited distributions restricted to specific lithologies. Acacia aneura, as represented by the closely related species in the A. aneura Complex, displayed a practically unlimited distribution whereas the other Acacia species were restricted either to outcropping skeletal soil areas or to the relatively deep solonised brown soils. Specifically, it was observed that A. linophylla preferred well-drained neutral to acid soils on higher ground. A. resinomarginea grew on ultramafic and mafic outcrops (Plate III-4), whereas A. burkittii flourished only on serpentinised clinopyroxenites. A. grasbyi occupied amphibole-chlorite soils which were usually intermediate in character between the skeletal and solonised brown soils. A. quadrimarginea characterised the steep sedimentary, and often silicified, ridges, whilst A. sowdenii was restricted to the deep solonised brown soils together with various Hakea species. The drainage tracts were marked by a distinctive vegetation community comprising Eucalyptus camuldensis, Acacia aff. aneura and A. dempsteri, a thorny, flattened phyllode and phreatophytic species.

The shrub layer also contained species which had restricted distributions over specific substrates. The basic metabasalts and metagabbros were characterised by Calytrix cf. desolata, Cassia manicula, Eremophila exilifolia while the serpentinites supported Dodonaea lobulata, E. aff. exilifolia, and three small species which appear to be worthy of further study. They are Hybanthus floribundus, Trymalium ledifolium and the Prostanthera genus, especially P. cf. striatiflora. These genera will be discussed in detail in Section IV.

Finally, three specific examples of geobotanical anomalies are now very briefly discussed. In the Marshall Pool area, Casuarina obesa delineated a band of magnetic soils overlying met dunites. This same tree species was observed at the Scotia and Carr Boyd nickel deposits, some 150 miles to the south in a very similar environment; and this example gives some indication of the large areas over which certain geobotanical relationships are maintained in the arid Eremean environment.

In the Wildara area, a monospecific community of Roycea sp. nov. delineated the contact zone of a granitic intrusion. Preliminary soil analyses have indicated that the soils are highly leached, at least with respect to the base metals. Further soil analyses will be enecessary to ascertain whether this geobotanical anomaly is indicating subsurface geochemical concentrations of certain metals.

The Mt. Clifford Complex is in an area of marked relief and Clifford Creek occupies a valley nearly a mile wide. It extends to the north onto Marriott Prospect and to the south onto the '880' Prospect. Acacia oswaldii was observed growing on lateritised and poorly outcropping serpentinites within the confines of the Clifford Creek Valley. It was usually found growing singly in an apparently random manner as is exhibited by other tree species e.g. Santalum spicatum, Eremophila oldfieldii var. augustifolia and Brachychiton gregori. Such a tree species would normally be dismissed as of no value in geobotanical or biogeochemical prospecting. However chemical analyses revealed the unusual nature of this tree species which is examined at length in Section VII.

4. EVALUATION OF THE BIOGEOCHEMICAL METHOD FOR NICKEL.

A. DESCRIPTION OF TEST AREAS.

(i) Criteria for area Selection.

The orientation biogeochemical survey carried out over the outcropping mineralised zone at Merriott Prospect indicated that the nickel content of *Acacia aneura* leaves could be used to locate a nickeliferous substrate. It then remained to show whether this exploration technique could be applied to soil-covered areas which occupy extensive tracts of the greenstone belts.

The choice of test areas in the Kurrajong Region was severely limited by the fact that no significant nickel mineralisation had been located under soil-covered flats. However vacuum drilling was being carried out in two such areas which also exhibited a flora dominated by *A. aneura*. The drill data were essential to allow evaluation of the biogeochemical results as the surface soil geochemistry bore no relationship to the bedrock situation.

(ii) Mt. Newman Area.

The Mt. Newman Prospect consists of a rather conspicuous near-circular outcrop of serpentinised peridotite, flanked to the west by laterite-capped sediments and dwarfed by a steep silicified chert ridge immediately to the east, The angular "blocky" scree sheds off the chert ridge and flows around the serpentinite outcrop, especially to the south and thus masks the bedrock geology. The serpentinite unit was suspected, from aerial and ground magnetic surveys, to extend southwards for at least 500 feet under the blanket of scree material (Fig. III-10). Induced polarisation surveys indicated anomalies which were correlated with the footwall graphitic shale units. The local strike of the area is slightly west

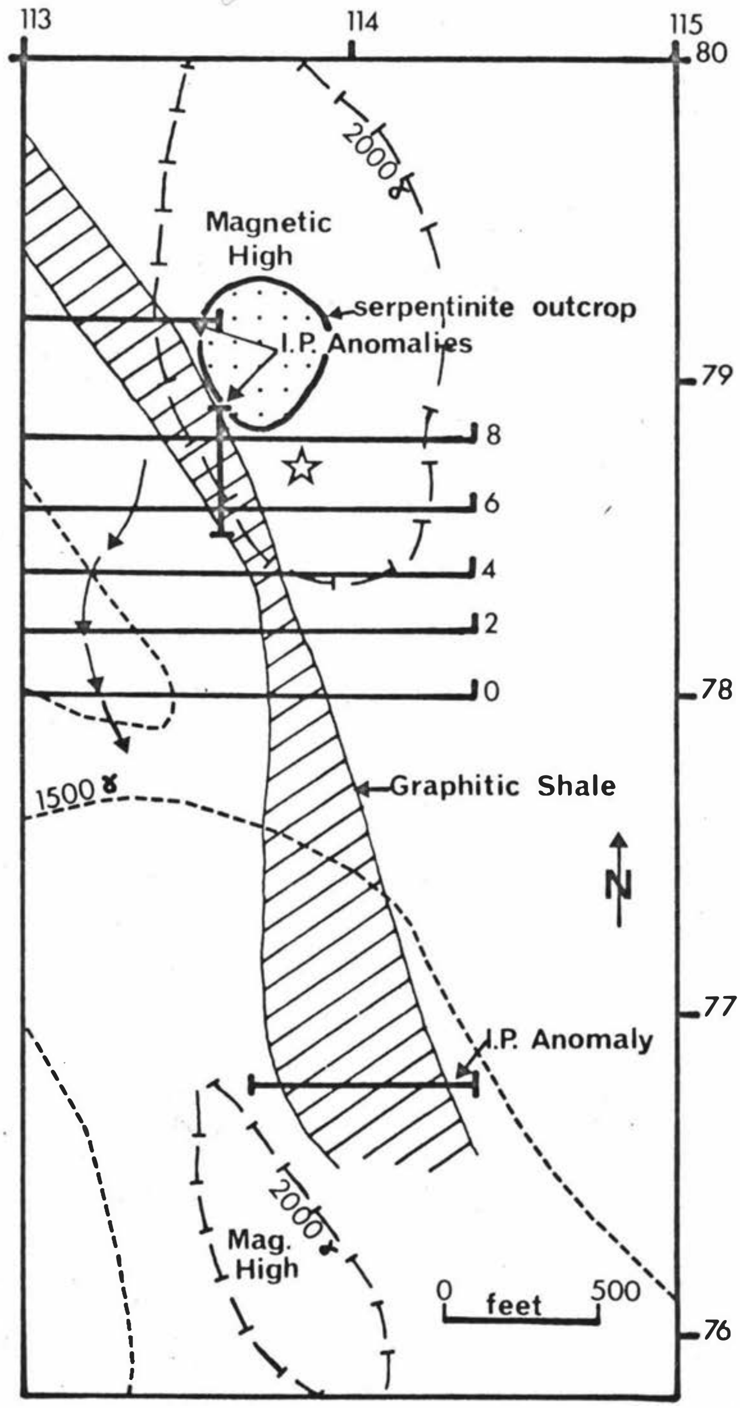


Fig. III–10

Plan of Mt. Newman Prospect, showing geophysical anomalies, serpentinite outcrop and biogeochemical study areas.

of north and the sequence dips steeply to the east. Drilling had located subeconomic grades of nickel mineralisation within the serpentinite outcrop, but possible extensions of the serpentinite unit under the scree had not been tested. Overburden was expected to be relatively shallow with a maximum depth of 20 feet. The vegetation over the scree consisted of a very uniform tree layer of A. aneura. A small creek drained the serpentinite outcrop and ran southwards in a shallow declivity between the ferruginous lateritised sediments to the west and the chert scree to the east.

The biogeochemical survey, was carried out over the scree-covered areas immediately south of the outcropping serpentinite as shown in Fig. III-10.

(iii) Clifford Creek Area.

The Clifford Creek test area lies immediately east of the '880' Prospect and some 6000 feet east of the Marriott Prospect in a broad valley with no outcrop.

The subsurface geology is blanketed by a colluvial-alluvial oberburden of generally unindurated material 25 feet thick and in some areas up to 70 feet deep. The outcropping areas are restricted to the '880' Prospect and to a small laterite hill in the northern part of the area (Fig. III-11).

Vacuum-drilling was carried out along north-south traverse lines and revealed an ultrabasic unit which, if correlated with the '880' serpentinite, appears to lense out towards the east from 1,200 feet to 100 feet over a strike distance of about half a mile. The sequence, as shown in Fig. III-11, dips oabout 40° to the north and therefore places this serpentinite unit or sill stragigraphically below the Marriott Prospect. Vacuum-drilling revealed encouraging values of 0.7% nickel and 0.1% copper on the footwall sediment contact of the serpentinite which may represent a contact zone gossan.

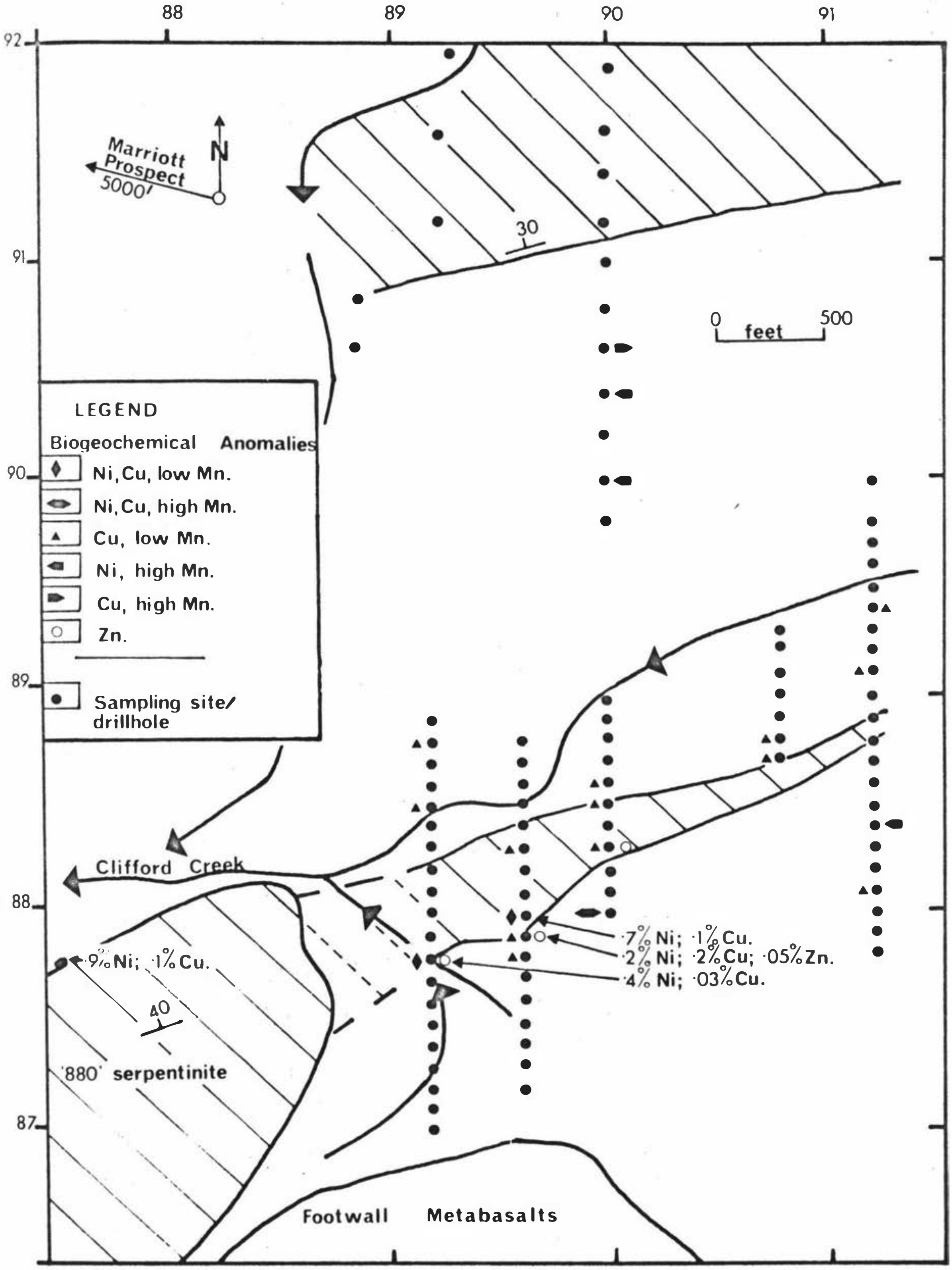


Fig. III–11 Clifford Creek Area, showing geology and biogeochemical anomalies obtained with *Acacia aneura*.

B. SAMPLING AND ANALYTICAL TECHNIQUES.

(i) Mt. Newman Area.

Leaves and twigs of A. aneura were sampled in the biogeochemical survey. Leaves were sampled in the Spring of two consecutive years, and all samples were analysed for nickel, copper, cobalt, chromium, zinc and manganese, iron, calcium and magnesium.

(ii) Clifford Creek Area.

Leaves and twigs of A. aneura were sampled in the Spring of 1970 and, in 1971 were resampled along with bark and sapwood tissue. The techniques using bark and sapwood was initiated by the writer whilst carrying out biogeochemical survey in the New Zealand beech forests over an ultramafic complex, and has since been adopted by other workers (Quin, 1972; Nielsen, 1972).

A. aneura typically attained a height of 10-25 feet and a chest-height diameter of 2-12 inches.

C. RESULTS.

(i) Mt. Newman Area.

Bedrock Geochemistry.

The serpentinised outcrop typically contained 0.2 - 0.5% nickel and 0.06 - 0.1% chromium, whilst copper and copper values are generally less than 200 ppm. The footwall sediment was characterised by relatively high copper and zinc values e.g. 320 ppm Cu and 230 ppm Zn., and by low (80 ppm) chromium levels. The small footwall contact gossan was characterised by coincident high nickel, copper values of 0.7% and 0.6% respectively.

Soil Geochemistry.

Nickel values in the surface soils (-80 mesh B.S.S.) were high over the serpentinite outcrop (400 - 1000 ppm) but decreased rapidly to about 60 ppm in the scree-covered areas to the south. Cobalt levels were 15 - 20 ppm in background areas but increased to 65 ppm over the serpentinite outcrop. Small copper/zinc anomalies (130 ppm/100 ppm) distinguished the footwall sediments and elsewhere the values fluctuated about 30 - 40 ppm. A drainage anomaly, especially for nickel, was observed in the small creek which was recognisable for at least 1000 feet downstream from the serpentinite outcrop.

Biogeochemistry.

Leaf and twig samples were collected on east-west lines spaced at 200 foot intervals as shown in Fig. III-10. The analytical data were evaluated by comparing frequency distribution plots of the various elements between several areas. Iso-concentration single-element biogeochemical plans were also correlated with topography, geology and drill data.

The analytical data were expressed on a dry weight basis (D.W.) and can be converted to an approximate ash weight basis (A.W.) with a factor of 22. The nickel leaf values were generally anomalous (Fig. III-12), with an average of 10 ppm; as compared to the Marriott and Sherwood areas. However, consideration of the manganese levels, which were also high (200 - 500 ppm), suggested that the high nickel levels were of lateritic origin. The soil is acid and iron content in soils and drill samples confirms the imprint of laterisation in this area. Manganese values were low only over the serpentinite outcrop and along the drainage tract as shown in Fig. III-12. A similar pattern for manganese in *A. aneura* leaf was observed at Sherwood, Fig. II-5.

Calcium levels were fairly constant at about

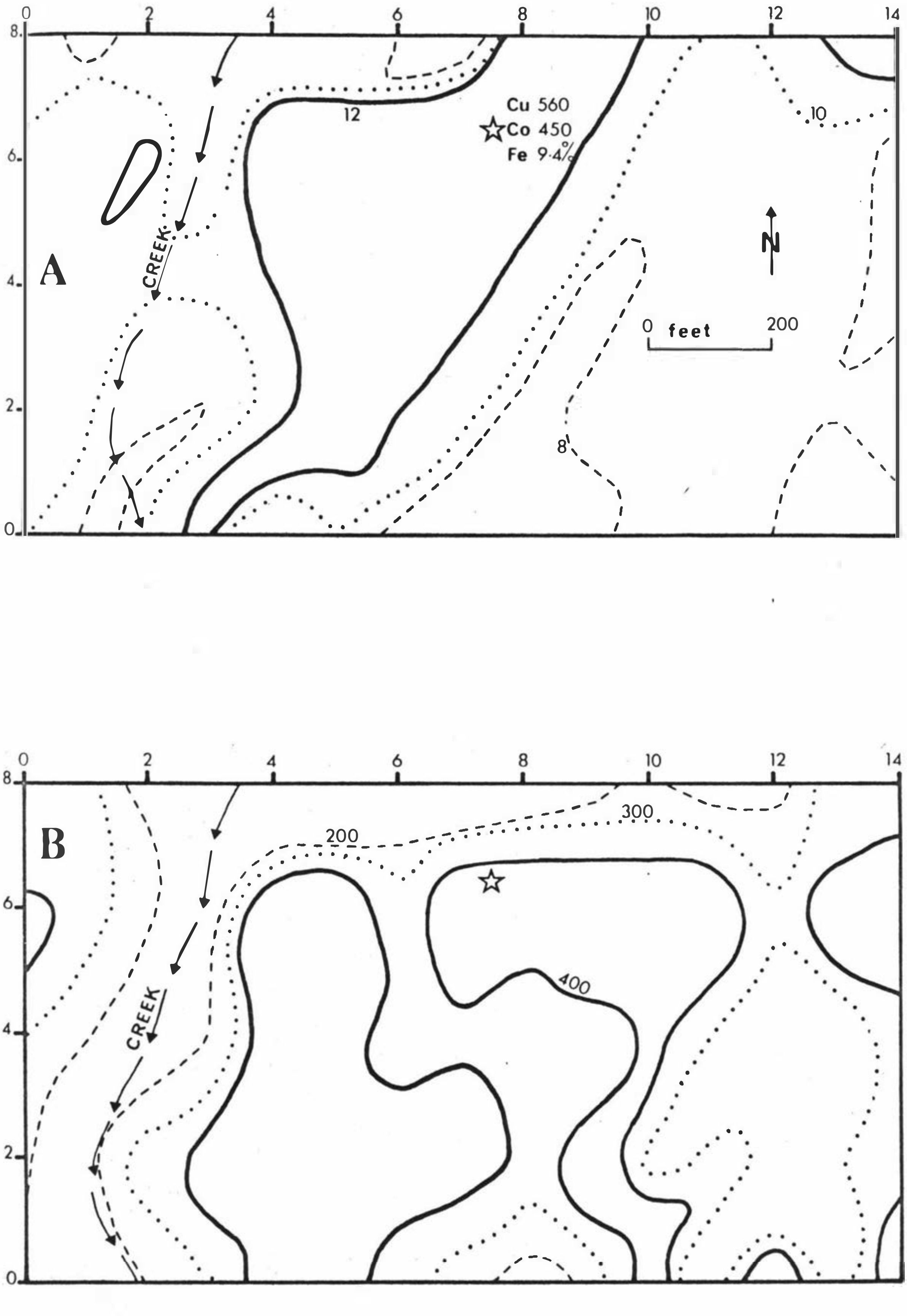


Fig. III–12 Mt. Newman Biogeochemical Plan showing nickel and manganese data obtained with leaf ash of *Acacia aneura.*

1% but magnesium values were high (3000 - 5000 ppm) over the serpentinite outcrop and low (1000 - 2000) over the scree-covered areas. The drill data revealed that magnesium values in a lateritic profile are generally very low due to leaching.

The copper and zinc levels were examined to determine whether the footwall sediment could be delineated. It was apparent however, that laterisation had obscured the original metal distributions. Even the serpentinite outcrop bore evidence of a previous lateritic cap in the form of joint planes filled with ferricrete which contained very high nickel and chromium levels.

The biogeochemical anomaly outlined south of the Mt. Newman serpentinite outcrop by leaf analysis, was not delineated as clearly by twig analysis. This result confirmed the findings obtained at Marriott Prospects. The origin of the anomaly was considered to be due to a lateritic environment as indicated by subsequent drill data. Vacuum drilling disclosed a minor anomaly of 0.06% copper and 0.05% cobalt; which with a high iron content (9.4%) suggested lateritic environment. The mantle of overburden was revealed to be 1 - 10 feet thick and the substrate beneath the biogeochemical nickel anomaly contained nickel concentrations of 400 - 500 ppm which contrasted with the adjacent background values of 100 - 200 ppm.

(ii) Clifford Creek Area.
Bedrock Geochemistry.

The upper surface of the bedrock has been severely altered, with regard to chemical composition, by several weathering processes over the past 10 million years. The following remarks are based on the basal vacuum-drill samples which are assumed to represent only partially weathered bedrock.

The ultrabasic units were characterised by high nickel (0.1 -0.3%) and chromium (0.1 - 1.0%) levels, whilst copper and zinc values were generally low and less than 0.01%.

Magnesium values were usually low, due to the weathered nature of the bedrock, even under 70 - 80 feet of unconsolidated overburden. The concentrations originally were 20% or more but now are commonly in the range 0.3 - 0.03%. The lateritic character of the weathering process is indicated by the generally high iron levels which may even exceed 20%.

The basic rocks had low nickel and chromium levels of about 300 ppm. Magnesium values in fresh basics may approach 10% but observed values were usually 1% or less. The sediments were characterised by their high zinc (400 ppm) and copper (200 ppm) contents. Magnesium (0.5%) and chromium (80 ppm) were usually present in low amounts, iron was around 5% but nickel exceeded 1600 ppm especially if near an ultra-basic contact.

Soil Geochemistry.

The soils were not systematically sampled as it was apparent from previous regional surveys that they were incapable of reflecting mineralisation in the bedrock beneath the deep soil cover. It was noted that the surface soils generally have a higher concentration of the trace metals (chromium, nickel, zinc) than those at depths of 2 feet or more. Sheetwash and deflation would account for the lateral dispersion of the metals from high to low areas. The apparent surface concentration (by a factor of 2 or 3) of the heavy metals, may possibly be explained by the action of ascending groundwaters which cause dilution of the B soil horizon with carbonate.

Biogeochemistry.

Leaf, twig, sapwood and bark tissues were sampled. The ash content varied significantly and averaged 5, 3, 2 and 14% respectively in the various organs.

The nickel contents on the ash weight basis, averaged about 90, 50, 20 and 40 ppm respectively in the aforementioned organs, whilst copper levels were higher, except in bark tissue. Manganese exhibited a high range of values (100 - 3000 ppm) but generally decreased from leaf through twigs to sapwood and then increased in the bark. Cobalt and chromium analyses were not performed on sapwood or bark samples but levels in twig and leaf tissue were uniformly very low.

Calcium, magnesium and iron values were fairly uniform in the non-outcropping areas and at this stage do not appear to yield any information to aid location of nickel mineralisation.

Some analytical data for Acacia aneura are given in Table III-2, and it can be seen that data from the greenstone belt stand out from the Red Bore samples, as exemplified by the nickel leaf ash values. Data for the other analyte elements is not shown, as elemental variations could not be interpreted.

The leaf data were expected to delineate mineralised areas better than the twig data, on the basis of the orientation survey over Harriott Prospect. This was found to be the case. Threshold anomalous values were obtained by the usual graphical technique and were 130 and 150 ppm respectively for nickel and copper. Manganese values, in leaves, ranged from 210 - 4500 ppm and the relatively high mean value of 1305 ppm suggested a lateritic environment.

The anomalous nickel and copper values were compared with the subsurface bedrock geochemistry as shown in Fig. III-11. Anomalies with coincident high manganese (more than 2000ppm) values are differentiated out and are considered to indicate lateritic enrichment only.

The twigs, sapwood and bark data did not contribute any additional information to that supplied by the leaf tissue. One exception to this statement was the zinc

TABLE III-2.

Averaged elemental data for ACACIA ANEURA from several study areas expressed as ppm in ash.

AREA	ELEMENT	LEAF	TWIG	SAPWOOD	BARK
Marriott Prospect (133 samples)	Ni	153	59		
	Cu	101	53		
	Zn	234	57		
	Mn	546	319		
Mt. Newman Area (75 samples)	Ni	288	80		
	Cu	150	64		
	Zn	256	65		
	Mn	2533	1584		
Clifford Creek Area (60 samples)	Ni	91	51	17	42
	Cu	124	52	78	39
	Zn	234	63	77	37
	Mn	1305	635	285	852
Red Bore Prospect (93 samples)	Ni	42	28		
	Cu	126	49		
	Zn	356	58		
	Mn	2584	1370		

content in twig ash. Background values were less than 80 ppm yet three anomalous values, ranging from 165 - 220 ppm, were obtained and were plotted over the footwall sediment as shown in Fig. III-11.

Eucalyptus camuldensis was sampled wherever it was encountered in the dry creek bed. The few sampled (6) of leaf, sapwood and bark tissue are insufficient to interpret. However, a constant unusual feature of its trace metal distribution was the high copper content in wood ash which averaged 320 ppm as compared to 10 ppm in bark and 200 ppm in leaf ash.

(iii) Statistical Analysis of Biogeochemical Data.

The *Acacia aneura* leaf data, comprising analyses for nickel, copper, cobalt, chromium, zinc, manganese, iron, calcium and magnesium were subjected to intensive statistical analysis. Results were generally disappointing and are briefly outlined below.

The Marriott Prospect data (111 damples were examined by discriminant analysis (Rao, 1952) on an IBM 1130 computer but results were disappointing.

Correlation analysis (Siegel, 1956) was applied to the Clifford Creek data in conjunction with the vacuum drill analyses. The parametric Pearson Product Moment Correlation Coefficient was computed using Fortran IID and an IBM 1620 computer.

Root fragments were observed, by wet-panning, in all drill samples down to the 25 - 30 foot sample. The deeper drill-holes were not logged but it is beleived that roots would penetrate at least to the bedrock interface. The biogeochemical data were correlated with the nickel drill data at various levels from the surface down to 35 feet. Below that level, too few drill-holes were available for reliable interpretation. No significant correlations could be obtained, even by employing logarithmic transformations and elemental ratios of the biogeochemical data. This result was not unexpected as the correlation coefficient is merely a measure of the degree to which large and small values of one variable, are associated with large and small values of another variable and is nothing more. A low value of the coefficient does not imply that there is no relationship between the two variables being examined and it is concluded that this statistic is an appropriate for this situation (Brookes and Dick, 1969).

Factor analysis (Blalock, 1960; Cattell, 1965) was applied to the Marriott Prospect leaf data in an attempt to determine the underlying factors which might control several of the observed variables. The technique has been used with success by several workers in the field of reconnaissance geochemical exploration (Cameron, 1968; 1969; Garrett, 1967; Garrett and Nichol, 1969). Factor analysis in this study was achieved using Thurstone's Centroid Method (Thurstone, 1947) on an IBM 1620 computer. The factor scores for each factor were listed in standard deviation units to facilitate rapid location of anomalous samples. Five of the obtained factors were considered to be interpretable in terms of lithology. These factors, with their component significant variables were:- ultrabasic (nickel chromium, -ve calcium); sediment (copper, zinc); laterite (nickel, manganese); magnesitic soils (nickel, magnesium); and mineralisation (nickel, copper).

The mineralisation factor was marginally superior to the raw data in delineating the mineralised zone; and improved results may well be obtained with the more refined techniques involving oblique rotation of the initial factor matrix.

D. DISCUSSION OF BIOGEOCHEMICAL RESULTS.

The orientation beiogeochemical survey indicated that the leaf of *Acacia aneura* could be used to locate outcropping nickel mineralisation in ultrabasic terrain by consideration of the nickel levels alone. Moreover, lateritic nickel anomalies could be recognized by coincident nickel-manganese biogeochemical anomalies.

The survey over the scree-covered Mt.Newman area clearly demonstrated the lateritic nature of the environment. Vacuum drilling revealed that bedrock nickel values were low, and that the potential for nickel mineralisation is negligible.

The Clifford Creek survey area presented a more difficult area for exploration as the overburden thickness is between 25 and 60 feet; whereas the Mt. Newman area was generally less than 10 feet. Neverthless, coincident nickel-copper biogeochemical anomalies with low manganese levels were observed only over the mineralised zone; as outlined by the drilling programme. This zone with up to 0.7% nickel and 0.1% copper represents contact-zone mineralisation which may be correlated with the footwall contact of the '880' serpentinite unit. As this unit lies stratigraphically below the ore-bearing structure at Harriott Prospect it seems likely that further evidence of nickel mineralisation will be found along the footwall contact of the '880' Prospect.

Although the biogeochemical method was successful in locating the mineralised zone some 30 feet beneath Clifford Creek, it is doubtful that a similar zone would have been recognised in strongly lateritised areas such as were observed in the western limits of the '880' Prospect and in the Mt. Newman area.

Further studies on the biogeochemistry of A. aneura would be directed to the discrimination, by inorganic chemotaxonomy, of the component species of the A. aneura complex.

The effectiveness of this sampling media may also be substantially increased if arsenic and selenium levels are monitored.

To conclude, the results presented in this section show that the nickel, copper, zinc and manganese content of *A. aneura* leaf can be used at least within the Kurrajong Region to detect nickel mineralisation, which has no surface soil geochemical expression.

5. BIOGEOCHEMICAL STUDIES ON ARSENIC AT AGNEW.

A. INTRODUCTION.

The association of arsenic with magmatic nickel sulphide ores and other types of mineralisation is well known (Mazzucchelli and James, . 1966; Warren et al, 1964; Wilding, 1965). In fact several of the recently discovered nickel ore deposits in Western Australia contain relatively high arsenic concentrations. It was decided therefore to carry out a preliminary biogeochemical survey over a known arsenical area. The ground surrounding the Emu goldmine at Agnew (for location, see Fig. I -1) was considered a suitable site as it contained surface soils with up to 0.04% arsenic and *Eremophila pantoni*, a tall shrub species of very widespread distribution, Plate III-5). Elkington (1969) carried out a biogeochemical survey, using two Eucalypt species and *Melaleuca sheathiana*, over arsenical (100 ppm) soils at Norseman, several hundred miles south of Agnew. (See Fig. I -1). After dry-ashing the plant material she could not detect arsenic in any of the samples including root tissues. However several arsenic accumulator plants have been reported and probably the best known is the Canadian Douglas Fir (*Pseudotsuga menziesii*) which can contain up to 1% arsenic in its needles (Warren et al, 1968).

The Emu goldmine is sited on a steeply dipping sediment-greenstone contact, which trends about north-north-east. This mine has produced rich ore in the past and is being worked intermittently at the present day.

The mine area is situated on an area of good outcrop but to the north is buried under colluvial-alluvial soils. In this northern area the vegetation is now dominated by *E. pantoni*; the original vegetation haveing been exploited long ago for the mine. See Plate III -5.

Soils and samples (leaf, twig) of *E. pantoni* were collected at 100 foot intervals along a traverse line orientated across the ? faulted contact, some 200 feet north of the main mine shaft (Kim shaft). Samples of E. pantoni were also collected from several unmineralised areas to establish background values.

B. ANALYTICAL METHODS FOR ARSENIC.

It was hoped to determine arsenic by atomic absorption spectroscopy. A Varian-Techtron AA5 instrument was used with an electrodeless discharge tube (E.D.T.) as the source. E.D.T.'s were made in the usual way (Dagnall et al, 1967) using 0.5 mg arsenic/0.1 mm Hg pressure in a 4 cm x 0.8 cm silica tube. A nitrogen-hydrogen-entrained air flame was employed to give a sensitivity with a standard 10 cm laminar burner of 0.2 ppm arsenic (Kahn and Schallis, 1968).

Long vycor tubes (91 cm x 1 cm), heated and insulated, were used with a Beckman (no. 4020) total consumption burner (Arazzi, 1965) and sensitivity was improved to 0.06 ppm arsenic in solution.

However, arsenic could not be determined in biological or geological materials, without a prior separation of arsenic, due to interferences which could not be adequately compensated for. A Colorimetric method of analysis was employed as an interim measure. A nitric/perchloric acid digestion mixture was used for soil and plant samples. The silver diethyldithiocarbamate method (Vogel, 1966) was used and gave adequate precision. Accuracy was established by correlation with other laboratories using the molybdenum blue method (Sandell, 1959).

C. RESULTS.

The soil and plant arsenic values were plotted on a logarithmic profile (Fig. III-13). The soil arsenic

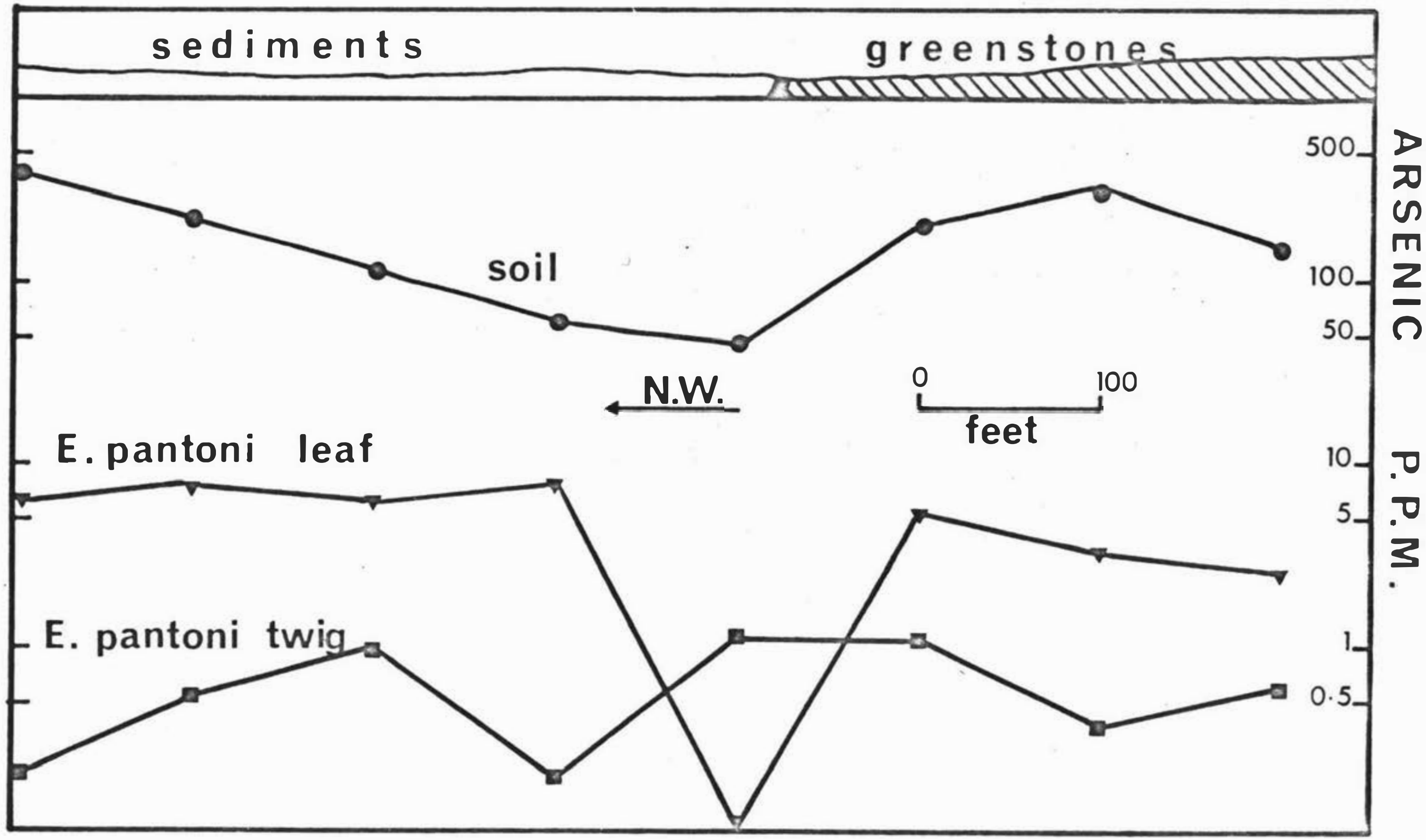


Fig. III–13 Arsenic levels in soils and *Eremophila pantoni* at the Emu goldmine, Agnew.

values are highly anomalous, attaining 380 ppm in the -80 mesh (B.S.S.) fraction collected at a 6 - 9 inch depth and the soil arsenic nadir seems to correspond with the extrapolated ?fault contact between the sediments and greenstones.

The arsenic values (expressed on a dry-weight basis) exhibit a pronounced biogeochemical anomaly of up to 7.8 ppm. The background control samples from four separate areas showed no detectable arsenic. The arsenic contents in the twigs show practically an inverse relationship to the leaf values and are generally much lower (around 1 ppm) than the corresponding leaf samples.

The low arsenic soil value which correlates with the extrapolated ? fault contact can be ascribed to several processes involving ground and rain-water. It may be simply dilution of the arsenical residual soils by barren soils being brought into this topographically-low area by sheet wash, or the physico-chemical characteristics of the contact zone in the bedrock results in preferential downward leaching. It is interesting to note in this context the biggest obstacle to further development of the Bau goldmine (200 feet to the south) is the vast inflow of fresh water.

The soil arsenic anomaly outlined on this one sampling traverse may be a result of the primary dispersion associated with the formation of the pyritic gold ore body. But it may also represent contamination resulting from the mining operations which have been carried out for more than 70 years.

The vegetation samples were carefully washed and undoubtedly the biogeochemical anomaly exhibited by _E. pantoni_ has resulted by uptake of arsenic through the root system from the soils. It is evident that _E. pantoni_ has the ability to indicate anomalous substrate arsenic levels. The depth of the root system is unknown but it is conceivable that in alkaline soils where arsenic has been leached from the surface horizons a biogeochemical anomaly may be obtained in the absence of a surface soil geochemical anomaly. The value of this particular shrub species is that (1) it favours relatively deep colluvial soils in areas of poor outcrop; (2) it has a wide distribution ranging from Meekatharra in the north to Kambalda in the south, and (3) it has a distinctive appearance that allows easy recognition in the field and its size (4 - 5 feet high) is amendable for sampling the leaf materials.

These preliminary observations indicate something of the versatility of the biogeochemical method of prospecting.

Further studies should investigate the geobotanical aspects of arsenic and the arsenic biogeochemistry of *Acacia aneura*. Perhaps there are arsenic accumulator plants in areas of gold mineralisation, as demonstrated in Canada (Warren, *et al*, 1964). If such plants exist in Western Australia they could be of more general application in locating other types of mineralisation which contain an arsenic component.

D. GENERAL DISCUSSION ON THE AGNEW-WILUNA AREA.

Brief investigations were carried out to ascertain the usefulness of botanical methods of prospecting in the Wiluna-Agnew region.

At Agnew it was established the biogeochemical prospecting for arsenic using the shrub *Eremophila pantoni* was feasible. The distribution of known toxic plants in this area was also investigated to cover the remote possibility of their being indicator plants. One shrub species commonly known as 'kite-leaf poinson' or 'Breelya' viz. *Gastrolobium laytonii* was observed to be restricted to fracture zones in granites where some metasomatism had obviously taken place. (Plate III -6). The genus *Gastrolobium* includes several species whose toxic principle is a monofluoroacetate alkaloid and in this case it was considered that *C. laytonii* also has an affinity for fluorine. The value of such plants in prospecting granite terrains for hydrothermal mineralisation is obvious.

Several abandoned gold mines around Wiluna were inspected and specimens of *Ptilotus rotundifolius* growing near the old workings typically displayed teratological effects caused by either the high antimony or arsenic levels in the substrate. The gold ore was known to contain significant amounts of antimony and arsenic and the visible effect of these metals was to cause strongly convoluted leaf margins which normally are quite flat.

Two areas of ultrabasic terrain were also examined near Wiluna. In one area free of laterite, the talc-carbonate rocks were characterised by two shrub species *Cryptandra leucophractra* and *Halgania cyanea*. However in a lateritised environment these two species were absent and were replaced by a small shrub of bizarre appearance, *Kallstroemia platyptera*.

The recently discocered Mt. Keith nickel sulphide deposits between Agnew and Wiluna appear to be in an acid soil environment and dominated by *Acacia aneura*. It is considered that the scope of the biogeochemical method is such that these mineralised areas, which lie at 60 feet or more below the ground surface, could probably be delineated by a biogeochemical survey using *A. aneura*.

The versatility of botanical prospecting methods in this region has been briefly indicated and has revealed several, possibly rewarding, avenues for more detailed investigations.

SECTION IV

HYBANTHUS FLORIBUNDUS - A NICKEL ACCUMULATING SHRUB

1. INTRODUCTION.

A. DISCOVERY.

In May, 1970, a small compact shrub with blue flowers was observed growing on the '880' serpentinite, in the Kurrajong Region near Mt. Clifford. Leaf and stem samples were collected from three specimens and analysed for nickel, cobalt, copper, chromium, zinc, manganese, iron, calcium and magnesium as part of the orientation studies.

The analytical results were initially viewed with some scepticism as nickel concentrations averaged 6% in the ash whilst cobalt exceeded 100 ppm. These results were 100 to 1000 times higher than for any of the other plant species encountered in the Kurrajong Region.

As a result of this serendipity, it was initially thought that this shrub, _Hybanthus floribundus_, was a nickel indicator plant (because of its high accumulation of nickel) and might therefore be indicating nickel mineralisation on the '880' Prospect. Although the '880' serpentinite is favourably located for a nickel discovery, no indications of significant mineralisation have been obtained to date.

In order to appraise the significance of _H. floribundus_ with regard to the nickel search, the literature was scrutinised for parallel examples.

B. LITERATURE SURVEY.

It seems to be an instructive exercise to outline the history of _Becium homblei_, the 'Northern Rhodesian copper flower'. The reasons for selecting this particular example are that this shrub is probably regarded as the most successful indicator plant in mineral exploration and it has been studied by many workers and organizations for the past 20 years.

Becium homblei (Labiatae), an 18 inch high perennial shrub, was discovered in the late 1940's to be an additional guide to prospecting for copper. It was also shown (Horizon, 1959) that it accumulated up to 4500 ppm copper in ash, and not 0.3% dry weight as misquoted by Peterson (1971). In Rhodesia, Wild (1968) found *B. homblei* growing on 5 of 28 copper prospects and the closely related species *B. obovatum* (the pseudo copper flower, Horscroft, 1961) on 4 of them. Howard-Williams (1970, 1971) also examined the distribution of these two species over metalliferous soils and concluded that the distributions were contrasting, with *B. obovatum* apparently not able to tolerate metalliferous soils. On the other hand Jacobsen (1968) noted that *B. homblei* and *B. obovatum* often grow within 50 feet of each other, even in soils containing up to 1% copper. This may be explained by soil acidity as Williams (1969) noted that *B. homblei* favours acid soils. Apparently in areas of high pH, *B. obovatum* can also thrive in metalliferous soils (Wild, 1970).

Studies on morphological variations have also been carried out on several populations (ecotypes) of *B. homblei* which, in Rhodesia, has an insular type distribution (Howard-Williams, 1971; Wild and Heyting, 1966). Reilly (1967) commenced studies on *B. homblei* in Zambia and examined the binding of copper in leaf tissue (Reilly, 1969; Reilly, *et al.* 1970). The maximum copper contents, on a dry weight basis, which have been recorded are: 250 ppm (Howard-Williams, 1971) and 324 ppm (Reilly, 1967). In Katanga, the maximum copper content was 77 ppm (Duvigneaud and Denaeyer, 1963). The ash fraction was high and averaged 7%, hence the copper ash concentration can be calculated as 1100 ppm. These authors revealed that *Haumaniastrum robertii* (with up to 2000 ppm copper D.W.) and *H. katangense* grew in soils with up to 10% copper. Several representatives of the *Becium* genus were found in the copper-contaminated aureoles around mineralised areas and included *B. ericoides*, *B. empetroides*, *B. homblei*,

B. aureoviride, B. aureoviride ssp. lupotoense, B. peschianum and B. metallorum. Evidently the Becium genus cannot tolerate strongly mineralised areas, and a similar conclusion was arrived at in neighbouring Zambia (Horscroft, 1961). Ernst, (1972) carried out ecophysiological studies in Zambia and Rhodesia and concluded that B. homblei was restricted to soils with less than 1000 ppm copper.

Obviously, a considerable amount of work has been carried out on Becium homblei in the three countries which share the 'Copper Belt'. The confusion and sometimes contradictory reports on B. homblei may be explained as follows. Recognition of the species is difficult and, because of its widespread (200 - 300 meridional miles) and insular distribution, it is most probably composed of many distinct ecotypes which can be expected to differ, by degree, in their physiological response to a cupriferous substrate. The situation has been put in perspective by the geologists Horscroft, (1961) and Jacobsen, (1968) who considered that no particular plant, including B. homblei, by its presence or absence indicates the presence or absence of copper.

For our second and final example, the nickel-accumulating shrub Alyssum bertolonii and its related species will be briefly surveyed.

Minguzzi and Vergnano (1948) discovered that A. bertolonii, growing on serpentinites near Florence, Italy, accumulated up to 10% nickel in leaf ash or 2.04% on a dry-weight basis. The Alyssum genus contains several known nickel accumulators and its distribution extends throughout the Mediterranean countries into Russia, (Vergnano, 1958).

A. adulterium was considered to characterise serpentine and primary sulphide areas (Malyuga, 1964) in Norway and A.murale was reported to contain more than 10% nickel (in its ash) in Georgia, U.S.S.R. A. tortuosum contained more than 1% nickel and 125 ppm cobalt (in ash) on the Kimpersaisky ultrabasic complex whereas A. biovulatum was found with 0.18% nickel and 180 ppm cobalt (in ash) at the Tura nickel-cobalt ore deposit (Malyuga, 1964). A. serpyllifolium ssp. lusitanicum also accumulated nickel, 0.52% dry weight, in a serpentine area in Northeast Portugal (De Sequeira, 1968).

The usefulness of this genus in mineral exploration has not been widely assessed. Unfortunately the data has not been widely published and it is probable that much information on Alyssum remains in the Russian literature. This genus is of direct interest to the present study, as Alyssum species have been reported to occur in Australia (Burbridge, 1963).

The Becium homblei situation is perhaps more illuminating. This species has a considerable reputation as a copper indicator but in fact the above detailed examination showed that it is not an infallible guide to copper mineralisation. It was considered pertinent to bear this statement in mind when evaluating the significance of Hybanthus floribundus.

The nickel-accumulating varieties of Hybanthus floribundus were discovered in 1970 and some preliminary results were published soon after (Severne and Brooks, 1972). Within the space of a few months the contents of this paper had been misquoted several times (New Scientist, 1972; The National Times, 1972; Nature, 1972). It is to be hoped that another Becium situation does not arise especially in view of the excellent classification key for the Hybanthus genus in Australia (Bennett, 1969).

Approximately 150 Hybanthus species (Willis, 1966) are known from the tropics and subtropics with a few extending into the temperate zone. The majority of the species are in the Southern hemisphere and the Gondwana continents, Africa, India, South America, and Australia all record native species. Hybanthus is notably absent from the young oceanic islands and Bennett (1969) considers that:- the genus has undergone no important development in 'recent' times; *Hybanthus* is an old genus; and that the present-day distribution patterns have existed for a very long time. In Australia: *Hybanthus floribundus* has the most widespread distribution of the 10 species recorded. The present-day distribution across the southern part of Australia is considered to be the relic of a much wider distribution which existed before the onset of the recent aridity. Now, this species occupies the warm temperate zone with summer and winter isotherms of 75 and 55^{o} respectively, and an annual rainfall in excess of 10 inches. Beyond this zone, in the more arid interior, the species is restricted to residual islands and appears to represent a classic example of biotype depletion, (Wild, 1968).

2. EVALUATION IN THE KURRAJONG REGION.

A. INTRODUCTION.

In the previous section _H. floribundus_ had been recorded over several of the known nickel prospects in the Kurrajong Region. It was therefore decided to investigate this shrub by the use of the following techniques:-

(i) to record its distribution on a regional scale throughout the Kurrajong Region on geological plans and in detail over individual prospects using the 100 foot grid system.

(ii) to collect herbarium specimens from each area.

(iii) to collect samples of the various plant tissues (flower, leaf, stem, wood, roots) and the associated soils and bedrock for chemical analysis.

B. DISTRIBUTION - GEOBOTANY.

The geobotanical survey was centred on the Mt. Clifford area but ranged as far north as Agnew.

H. floribundus was observed, during the arsenic biogeo chemical studies, a few thousand feet south of the Emu goldmine in a drainage tract. A further search, following the drainage geobotanical anomaly to its source, revealed _H. floribundus_ growing on strongly lateritised ultrabasic outcrops. These plants were then followed for more than a mile southwards always on lateritised ultrabasics and never on the juxtaposed sediments.

Reconnaissance some 15 miles east of Agnew revealed a limited population of _H. floribundus_ growing on a small sheared pod of greenstone within sediments and granite near Yillaree Cliffs. Some 25 miles to the north, near Mt. McClure, laterite-free serpentinites were examined but _H. floribundus_ was absent. Between Weebo and Wildara homesteads the lateritised extensions of the Wildara ultrabasic belts were traversed (lines A and B in Fig. III-1), and H. floribundus was observed in profusion.

In the Wildara area, where detailed geochemical/ geobotanical studies were carried out (Section III), H. floribundus was observed only on ultrabasics; in the eastern belt over and around the main Wildara gossan and over the lateritised western belt, especially around the small copper prospect.

At the Marshall Pool area, some 10 miles further south (Fi . III-1) H. floribundus was recorded over lateritised and non-ferruginous serpentinites. The plant was used here to rapidly map the serpentinised ultrabasic units from mafic and ultramafic units.

In the Mt. Clifford area, H. floribundus was recorded only over serpentinised ultrabasics at the Mt. Newman, '107' and '880' Prospects. Despite careful and repeated searches, this shrub species was not observed anywhere on or near the Marriott Prospect. However, some 3000 feet further west, a very few specimens were located in a rocky serpentinised peridotite outcrop with lateritised areas nearby.

Reconnaissance trips were made to many other Prospects and included:- The Pinnacles Prospect 12 miles south of Agnew; The Bannockburn Goldmine; The Doyle Well - Mt. Fouracre area; and the Windara Prospects north of Laverton. H. floribundus was not observed at any of these areas.

(i) '880' Prospect.

The largest distribution of H. floribundus in the vicinity of Mt. Clifford was recorded over the '880' Prospect and more detailed distribution studies were implemented there. The study was carried out using the 100 foot grid system which covered an area approximately 4000 feet by 7000 feet as shown in Fig. IV-1. 179 Quadrats (each of 10^4 ft.^{2}) contained one or more specimens of H. floribundus.

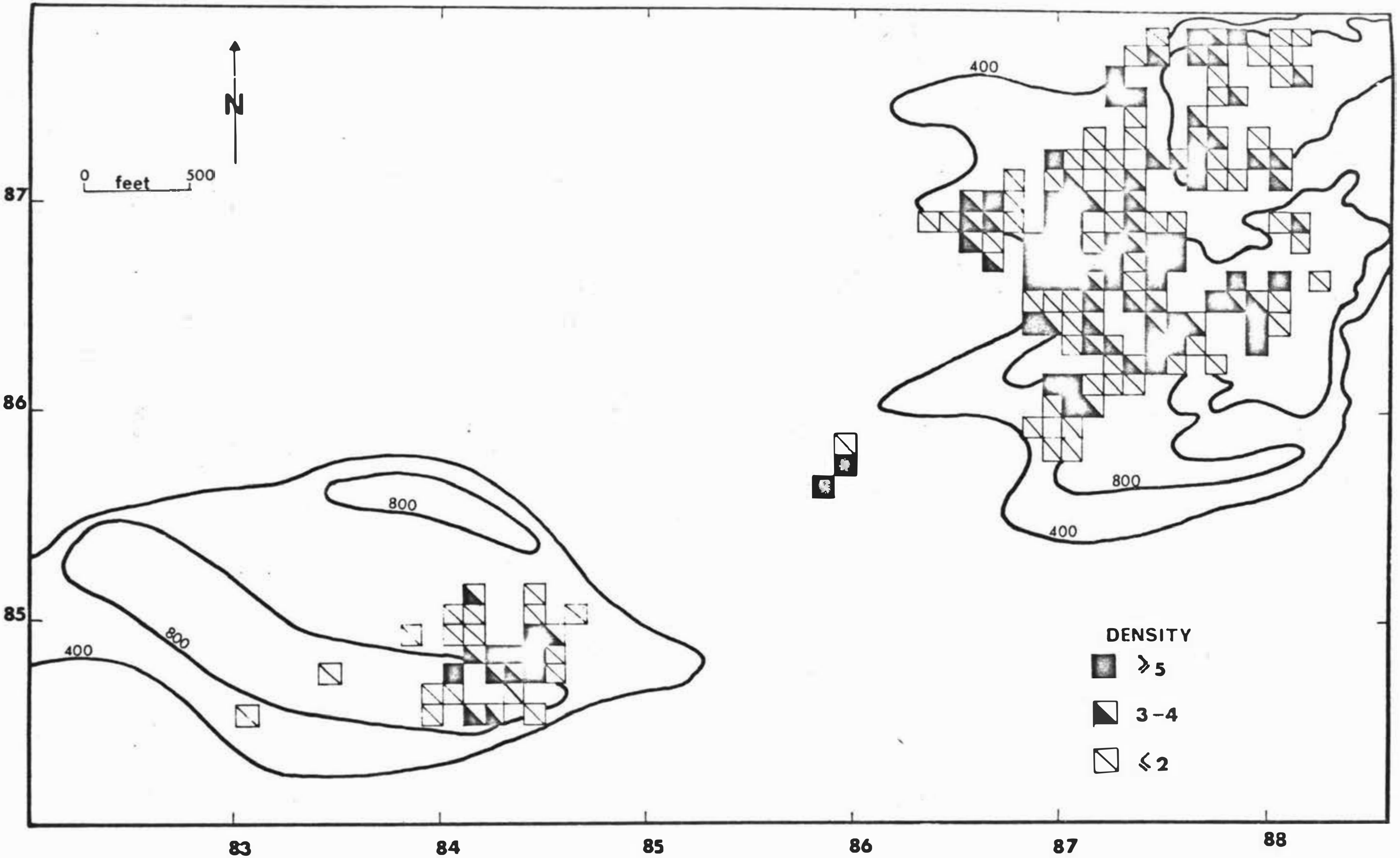


Fig. IV–1 The distribution of *H. floribundus* ssp. *curvifolius* Form A correlated with nickeliferous soils over the '880' prospect, Kurrajong Region.

(See Plate IV-1, -2). The density distribution of this species was examined by histograms and cumulative frequency diagrams (Williams, 1967). It was then interpreted that a density of 5 or more was anomalous and some 30% of the quadrats bearing H. floribundus were thereby designated anomalous quadrats. 42% of the quadrats with this shrub contained only one or two specimens and gradually exhibited a dispersive pattern around the anomalous areas. The distribution of H. floribundus over the '880' Prospect is shown in Fig. IV-1 together with the high iso-concentration contours of nickel in the soil. It can be seen that the distribution of H. floribundus corresponds with the serpentine soils containing more than 880 ppm nickel. Natural dispersion of this shrub is observed onto the adjacent soils with lower but still anomalous nickel levels. The soil data was obtained during a regional survey on north-south lines spaced 800 feet apart. The small geobotanical anomaly at about 860 N: 806E appears to be spurious, in view of the low nickel levels in soils as indicated in Fig. IV -1. However, at this point a small outcrop of serpentinised peridotite protrudes above the lateritic scree cover, and the soils locally contain up to 800 ppm nickel. The large expanses of low nickel surface soils in this area are correlated with lateritised areas in the north and siliceous scree in the south, overlying metabasalts.

The absence of H. floribundus over Marriott Prospect required an explanation. Accordingly, the soil geochemistry was compared with other areas where the shrub flourished. Considering these latter areas first, it was apparent that copper, zinc, and cobalt values were uniformly low and less than 75 ppm. Nickel values (total estimate by HF/HNO_3 or $HClO_4/HNO_3$ digestion) typically averaged 730 to 850 ppm and chromium values often averaged more than 1000 ppm. Manganese and iron contents were above 'normal' levels at 400 to 500 ppm and 6.0 to 7.0% respectively. These values together with the relatively low pH, for this region, of 6.0 to 6.8, were indicative of a lateritic environment. The Marriott Prospect contrasted sharply with much lower chromium values, significantly lower iron, nickel and manganese levels and a higher pH, typically above 7.0.

(ii) Flower Survey.

There are several reports of variation in flower morphology being correlated with a mineralised substrate (Vasilevskaya and Sibireva, 1950; Malyuga et al, 1959; Shacklette, 1964). It seemed relevant therefore to examine the flower morphology of H. floribundus with the aim of determining whether visual examination would allow the observer to predict any substrate condition.

Fiftyone flowering plants were sampled in the Marshall Pool area and over the '880' Prospect. Leaf and soil samples were collected with flowers, and analysed for nickel, copper, cobalt, chromium, zinc, manganese and iron. Flower morphology was measured with six selected variables, as listed below:-

Variable.	Floral Character.
1.	Size of violet-coloured collar on lower petal.
2.	Colour of lower petal ranging from blue to white.
3.	Intensity of yellow colour in throat of lower petal.
4.	Degree of keeling of lower petal.
5.	Colour of upper petals and pedicel.
6.	Overall flower colour ranging from blue to white.

These variables were categorised as large, medium, small, etc. The most conspicuous feature of the flower is the grossly enlarged lower petal which is uniformly about twice as long as the rest of the flower. See Plate IV -5, -6. The raw data comprising analytical and morphological data were analysed initially by computer which calculated all possible parametric correlation co-efficients. The apparently significant correlations were also examined by graphs.

Several possibly significant correlations were observed between soil metal values and flower morphology as tabulated in Table IV -1. The overall colour of the flower was, as expected, strongly correlated with the colour of the lower petal and the colour of the upper petals and pedicel. The pedicel was well defined in H. floribundus by a pair of conspicuous bracts at the junction with the peduncle.

The blue colouration (Beyer, 1966) of the flower became more pronounced as the soil nickel content increased. This relationship is shown in Fig. IV -2, and it can be stated that specimens of H. floribundus growing in soils with more than 700 ppm nickel usually have blue flowers.

It was realized that ageing of the flowers might result in bleaching of the pigments and that colour variations might not be related to substrate or genotype variation. Accordingly the survey was undertaken in winter (June) at the beginning of the flowering season, to minimise these errors. A further sampling media for this technique would be the mature seed as its morphology could be expected to be relatively invariable. Perhaps it is no more than coincidence but blue flowers seem to be the rule for several accumulator plants, including Becium Lomblei, Dicoma niccolifera, Barleria aromatica and Hybanthus floribundus.

C. BIOGEOCHEMISTRY.

More than 200 specimens of H. floribundus, with the associated substrate were collected in the Kurrajong Region for chemical analyses. Emission spectrography was employed to scan (2500 to 8000°A) several leaf and substrate samples of H. floribundus.

In addition to the elements mentioned in the introduction, strontium, thallium, lithium and ribidium, were observed (Brooks, pers. comm.) in the leaf samples but not in the substrate. No attempt was made to measure these elements

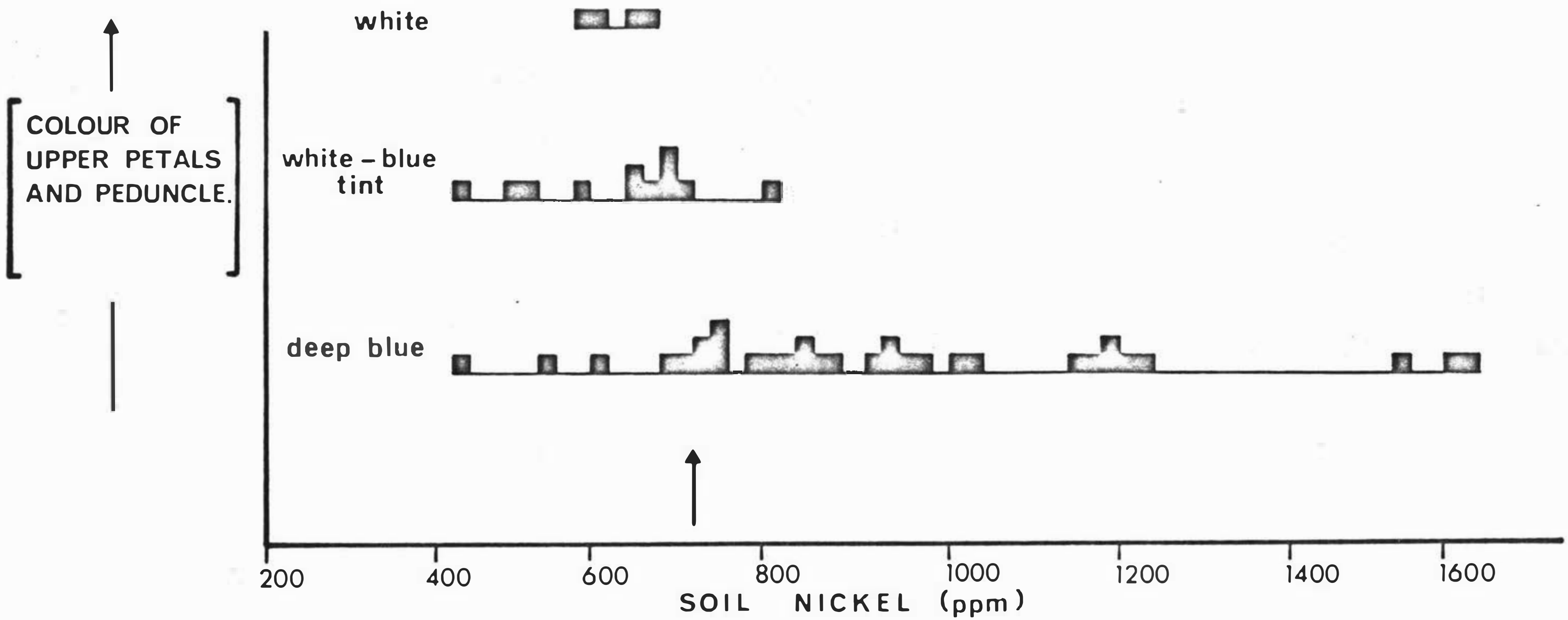


Fig. IV–2 Relationship of *H. floribundus* flower color with soil nickel level.

TABLE IV -1.

Significant correlation coefficients for soil-flower morphology relationships. Values greater than ± 0.40 are significant at the 0.1% level.

Flower morphology	Soil Analyses						
	Ni	Cu	Co	Cr	Zn	Mn	Fe
1							
2	-.46	.21	-.21				-.29
3	-.35			.20	.26		
4				.35	.42	[illegible]	.34
5	-.47		-.29		-.28		-.45
6	-.42						-.28

TABLE IV -2.

Elemental concentrations in the ash of accumulator plants compared with values for cobalt and nickel in *Hybanthus floribundus*.

Element	Species	Normal content (ppm) in plants[b]	Max. value recorded (ppm)	Reference
Cobalt	*Crotalaria cobalticola*	9	18,000	Duvigneaud (1959)
	Hybanthus floribundus	9	4,000	
Copper	*Becium homblei*	183	5,200[a]	Reilly (1967)
Manganese	*Fucus vesiculosus*	4815	90,000	Malyuga (1964)
Nickel	*Alyssum bertolonii*	65	100,000	Minguzzi and Vergnano (1948)
	Hybanthus floribundus	65	230,000	
Selenium	*Astragalus pattersoni*	1	46,000	Cannon (1960b)
Uranium	*Uncinia leptostachya*	1	25,000	Whitehead (1970)
Zinc	*Thlaspi calaminare*	1400	10,000	Dorn (1937)

[a]Estimated from dry-weight data.

[b]Cannon (1960a).

quantitatively. The analytical data obtained by atomic absorption spectrophotometry, are reported tin Table IV -2. Data for 'normal' vegetation (Brooks, 1972; Bowen, 1966) are included for comparative purposes.

(i) The Serpentine Environment.

It is clear from the data in Table IV-2 and from the preceding sections that H. floribundus has a preference for serpentine soils which are here defined as residual (skeletal) soils overlying ultrabasic or even ultramafic rocks which are fresh or have been altered by serpentinisation, lateritisation or steatisation. Serpentine soils have been extensively studied during the last century because of the general infertility of these areas. The soils usually display at least one of the following chemical characteristics:- high magnesium and low calcium contents; high "toxic" concentrations of heavy metals such as nickel, chromium and cobalt; deficiency of essential nutrients such as nitrogen, phosphorus and potassium. Table IV-2 shows the average composition of the serpentine soil and rocks which constituted the substrate of the Hybanthus plants considered here.

The data shown in Table IV-2 are similar to available figures compiled from areas of similar climate. The most obvious discrepancy between rock and soil values is the loss of some 95% of the magnesium and 15% of the calcium during the weathering of rock to soil. Significant losses are also shown by nickel and chromium (about 66%). Trescases (1969) studied serpentine soils in New Caledonia and found that whereas rocks contained 44% MgO the soils contained less than 1% and CaO values were also very low. Similar results in this area were also obtained by Birrell & Wright (1945).

Most research on the serpentine problem has been carried out in agricultural countries with a correspondingly more temperate climate than Western Australia. In these areas of higher raingall, the magnesium content of

TABLE IV -3.

Mean Elemental Concentrations in *Hybanthus floribundus* and its substrate. (217 samples)

Sample Description	Elemental concentrations expressed in ppm dry weight								
	Ni	Cu	Co	Cr	Zn	Mn	Fe	Ca	Mg
Rock	3,000	50	100	3,000	70	700	70,000	6,000	200,000
Soil (-80 mesh)	1,000	50	40	1,000	50	500	70,000	5,000	10,000
Fresh leaves	2,500	3	10	2	15	50	180	2,500	2,100
Dried leaves	5,000	5	20	3	30	100	370	3,920	3,320
Ashed leaves	96,000	100	400	60	600	2,800	7,500	98,000	83,000
Vegetation in general* (ash weight)	65	180	9	9	1,400	4,800	6,700	281,250	50,000

*After Brooks (1972) and Bowen (1966).

TABLE IV -4

Comparative data for elemental concentrations in three nickel accumulating plants (number of samples in parenthesis).

	Elemental concentrations expressed as % ash						
	Nickel		Calcium		Magnesium		
	Mean	Range	Mean	Range	Mean	Range	Reference
Alyssum bertolonii (6)	5.5	2.8-10.0	17.1	14.3-18.7	6.1	5.3-6.5	Minguzzi & Vergnano (1948)
Hybanthus floribundus (217)	9.6	3.1-25.0	9.8	6.5-18.0	8.3	2.3-14.1	This paper
Pimelea suteri (20)	0.6	0.2-1.3	5.0	3.0- 9.2	15.7	9.5-23.2	Lyon (1969)

serpentine soils is usually five to ten times higher than in tropical soils. For example, Walker (1954) reported a minimum of 13% magnesium in Californian serpentine soils. In New Zealand, soils from Dun Mountain (type locality for dunite) averaged 8% magnesium and 0.2% calcium. Lyon (1969) showed that dilute acetic acid extracted 3% and 5% of calcium and magnesium from these soils respectively. Similarly, Timperley (1971) reported that soils overlying serpentinised pyroxenites averaged 4.7% magnesium and 5.9% calcium from which 1M hydrochloric acid extracted 2.4% and 0.3% of these two elements respectively. These data, from areas of high rainfall, are similar to those obtained in the United States and Great Britain.

The above data obtained from a semi-desert environment (Table IV-2) indicate that the serpentine soil does not display a particularly unfavourable calcium-magnesium imbalance. In fact Walker, (1954) suggested that if the soil Ca/Mg ratio is such as to allow a Ca/Mg ratio in the plant of more than 0.2, then no adverse effects would be observed.

Several workers (Robinson et al, 1935; Soane & Saunder, 1959; Kotilainen, 1944; Mitchell, 1945) have ascribed the infertility of serpentine soils to heavy-metal (chromium, cobalt and nickel) toxicity rather than to a calcium-magnesium imbalance. The West Australian serpentine soils do exhibit pronounced differences to adjacent soils, particularly with respect to their nickel and chromium contents.

In an attempt to measure the plant-available amounts of nickel in these serpentine soils, extractions were made with several solvents from representative samples averaging 800 ppm nickel. Hydrochloric acid (1M) released 45 ppm (about 5%), 2.5% acetic acid gave 20 ppm and distilled water extracted 10 ppm. Nielsen (1972) showed that 1M hydrochloric acid solubilised 8% of the nickel (1200 ppm) from a laterised serpentine soil also in Western Australia. In New Zealand, Lyon (1969) showed that acetic acid extracted 5.4% of the soil. Accordingly *H. floribundus* is an accumulator of nickel only.

Such a definition is entirely arbitrary but was adopted in view of the fact that no suitable method exists to measure the plant-available metal content of soils.

Up to 25% nickel and 0.4% cobalt in leaf ash have been obtained in *H. floribundus*. However, the average concentrations respectively are about 10% and 0.04%. The distributions of nickel levels in leaf, stem and wood are positively skewed and approach log normality. The leaf nickel values usually lie within the range of 4 to 16%.

It is evident (Table IV-3) that the nickel content of *H. floribundus* is about a thousand times greater than in "normal" plants, and this is shown as a bar diagram in Fig. IV-3. In fact the nickel concentrations observed in the leaf ash of *H. floribundus* represent the highest values recorded for any 'trace metal' in land plants (Severne and Brooks, 1972) and Table IV-3 compares the maximum elemental concentrations of some other accumulator plants with those of *H. floribundus*.

The chromium concentrations in this plant are low and hence difficult to analyse reliably (by atomic absorption) and will not be considered further.

The copper, zinc, manganese and iron concentrations in *H. floribundus* are comparable to "normal" levels. The calcium and magnesium data were worthy of comment and in Table IV-4 *H. floribundus* is compared with two other nickel accumulating shrubs from Italy and New Zealand. The calcium (Ca)/magnesium (Mg) balance in serpentine soils is often considered to be a prime factor in creating serpentine endemic plants, and such plants may exhibit an unusually low Ca/Mg ratio. In Table IV-5 are listed several families of plants including those with a high proportion of serpentine species. It is seen that these 'serpentine-tolerant families' have low Ca/Mg ratios in the range 1.6 to 2.7. Comparable data for

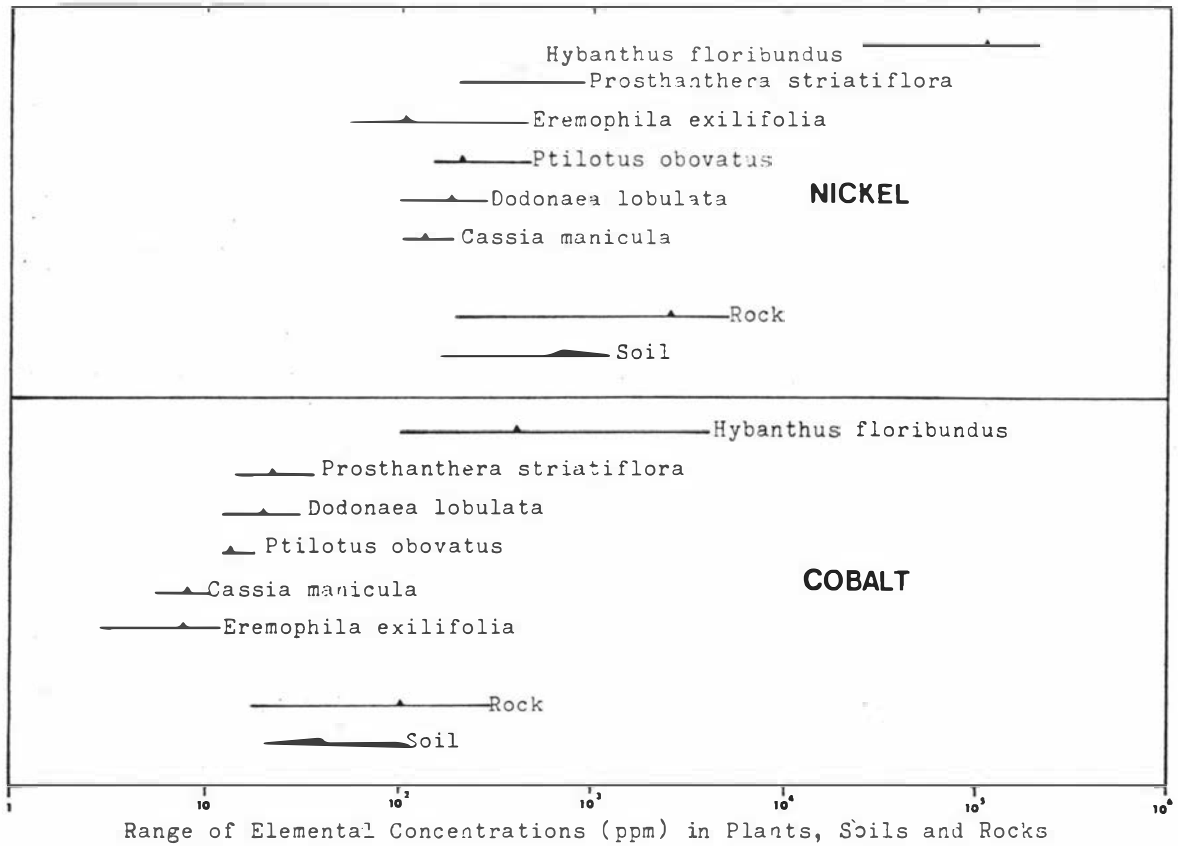


Fig. IV–3 Comparison of nickel and cobalt values in *H. floribundus* with other shrub species from the Kurrajong Region.

the Violaceae were not available, apart from *Viola calaminaria* (Jansch, 1894) which is a zinc accumulator. However, the Violaceae and Cruciferae families exhibit high Ca/Mg ratios (e.g. 4.6 and 6.1) whilst their nickel-accumulating serpentine representatives have low Ca/Mg ratios viz. 1.1 and 2.2.

Although the Ca/Mg ratios in these nickel-accumulating species and in other serpentine endemics (Lyon, 1969) is low, it is apparent from plant/soil ratios for calcium and magnesium that these plants either relatively accumulate calcium or exclude magnesium. For *H. floribundus* at least, it is clear that on an absolute basis (Table IV-3) magnesium is partially excluded with an average concentration (dry-weight) that is only 33% of that in the soil.

The calcium content of serpentine floras is often low but the calcium requirement of many higher plants has been overstated for many years (Jones and Lund, 1967). Despite the longevity of the calcium-pectate theory, certain difficulties remain, e.g. the extremely low (50 ppm dry-weight) calcium content of some healthy tissues. It is therefore suggested that *H. floribundus* and *Alyssum* have adapted to the serpentine environment by restricting magnesium uptake and thus off-setting the low calcium levels in the soil.

(iii) Correlation analysis.

The Pearson product moment correlation coefficient (r) was used to rapidly screen the analytical data. A number of significant correlations were obtained and are listed in Table IV-6. It was observed that nickel was correlated with 5 other elements including cobalt in the leaf, 2 in the stem and one in the wood. The remarkable feature of Table IV-6 was the significant nickel-calcium negative correlation which alone persisted in all three tissues, viz. leaf, photosynthetic stem and wood. Flowers were not analysed for calcium but nickel did correlate with manganese and cobalt.

Considering the plant-soil systems it was

TABLE IV -5.

Calcium/magnesium ratios in the aerial parts of some plant families. Except where otherwise stated, all data are from non-serpentine substrates (after Krause, 1958).

Family or species	Elemental content (ppm dry weight) Calcium	Magnesium	Ca/Mg
Chenopodiaceae	10,700	6,800	1.57
Lycopodiae	2,200	1,400	1.57
Caryophyllaceae S	11,100	6,800	1.63
Ascomycetaceae S	2,000	1,100	1.81
Basidiomycetae	2,300	1,200	2.01
Polypodiaceae S	6,500	3,100	2.09
Graminae S	3,800	1,700	2.25
Leguminosae S	4,300	1,700	2.50
Ericaceae S	3,800	1,400	2.69
Compositae	15,900	5,200	3.03
Cyperaceae	4,800	1,600	3.06
Polygonaceae	16,200	5,000	3.23
Lemnaceae	8,100	2,300	3.50
Violaceae*	13,000	2,800	4.64
Umbelliferae	23,100	4,400	5.20
Land plants in general+	18,000	3,200	5.62
Cruciferae	16,000	2,600	6.15
Alyssum bertolonii++	12,200	3,400	2.26
Hybanthus floribundus	3,920	3,320	1.18

S families with a high proportion of serpentine plants
* data based only on *Viola calaminaria* (Jensch 1898)
++ data from Minguzzi and Vergnano (1948)
\+ data from Bowen (1966).

apparent that nickel in any tissue of H. floribundus was not correlated with soil or rock nickel values. This result implied that the shrub had little potential for biogeochemical prospecting. The appropriate graphs seemed to confirm the above inference.

(iv) Biogeochemical Traverse.

Nevertheless it was decided to check the theory in the field. Hence, this shrub was sampled along two traverses over the Wildara ultrabasics (A and B in Fig. III-1) and the results for line A are shown in Fig. IV-4. This profile diagram showed that the biogeochemical anomaly (more than 1% nickel in dry leaf) corresponded with creek bed (perhaps a high exchangeable nickel area) and not with the soil peak of 1800 ppm. All the evidence showed that H. floribundus had little if any application to biogeochemical prospecting.

D. PROVISIONAL EVALUATION.

Very briefly it can be stated that Hybanthus floribundus:-

(i) accumulates nickel

(ii) is restricted to lateritised ultrabasic outcrops and in the creeks draining these areas.

(iii) has little application in biogeochemical prospecting.

The accumulation of nickel by this shrub suggests that nickel is beneficial, if not essential for it. Therefore this shrub has a preference, if not a necessity, for a nickeliferous substrate, which is, in geological terms, an ultrabasic lithology. The effect of laterisation is twofold. It increased the substrate nickel concentration by supergene enrichment and by lowering the soil pH it increased the 'availability' of this nickel to H. floribundus.

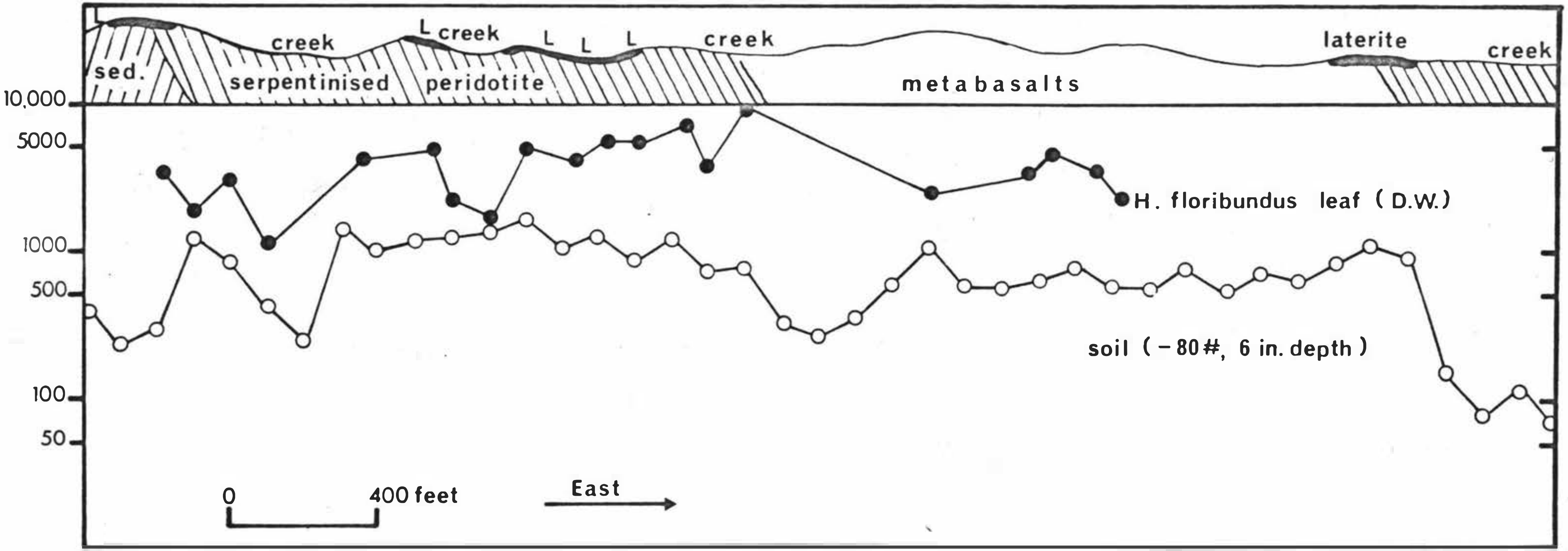


Fig. IV–4 Biogeochemical/geochemical traverse at Wildara using *H. floribundus*.

TABLE IV -6.

Significant correlations between pairs of elements (A and B) among organs of *Hybanthus floribundus* and for plant-soil relationships (number of data pairs are parenthesised).

A	B	Sig.
Leaf X Leaf (56)		
Ni	Cu	-***
Ni	Co	+*
Ni	Cr	-**
Ni	Fe	-***
Ni	Ca	-**
Cu	Mg	-*
Cu	Fe	+***
Cu	Zn	+**
Cu	Cr	+*
Co	Mn	+***
Cr	Mg	-**
Cr	Fe	+***
Stem X stem (74)		
Ni	Co	+*
Ni	Ca	-***
Cu	Fe	+**
Cu	Zn	+*
Co	Mn	+***
Flower X leaf (51)		
Ni	Mn	+***
Cu	Cu	+**
Zn	Zn	+***
Mn	Mn	+***
Fe	Cr	+***
Co	Mn	+**

A.	B	Sig
Wood X wood (51)		
Ni	Ca	-***
Co	Cr	+*
Leaf x wood (39)		
Ni	Ni	-***
Cr	Ni	-***
Cr	Cr	+***
Leaf X stem (46)		
Mn	Mn	+**
Ca	Ca	+***
Mg	Mg	+***
Ni	Ni	+*
Co	Co	+**
Cr	Cr	+***
Zn	Zn	+***
Stem X wood (42)		
Ni	Ni	+***
Cu	Cu	+*
Co	Co	+**
Cr	Cr	+***
Zn	Zn	+**
Ca	Ca	+***
Flower X flower (51)		
Ni	Mn	-***
Ni	Co	+***
Co	Mn	+**

A	B	Sig
Leaf X soil (40)		
Ni	Cr	-**
Zn	Ni	-**
Co	Co	+*
Zn	Co	-**
Cr	Zn	+***
Cr	Cr	+**
Zn	Cr	-**
Stem X soil (57)		
Cu	Ni	+*
Co	Cu	+**
Cr	Co	+*
Cr	Zn	+***
Cr	Cr	+*
Zn	Cr	-*
Wood X soil (39)		
Ni	Zn	-*
Ni	Cr	-**
Co	Cu	+***
Cr	Zn	+**

+ positive correlation
- negative correlation
* significant at 5% level
** significant at 1% level
*** significant at 0.1% level

The value of this shrub in the Kurrajong Region would seem to be as a geobotanical indicator either for the ground prospector or for the remote sensing as discussed in Section VI. Even in this field, the application might seem limited as the plant prefers skeletal soils where the bedrock is usually well-exposed. However, to be able to delineate ultra-basic areas, on aerial photos by using this shrub would be a great advantage to exploration personnel. For the ground prospector, the observation of H. floribundus in drainage tracts, sometimes several miles below the source area, would also be very useful. This evaluation of H. floribundus encouraged the second stage of the investigations which was to evaluate this shrub in other Western Australian nickel-fields.

3. EVALUATION BY RECONNAISSANCE GEOBOTANY.

A. INTRODUCTION.

The only reference to the distribution of *H. floribundus* in Western Australia is the work of Bennett (1969) which contains distribution maps for the three subspecies, viz. ssp. *floribundus*, ssp. *curvifolius* and ssp. *adpressus*. Her maps and detailed location notes indicated that one or more of these subspecies would be found in the Kalgoorlie-Kambalda area, the Norseman and Ravensthorpe localities and near Southern Cross. It was decided therefore to undertake a reconnaissance survey commencing at Leonora and travelling south through Kalgoorlie to Esperance, then eastwards to Ravensthorpe and back to Kalgoorlie via Southern Cross. The main roads which were used are shown in Fig. I-1, including the localities visited. The co-operation of several mining companies was sought and resulted in guided tours over the following nickel prospects or mines:- Scotia-Carr Boyd (Great Boulder Mines) some 30 miles north of Kalgoorlie; Widgiemooltha-3 (Anaconda) and Spargoville (Australian Selection) which are some 15 miles west and south-west of the Kambalda nickel mines. Several W.M.C. nickel prospects were examined south of Kambalda as far as Republican Hill.

B. GEOBOTANY.

At the Scotia and Carr-Boyd nickel mines *H. floribundus* was not located even though ultrabasics outcropped along a gentle rise. The calcareous substrate was evidenced by the local dominance of the she-oak (*Casuarina obesa*).

At Kambalda however, *H. floribundus* ssp. *curvifolius* Form B (Plate IV-4) was found in the localities listed by Elkington (1969) and on ultrabasic outcrops near gossans on the eastern, northern and western flanks of the domal structure. The appearance of this variety is greatly different from the Kurrajong Region specimens and, after consultation with Bennett (W.A. Herbarium), it was decided to refer to this variety or ecotype as Form B, and to the northern variety as Form A. See Plate IV-3, -4. South of Lake Lefroy, this shrub was found flourishing over the ultrabasics at Republican Hill but nowhere else in this alkaline environment. In these Eucalypt woodlands two shrub species, Trymalium myrtillus and Westringia rigida, as recorded by Elkington (1969) displayed an affinity for ultrabasic terrain. Chemical analyses revealed above background nickel concentrations but not on a comparable scale to Hybanthus.

H. floribundus ssp. curvifolius Form B. was also located over lateritised ultrabasics at Blackbourne Mine, some 4 miles south of Southern Cross and at Spargoville. At Widgiemooltha-3 this shrub flourished over steep hill of mineralised serpentinite (0.5% nickel) which was quite free of laterite. The conspicuous blue flowers implied more than 700 ppm nickel in the soil which was certainly the case. The analytical data are presented in Table IV-7.

In the Ravensthorpe district H. floribundus ssp. adpressus was located on ultramafic outcrops a few miles east and south of Ravensthorpe and the legacy of laterisation was again evident.

On the Ravensthorpe-Lake King road, H. floribundus ssp. floribundus was observed in lateritic scree and again, a further 10 miles north, on the very rough track which trends towards Southern Cross, east of the rabbit-proof fence. H. floribundus ssp. floribundus was also sampled on sandplain soils, east of Southern Cross, and on laterite at Parkerville, Perth, in the Darling Ranges.

A rather unusual species of Hybanthus, H. epacroides ssp. bilobus was sampled at Sedden (Fig. I-1) on leached quartz sands. Several other Hybanthus species have been recorded in Western Australia (Bennett, 1969) but time

LOCATION	VARIETY	Leaf (ppm) d.w.							Soil (ppm)							
		Ni	Cu	Co	Cr	Zn	Mn	Fe	Ni	Cu	Co	Cr	Zn	Mn	Fe	pH
Marshall Pool (34) *	H.floribundus ssp.curvifolius Form A	7025	3.4	63	1.7	38	170	243	800	40	70	840	80	480	6.1	5.5
'880 Prospect (22)	" "	3100	4.3	26	4.3	37	122	446	900	50	90	2000	100	600	7.4	6.5
Kambalda (3)	H.floribundus ssp.curvifolius Form B	3000	8	7	3.5	30	215	230	900	100	-	700	70	550	6.5	7.0
Southern Cross	(6)" "	4510	4	129	1.5	45	174	190	1400	40	250	2700	60	1400	7.1	6.5
Widgiemooltha	(4)" "	6010	2.7	23	1.1	28	110	182	2000	-	-	-	-	-	-	-
Spargoville (4)	" "	740	6	7	4	44	175	230	970	170	85	1070	290	290	7.8	6.5
Ravensthorpe (12)	H.floribundus ssp.adpressus	1270	4.2	51	2.1	3.6	230	822	134	37	35	240	40	240	3.9	-
L.King-Southern Cross (4)	H.floribundus ssp.floribundus	263	3.1	170	1.2	38	278	205	50	17	15	87	15	83	3.0	-
East of Southern Cross (2)	" "	1020	5	550	1.2	33	160	230	50	15	20	70	10	60	2.1	-
Parkerville Perth (1)	" "	8	5	-	1.2	65	110	190	-	-	-	-	-	-	-	-
Scadden (3)	H.epacroides ssp.bilobus	200	4.6	62	2.1	21	85	730	10	5	5	10	10	20	0.3	-
Adelaide, South Australia (4)	H. floribundus	110	4	100	-	65	-	-	30	30	-	-	-	-	-	-

prevented their examination.

C. BIOGEOCHEMISTRY.

All the *Hybanthus* varieties which were collected during this study were analysed for nickel and other metals along with their substrates and the data are recorded in Table IV-7. Data for South Australian specimens are also included.

It is clear that the varieties *H. floribundus* ssp. *curvifolius* (Forms A and B) and ssp. *adpressus* all have the capacity to accumulate more than 0.1% nickel (D.W.) which is equivalent to more than 2% A.W. (ash weight). Although the nickel concentrations in *H. floribundus* ssp. and *H. epacroides* ssp. *bilobus* are generally lower, the relative accumulation (concentration in leaf/soil) can exceed a value of 20 in all of the varieties listed in Table IV-7, excepting the Parkerville sample. The accumulation of cobalt is also noteworthy and might have been expexted in view of the close association of nickel and cobalt in geochemical systems. Copper, zinc and chromium concentrations in *Hybanthus* were uniformly low. Manganese, and iron levels were comparable to the normal vegetation as examined in previous sections, although ssp. *adpressus* exhibited some very high (3000 ppm) iron concentrations.

The Scaddan samples of ssp. *bilobus*, which were obtained from a leached rather acid substrate, managed to retain normal iron levels but other metal concentrations (zinc, manganese) were significantly lower than in the other varieties.

H. floribundus samples were obtained from the Adelaide Hills (Black Hill) in South Australia. The substrate was Upper Proterozoic (Adelaidean) sandstones which appeared to have very low base metal concentrations. Specimens of this species were also obtained from Warracknabeal and Mildura, in Victoria, but nickel concentrations were relatively low and ranged from 170 to 15 ppm (D.W.).

D. DISCUSSION.

The reconnaissance survey will probably represent a preliminary examination of the genus Hybanthus in Western Australia. From a geobotanical view point, it was encouraging to observe that three varieties of Hybanthus H. floribundus ssp. curvifolius Form A., H. floribundus ssp. curvifolius Form B. and H. floribundus ssp. adpressus were confined to nickeliferous ultramafic or ultrabasic substrates. The other varieties of Hybanthus appear to be of less importance at this stage.

The flower colour in the three "serpentine endemic" varieties does appear to be a useful guide to soil nickel levels; and often the specimens growing in the creek sediment with lower nickel values (less than 200 ppm) exhibited white flowers.

Concerning the biogeochemistry of the Hybanthus genus it has already been shown that these shrubs have little or no application in biogeochemical prospecting. However, the specimens with more than 3000 ppm nickel (D.W.) belong to the "serpentine endemic" species viz. H. floribundus ssp. curvifolius (Forms A and B) and H. floribundus ssp. adpressus. Thus a chemical field-test for specimens with more than 0.3% nickel might be useful in locating serpentinite areas.

It is interesting to note that the nickel concentrations in Hybanthus decrease, in a general manner towards the higher rainfall areas in the south, and in the next section the biogeochemical nickel concentrations are considered in an ecophysiological context.

4. THE FUTURE ROLE FOR HYBANTHUS IN MINERAL EXPLORATION.

A. INTRODUCTION.

The following discussion is concerned with outlining the possible role that *Hybanthus* may play in the nickel search in Western Australia, and possibly in the other States.

It has been established that certain varieties of *Hybanthus* grow only on nickeliferous substrates, specifically the host rocks for nickel ore-bodies. The distribution of these varieties viz. *H. floribundus* ssp. *curvifolius* (Forms A and B) and *H. floribundus* ssp. *adpressus*, especially the former two, occupy remote and arid regions. It can be expected that not all the populations of these species have yet been located. Moreover, in the course of this study only a small fraction of all the known localities were visited. Some 10 species of *Hybanthus* have been recorded in Australia, each with several subspecies. However, only two species and some of their subspecies have been examined, even in a cursory manner, using a geobotanical approach. In other words the potential of the *Hybanthus* genus in mineral exploration is largely untested.

B. TERMINOLOGY.

The three more important varieties of *Hybanthus* examined to date are *H. floribundus* ssp. *curvifolius* (Forms A and B) and *H. floribundus* ssp. *adpressus*.

Typical specimens of these varieties are shown in the frontispiece, by line drawing. The varieties ssp. *adpressus* and ssp. *curvifolius* Form B were classified by Bennett (1969) and are appropriately named as they respectively exhibit adpressed and curved leaves.

H. floribundus ssp. *curvifolius* Form A. was discovered by the writer in 1970, and Bennett (pers. comm.) considered that this variety from the Kurrajong Region was merely another form of ssp. curvifolius.

The line drawings in the frontispiece show that there is considerable difference, even in leaf morphology, between these two varieties. The present writer considers that these are distinct ecotypes, with separate distributions at least 200 miles apart.

It is therefore proposed that the precedent set by Wild (1971) with Dicoma niccolifera be adopted. In this case Wild examined the serpentine flora of Rhodesia (Wild, 1970) and noted that a form of the widespread species, Dicoma schinzii was almost entirely confined to nickeliferous serpentine soils, and accumulated up to 2,120 ppm nickel (presumably D.W.). Accordingly it is suggested that H. floribundus ssp. curvifolius Form A be classified as Hybanthus niccolifera sp. nov.

C. ROLE OF HYBANTHUS IN THE NICKEL SEARCH.

The role of Hybanthus lies in its ability to draw attention to nickeliferous (serpentine) areas which might otherwise be overlooked.

A vast pool of information on the distribution of the various Hybanthus species is lodged in the State herbaria and some of this data is presented in Bennett, (1969).

It is impossible to gauge the success that might result from an investigation of Hybanthus in Western Australia. The initial step would be to follow up the known nickel-accumulating Hybanthus species to determine whether any specimens have been recorded (in herbarium records) from previously overlooked areas.

A second but more labour-demanding step would be to evaluate the many other Hybanthus varieties to determine whether they contain any unusual metal concentrations.

Perhaps the ultimate goal would be to achieve a remote-sensing capability for the 'serpentine endemic' species and preliminary investigations in this direction are discussed in Section VI.

To conclude, the value of the *Hybanthus* genus in the nickel search appears to be as an indicator plant, for nickeliferous (more than 0.04% nickel) soils, and it can be used in this capacity at the moment by ground prospectors and aero-visual surveys (Kasynova, 1961). However, a reliable assessment of the value of the nickel-accumulating *Hybanthus* species must await their use by exploration personnel over a period of several years.

BIBLIOGRAPHY

Abu-Erreish, G.M.; Whitehead, E.L., and Olson, O.E., 1968. Evolution of volatile selenium from soils. Soil. Sci. v.106. p.415-421.

Agazzi, E.J., 1965. The determination of tin in hydrogen peroxide solutions by atomic Absorption spectrometry. Anal. Chem., v.37, p.364-366.

Ahrens, L.H., and Taylor, S.R., 1961. Soectrochemical analysis. 2nd ed., Pergamon, Oxford, 93 pp.

Alexkouskii, V.B., Mokhov, A.A., and Spirov, V.N., 1959. Application of the biogeochemical method to prospecting for nickel on the Kola peninsula. Geochemistry m.3, p.330-338.

Allan, J.E., 1963. Absorption flame photometry below 2,000 Å. Proc. Fourth Aust. Spec. Conf., Canberra, Australia.

Allaway, W.H., and Cary, E.E., 1964. Determination of submicrogram amounts of selenium in biological material. Anal. Chem. v.36, p.1359-1362.

Allaway, W.H., Cary, E.E., and Ehlig, C.F., 1967. The cycling of low levels of selenium in soils, plants and animals. In, Selenium in Biomedicine, AVI Pub. Westport, Conn., p.273-396.

Allen, W.A., and Richardson, A.J., 1968. Interacti[illegible] plant canopy, J. Opt. Soc. Amer. v.58, p.1023-1028.

Al-Rais, A.H., Myers, A., and Watson, L., 1971. The isolation and properties of oxalate crystals from plants. Ann. Bot., v.35, 1213-1218.

Amos, M.D., Bennett, P.A., Brodie, K.G., Lung, P.W.Y., and Matousek, J.P., 1971. Carbon rod atomiser in atomic absorption and fluorescence spectrometry and its clinical application. Anal. Chem., v.43, p.211-215.

Ando, A., Suzuki, M., Fuwa, K., and Vallee, B.L., 1969. Atomic abs[illegible] of arsenic in nitrogen (entrained air)- hydrogen flames. Anal. Chem. v.41 p.1974-1979.

Anon., 1959. A flower that led to a copper discovery. Horizon, Salisbury, v.1, p.35-39.

Anon., 1969, Gel filtration in theory and practice, Bull. Pharmacia Fine Chemicals, Sweden.

Austminex., 1970. Biogeochemical Survey, Pernatty Lagoon, South Australia. Unpubl. company rept. p.1-14.

Aust. Inst. Min. Metal., 1972. In, Suppl. Aus. I.M.M. Bull. No.353, 25 p.

Bagnall, K.W., 1966. The chemistry of selenium, tellurium and polonium. Elsevier, London, p.200.

Bailey, R.W., and Jones, D.I.H., 1971. Pasture quality and ruminant nutrition. Part III. Hydrolysis [illegible] with carbohydrases in relation to rumen digestion. N.Z. J. Agric. Res., v.14, p.847-857.

Bayer, E., 1966. Complex formation and flower colours. Angrew. Chem. Internal. Edit. v.5, p.791-798.

Bazilevskaya, N.A., and Sibireva, Z.A., 1959. Change in the colour of the corolla in Eschscholtzia californica under the influence of microelements (Russ.). Byull. glavn. bot. Sada, Leningr., n.6, p.32-38.

Bennett, E.M., 1969. The genus Hybanthus Jacquin in Australia including the cytology and anatomy of the Western Australia species. M.Sc. Thesis, Univ. West. Australia.

Bieleski, R.L., and Turner, N.A., 1966. Separation and estimation of amino acids in crude plant extracts by thin-layer electrophresis and chromatography. Anal. Biochem., v.17, p.278-293.

Billings, G.K., 1965. Light scattering in trace-element analysis by atomic absorption. Atom. Absorp. Newsl., v.4, p.357-362.

Billings, W.D., and Morris, R.J., 1951. Reflection of visible and infra-red radiation from leaves of different ecological groups. Am. J. Bot. v.38, p327-331.

Birrell, N.S., and Wright, A.C.S., 1945. A sepentine soil in New Caledonia. N.Z. J. Sci. Technol. 27A, p.73-76.

Blalock, H.M., 1960. In, Social Statistics. McGraw-Hill, New York.

Bloss, D., and Steiner, R.L., 1960. Biogeochemical prospecting for manganese in N.E. Tennessee. Bull. geol. Soc. Am., v.71, p.1053-1066.

Boehm, H., Mueller, P., and Schulte, H.R., 1966. Accumulation of N .-acetyl ornithine in the latex of Papaver bracteatum. Flora (Jena) v.156, p.445-450.

Bollard, E.G., and Butler, G.W., 1966. Mineral nutrition of plants. Ann. Rev. Pl. Physiol. v.17, p.17-112.

Bowen, H.J.M., 1966. Trace Elements in Biochemistry. McMillan, London.

Bowen, H.J.M., Cawse, P.A., and Thick, J., 1962. The distribution of some inorganic elements in plant tissue extracts. J. Exp. Bot. v.13, p.257-167.

Bradshaw, A.D., 1969. In, Ecological Aspects of the Mineral Nutrition of Plants (Ed. I.H. Rorison). Blackwell Scientific Publications, Oxford.

Bratzell, M.P., Dagnell, R.M., and Winefordner, J.D., 1970. A hot wire loop atomizer for atomic fluorescence spectrometry. Appl. Spectrosc., v.24, p.518-521.

Brockway, G.E., 1949. Forests of the drier areas of Western Australia. Paper prepared for the Australia Forestry Conference.

Broda, E., 1960. Radioactive isotopes in biochemistry. Amsterdam, Elsevier, 376 p.

Brookes, B.C., and Dick, W.F.L., 1969. An introduction to Statistical Method. Heineman Books, London, 322 p.

Brooks, R.R., 1972. Geobotany and Biogeochemistry in Mineral Exploration. Harper and Row, New York.

Brown, D.H., and Fowden, L., 1966. Characterisation of -acetyl-L-ornithine isolated from Onobrychis viciifolia Scop. Phytochem. v.5, p.881-886.

Browner, R.F., Patel, B.M., Glenn, T.H., Rietta, M.E., and Winefordner, J.D., 1972. Improvements in Electrodeless Discharge Lamp Radiant Flux and Stability by Precise Temperature Control. Proc. Pittsburgh Conf. March 1972.

Brundin, N., 1939. Method of locating metals and minerals in the ground. U.S. Pat. 2158980.

Bujard, E.L., and Mauron, J., 1966. A two-dimensional separation of acid, neutral and basic amino acids by thin layer chromatography on cellulose. J. Chromat. v.21, p.19-26.

Burbridge, N.T., 1963. Dictionary of Australian Plant Genera. Angus and Robertson, Sydney. 345 p.

Burrill, G.H.R., and Howland-Rose, A.W., 1970. Mineral exploration in Western Australia. Can. Min. J. v.91, p.106-110.

Byers, H.G., Miller, J.T., Williams, K.T., and Lakin, H.W., 1938. Selenium occurrence in certain soils in the United States with a discussion of related topics, 3rd report U.S. Dept. Agr. Tech. Bull. n.601, p.1-74.

Cameron, E.M., 1968. A geochemical profile of the Swan Hills Reef. Can. J. Earth Sci., v.5, p.287-309.

Cameron E.M., 1969. Regional geochimical study of the Slave Point carbonates. Western Canada. Can. J. Earth. Sci., v.6, p.247-268.

Canney, F.C., and Hawkins, D.B., 1960. Field application of ion-exchange resins in hydrogeochemical prospecting. U.S. Geol. Surv. Prof. Pap. 400-B p.89-90.

Canney, F.C., 1970. Remote detection of geochemical soil anomalies. Proc. UNESCO/ECAFE Seminar on Geochem. Explor. Perleniya, Ceylon.

Cannon, H.L., 1952. The effect of uranium-vanadium deposits on the vegetation of the Colorado Plateau. Am. J. Sci. v.250, p.735-770.

Cannon, H.L., and Starrett, W.H., 1956. Botanical prospecting for uranium on La Ventrua Mesa, Sandoval County, New Mexico. Bull. U.S. geol. Surv. 1278A, p.391-407.

Cannon, H.L., 1957. Description of indicator plants and methods of botanical prospecting for uranium deposits on the Colorado Plateau. U.S. Geol. Surv. Bull. 1030-M, p.399-516.

Cannon, H.L., 1960 a. The devolopment of botanical methods of prospecting for uranium on the Colorado Plateau. U.S. Geol. Surv. Bul. 1085-A, p.1-50.

Cannon, H.L., 1960 b. Botanical prospecting for ore deposits. Science, v.132, p.591-8.

Cannon, H.L., 1964. Geochemistry of rocks and related soils and vegetation in the Yellow Cat area. Grand County, Utah. Bull. U.S. geol. Surv., n.1176, 127 p.

Cannon, H.L., 1971. The use of plant indicators in ground water surveys, geologic mapping and mineral exploration. Taxon. v.20, p.227-256.

Carlisle, D., and Cleveland, G.B., 1958. Plants as a guide to mineralisation. Spec. Rep. Div. Mines Calif., No. 50, 31 p.

Carnegie, P.R., 1965. A peptide-mapping technique for the estimation of molecular size. Nature v.206, p.1128-1130.

Carter, D.L., Robbins, C.W., and Brown, M.J., 1970. Selenium concentrations in Forage on some high northwestern ranges. J. Range Management. v.23. p.234-238.

Cattell, R.B., 1965. Factor Analysis. An introduction to essentials I. The purpose and underlying models. Biometric. v.21, p.190-215, p.405-434.

Chaffe, M.A., and Hessin T.D., 1971. An evaluation of Geochemical Sampling in the search for concealed 'Porphyry' copper-molybdenum deposits on pediments in Southern Arizona. Can. Inst. Min. Spec. v.11, p.401-409.

Christian, C.S., and Slatyer, R.D., 1958. Some observations on vegetation changes and water relationships in arid areas. In, Arid Zone Research XI. Reviews of Research UNESCO. Switzerland.

Clarke, E. de C., Teichert, C., and McWhae, J.R.H., 1948. Tertiary deposits near Norseman, Western Australia. J. Roy. Soc. W. Aust., v.32, p.85-103.

Clausen, J., 1929. Chromosome number and the relationship of some north american species of Viola. Ann. Bot., v.43, p.741-764.

Cochrane, G.R., 1968. False-colour film fails in practise. Photogmm. Engng. v.34, p.1142-1146.

Cole, M.M., 1964. The use of vegetation in mineral exploration in Australia. Eighth Commonw. Min. Metall. Congr., v.6, p.1429-58.

Cole, M.M., Provan, D.M.J., and Tooms, J.S., 1968. Geobotany, biogeochemistry, and geochemistry in the Bulman - Waimuna Springs area, Northern Territory, Australia. Trans. Inst. Min. Metall., Sect. B., v.77, p.81-104.

Cole, M.M., 1971. The importance of enviroment in Biogeographical, Geobotanical and Biogeochemical Investigations. Cand. Inst. Min. Spec. Vol. No. 11.

Cole, M.M., 1971 a. Biogeographical, Geobotanical and Biogeochemical Investigations connected with exploration for nickel-copper ores in the hot, wet, summer, dry winter savanna woodland environment. J. Sth Afr. Inst. Min. Metall. p.199-209.

Coleman, R.G., and Delavaux, M., 1957. Occurrence of selenium in sulphides from some sedimertary rocks of the western United States (Abstr.). Econ. Geol. v.51, p.112.

Collins, M.I., 1924. Studies in the vegetation of arid and semi-arid New South Wales. Proc. Linn. Soc. N.S.W., v.49, p.1-18.

Colwell, R.N., 1965. Determining the prevalence of certain cereal crop diseases by means of aerial photography. Hilgardia, v.26, p.223-286.

Cousins, F.B., 1960. A fluorometric microdetermination of selenium in biological material. Aust. J. Exp. Biol. v.38, 1.11-16.

Curzon, G., and Giltrow, J., 1953. A chromatographic colour reagent for a group of aminoacids. Nature. v.172, p.356.

Dagnall, R.M., Thompson, K.C., and West, T.S., 1967. Studies in Atomic-Fluorescence Spectroscopy. IV. The stomic-fluorescence spectroscopic determination of selenium and tellurium. Talanta, v.14, p.557-563.

Davies, C.E.S., Ewers, W.E., and Fletcher, A.B., 1969. Determination of traces of tellurium in rocks by atomic absorption spectroscopy after volatilization with synthetic pyrite. Aust. Inst. Min. Metall. n.232, p.67-71.

Dawson, R.M.C., (ed) 1959. Data for biochemical research. Oxford Univ. Press.

Day, F.H., 1963. The Chemical Elements in Nature. Harrap. London. 372 p.

Debnam, A.H., 1955. Biogeochemical Investigations in the Northern Territory, 1954. Rec. Commonw. Wust. Dep. Natn. Dev. Bur. Min. Resour. Geol. Geophys. n. 1955/43, 24 p.

DeSequeira E. Menezes., 1970. Toxicity and movement of heavy metals in serpentine soils. (N.E. Portugal) Agron. Lusitana. v.30, p.115-154.

Dorfmuller, W., 1941. The influence of boron on the water budget of legumes. Planta, v.32, p.51.

Dunn, P.R., Smith, J.W., and Roberts, H.G., 1966. A proposal for time-stratigraphic sub-division of the Australian Precambrian, J. geol. soc. Aust. v.13, p.593-608.

Dunnill, P.M., and Fowden, L., 1967. The aminoacids of the genus Astragalus. Phytochem., v.6, p.1659-1663.

Duvigneaud, P., 1958. 'Cobaltophyte' plants in Upper Katanga. Bull Soc. roy. Bot. Belg. v.91. p.1-134.

Duvigneaud, P., 1958. La vegetation du Katanga et de ses sols metalliferes. Bull. Soc. roy. Bot. Belg. v.90, p.127-286.

Duvigneaud, P., and Denaeyer-de Smet, S., 1963. Studies on the Katanga vegetation and its metalliferous soils. Bull. Soc. roy. Bot. Belg. v.96, p.93-229.

Eastman Kodak, 1970. Kodak filters for Scientific and Technical uses. Eastman Kodak Company, 88 p.

Eaton, J.P., 1962. Crustral structure and volcanism in Hawaii. In, The crust of the pacific Basin. Ed. G.A. MacDonald and H. Kuno. Am. geophys. Union, Mem. 6, p.13-29.

Efron, M., 1960. High Voltage Paper Electrophoresis. In, Chromatographic and Electrophoretic Techniques. v.2, (ed. I. Smith) Heinemann Medical Books, London.

Elkington, J.E., 1969. Vegetation studies in the Eastern goldfields of Western Australia with particular reference to their role in Geological Reconnaissance and Mineral Exploration. Ph.D. Thesis, University of London.

El Shazly, E.M., Barakat, N., Eissa, E.A., Emora, H.H., Ali, I.S., Shaltout, S., and Sharaf, F.S., 1971. The use of Acacia trees in biogeochemical prospecting. Can. Inst. Min. Spec. v.11, p.426-434.

Elwell, W.T., and Gidley, J.A.F., 1967. Atomic absorption spectrophotometry. Oxford, Permagon, 139 p.

Ernst, W., 1972. Ecophysiological Studies on heavy metal Plants in South Central Africa. Kirkia, v.8, p.125-145.

Evans, R., 1948. An introduction to colour, Wiley, New York.

Eyre, L.A., 1971. High-altitude colour photos. Photogmm. Engng. v.37, p.1149-1153.

Fairburn, H.W., and others, 1951. A cooperative investigation of precision and accuracy in chemical, spectrochemical, and modal analysis of silicate rocks. U.S. Geol. Surv. Bull. 980, 71 p.

Fiegl, I.F., 1939. Qualitative Analysis by Spot Tests. Nordeman, New York. 462 p.

Fletcher, K., 1970. Some applications of background correction to trace metal analysis of geochemical samples by atomic-absorption spectrophotometry. Econ. Geol., v.65, p.588-591.

Fowden, L., 1958. -acetyl ornithine, a constituent of som[illegible] grasses. Nature, v.182, p.406-407.

Freckmann, W., 1934. Can we hinder or avoid frost damage in our moors? Mitt. Ver. Ford. Moorkult. dt. Reiche, 9/10.

Freere, R.H., 1967. Filters and their use in microscopy. Lab. Pract., v.16, p.1110-1121.

Fritz, N.L., 1967. Optimum methods for using infrared-sensitive colour films. Photogramm. Engng. v.33, p.1128-1138.

Froelich, A.J., and Kleinhampl, F.J., 1960. Botanical prospecting for uranium in the Deer Flats area, White Canyon District, San Juan County, Utah. Bull. U.S. geol. Surv., No. 1085-B, p.51-84.

Fuwa, K., and Vallee, B.L., 1963. The physical basis of analytical atomic absorption spectrometry. Anal. Chem. v.35, p.942-946.

Gambi, O.V., 1967. Preliminary data on the histological localisation of nickel in Alyssum bertolonii Desv. Nuovo G. bot. Ital. v.101, p.59-60.

Gardiner, M.R., Armstrong, J., Fels, H., and Glencross, R.N., 1962. A preliminary report on selenium and animal health in Western Australia. Aust. J. Expt. Agr. Anim. Husb. v.2, p.261-269.

Gardiner, M.R., and Gorman, R.C., 1963. Further observations on plant selenium levels in Western Australia. Aust. J. Expt. Agr. Anim. Husb., v.3, p.284-289.

Gardiner, M.R., Linton, Ac., and Aplin, T.E.H., 1969. Toxicity of *Swainsona canescens* for sheep in Western Australia. Aust. J. Agri. Res. v.20, p.87-97.

Gardner, C.A., 1942. The vegetation of Western Australia. J. Roy. Soc. W. Aust. v.28, p.xi-xxxvii.

Garrett, R.G., 1967. The geochemistry of the Fremont Lake quartz monzonites and associated gruss. NASA Sonora Pass geological test site, Sierra Nevada, California. N-West Univ. Rep. No. 14, 38 p.

Garrett, R.G., and Nichol, I., 1969. Factor analysis as an aid in the interpretation of regional geochemical stream sediment data. Colo. Sch. Mines Q., v.64, p.245-264.

Gates, D.M., Keegan, H.J., Schleter, J.C., and Weidner, B.R., 1965. Spectral properties of plants. Appl. Optics, v.4, p.11-20.

Gidley, J.A.F., 1964. Limitations in trace determinations by atomic absorption spectrophotometry. In, Liminations of detection in spectrochemical analysis. London, Hilger and Watts Ltd., p.25-44.

Geotimes, 1972. ERTS and EROS., Geotimes, v.17, n.3, p.20-23.

Goldschmidt, V.M., 1954. Geochemistry. Oxford, Univ. Press. London, p.532-540.

Gross, G.A., 1970. Geological concepts leading to mineral discovery. Can. Min. J. v.91, p.51-53.

Hamilton, J.W., and Beath, O.A., 1964. Amount and chemical form of selenium in vegetable plants. Agric. Fd. Chem. v.12, p.371-374.

Harbaugh, D.V., 1950. Biogeochemical investigations in the Tri-State District. Econ. Geol., v.45, p.548-567.

Harris, D.R., 1965. Plants, animals and man in the outer Leeward islands, west Indies. Univ. Calif. Publ. in geogr. v.18.

Hemwood, W.J., 1857. Notice of the copper turf of Merioneth. Edinb. new phil. J., v.5, p.61-63.

Hirs, C.H.W., Moore, S., and Stein W.H., 1952. Isolation of amino acids by chromatography on Ion-exchange columns. Use of volatile buffers. J. Bio. Chem. v.195, p.669-663.

Horizon, 1959. A flower that led to a copper discovery. Horizon, Salisbury, v.1, p.35-39.

Horscroft, F.D.M., 1961. In, The geology of the Northern Rhodesian Copper Belt. (ed. F. Mendelsohn). p.73-80.

Hostrup, B.W., and Kowaguchi, T., 1971. Aerial colour in Forestry, Photogmm. Engng. v.37, p.555-563.

Howard, J.A., 1966. Spectral energy relations of isobilateral leaves. Aust. J. Biol. Sci. v.19, p.757-66.

Howard-Williams, C., 1970. The ecology of Becium homblei in Central Africa with special reference to metalliferous soils. J. Ecol. v58, p.745-764.

Howard-Williams, C., 1971. Environmental factors controlling the growth of plants on heacy metal soils. Kirkia, v.8, p.91-102.

Howard-Williams, C., 1971b. Morphological variation between isolated populations of Becium homblei (de Wild.) Duvign. & Plancke growing on heavy metal soils. Vegetatio. v.23, p.141-151.

Hutchinson, G.E., 1943. The biogeochemistry of aluminium and certain related elements. Q. Rev. Biol. v.18, p.331-363.

Ishizuka, Y., 1971. Nutrient deficiencies of crops. Talpei, ASPAC Food & Fertilizer Technology Center. 112 p.

Jacobsen, G., 1945. Iron in the leaves and chloroplasts of some plants in relation to their chlorophyll content. Plant Physiol. v.20, p.233-245.

Jacobsen, W.G., 1968. The influence of the copper content of the soil on the vegetation at Silverside South, Mangula Area. Kirkia, v.6, p.256-277.

Jacobson, L., and Overstreet, R., 1948. The uptake by plants of plutonium and some products of nuclear fission absorbed on soil colloids. Soil. Sci. v.65, p.129-134.

Jensch, E., 1894. Zinc flora of Upper Silesia. Z. angew. Chem. v.1, p.14-15

Jessup, R.W., 1946. The ecology of the area adjacent to Lakes Alexandrina and Albert. Trans. roy Soc. S. Aust., v.70, p.3-34.

Johnson, H., 1970. Determination of selenium in solid waste. Environ. Sci. Tech. v.4, p.850-853.

Jones, R.G.W., and Lund, O.R., 1967. Function of calcium in plants. Bot. Rev. v.33, p.414-426.

Jones, H., 1970. Prospecting by infra-red techniques. Mining Mag., v.122, p.39-57.

Jowett, D., 1964. Population studies on lead tolerant Agrostic tenuis. Evolution, v.18, p.70-80.

Jutson, J.T., 1934. Physiography of Western Australia, geol. Surv. W. Aust., Bull. 95, 358 p.

Kahn, H.L., and Schallis, J.E., 1968. Improvement of Detection Limits for arsenic, selenium and other elements with an argon-hydrogen flame. Atom. Abspn. Newsl. v.7, p.5-9.

Kasynova, M.S., 1961. Aerovisual geobotanical observations in deserts and semi-arid regions. Int. Geol. Rev., v.3, p.626-628.

Keith, J.R., 1968. Relationships of lead and zinc contents of trees and soils, Upper Mississippi Valley District. Prepr. Soc. Min. Eng. AIME, n.68-L-320, p.12.

Kikkawa, H., Ogita, Z., and Fujito, S., 1955. Nature of pigments derived from tyrosine and tryptophan in animals. Science, v.121, p.43-47.

Kleinhampl, F.J., and Koteff, C., 1960. Botanical prospecting for uranium in the Circle Cliffs area, Garfield County, Utah. Bull. U.S. geol. Surv., No. 1085-C, p.85-104.

Knight, S.H., 1937. Occurrence of selenium and seleniferous vegetation in Wyoming. I. The rocks of Wyoming and their relations to the selenium problem. Wyoming Agr. Expt. Sta. Bull. no. 221, p.2-27.

Knipling, E.B., 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Rem. Sens. Envir. v.1, p.155-159.

Knott, S.G., McGray, C.W.R., and Hall, W.T.J., 1958. Selenium poisoning in horses in North Queensland. Qld. J. Agric. Sci. v.15, p.43-58.

Kotilainen, M.J., 1944. Specialised plants as substrate indicators. Soc. scient. fen. v.6, p.1-18.

Krause, W., 1958. The significance of minerals for plant colonisation of soils. In, Handbuch der Pflanzenphysiologie, v.IV, Springer, Berlin.

Kruckeberg, A.R., 1954. The ecology of Serpentine soils II. Plant specied in relation to serpentine soils. Ecology, v. 35, p.267-274.

Lakin, H.W., 1961 (a). Geochemistry of Selenium in Relation to agriculture. In, Selenium in agriculture, U.S. Dept. Agr. Handbook No. 200, p.3-24.

Lakin, H.W., 1961 (b). Selenium Content of soils. In. Selenium in Agriculture. U.S. Dept. Agr. Handbook No. 200 p.27-34.

Lakin, H.W., and Davidson, D.F., 1967., 1967. The relation of the Geochemistry of Selenium to its occurrence in soils. In, Selenium in Biomedicine (ed. Muth), p.27-56.

LARS annual report. Purdue University LARS bull. No. 831. annual report v.1, 1967, 36 p.

LARS annual report. Purdue University LARS res. bull. No. 832, annual report v.2. 1967, 75 p.

LARS annual report. Purdue University LARS res. bull. No. 844, annual report v.3. 1968. 175 p.

LARS annual report. Purdue University LARS res. bull. No. 873. annual report v.4. 1970, 112 p.

Lauchli, A., Spurr, A.R., and Epstein, E., 1970. Lateral transport of ions into the xylem of corn roots. Plant physiol. v.48, p.118-124.

Liebich, H., 1941. A quantitative chemical investigation of the iron in the chloroplasts and other cell components of Spinacia oleracea. Z. Bot. v.37, p.129-157.

Linstow, O. von., 1929. Plant indicators of soil. Berlin, Preuss. geol. Landesanstalt, p.246.

Litchfield, W.H., 1963. Soils of the Wiluna - Meekatharra Area. In, Lands of the Wiluna-Meekatharra Area, Western Australia, 1958. C.S.I.R.O. Land Research Series No. 7, p.123-142.

Loftus-Hills, G.D., Groves, D.I., and Solomon, M., 1969. The selenium content of some Tasmanian sulphides. Aust. Inst. Min. Metall. No. 232, p.55-65.

Luke, C.L., 1959. Photometric determination of Traces of Selenium or Tellurium in Lead or Copper. Anal. Chem. v.31, p.572-574.

Lyon, G.L., 1969. Trace Elements in New Zealand Plants. Ph.D. Thesis, Massey University, New Zealand.

Mabbutt, J.A., 1963. Geomorphology of the Wiluna-Meekatharra Area. In, Lands of the Wiluna-Meekatharra Area, Western Australia, 1958. C.S.I.R.O. Land Research Series No.7, p.107-122.

Malahoff, A., and Woolland, G.P., 1966. Magnetic measurements over the Hawaiian ridge and their volcanological implications. Bull. Volc. v.29, p.735.

Malytuga, D.P., 1964. Biogeochemical methods of prospecting. New York, Consultants Bureau, 205 p.

Malyuga, D.P., Malashkina, N.S., and Makarova, A.I., 1959. Biogeochemical investigations at Kadzharen, Armeniam SSR (Russ.). Geokhimiya, No. 5, p.423-430.

Manske, R.H.F., 1937. The natural occurrence of acetylornithine, Can. J. Res. v.158, p.84.

Marshall, N.J., 1970 (a). Review of Geochemical Exploration Research by Australian Selection (PTY) Ltd. UNESCO/ECAFE Seminar on Geochemical Prospecting Methods and Techniques, Peradeniya, Ceylon.

Marshall, N.J., 1970 (b). Applications of aerial photography in regional geologic mapping. Proc. UNESCO/ECAFE Seminar on Geochem. Explor. Peradeniya, Ceylon.

Massman, H., 1968. Atomic absorption analysis with a heated graphite cell (Fr.). Meth. phys. Anal., v.4, p.193-201.

Mason, B., 1958. Principles of Geochemistry. Wiley, New York, 310 p.

Mazzucchell, R.H., and James, C.H., 1966. Arsenic as a guide to gold mineralisation in laterite-covered areas of Western Australia. Trans. Inst. Min. Metall. Sect.B. Appli. earth Sci. v.75, B286-294.

McCall, G.J.H., and Doepel, J.J.G., 1969. Stratiform basic bodies within the Yilmia ophiolites, Western Australia. Proc. Aust. Inst. Min. Met., No. 231, p.67-73.

McCall, G.J.H., and Leishman, J., 1971. Clues to the origin of Archaean Eugeosynclinal peridotites and the nature of serpentinisation Sec. Publ. geol. Soc. Aust. No.3, p.281-299.

McCray, C.W.R., and Hurwood, I.S., 1963. Selenosis in North-western Queensland associated with a marine Cretaceous Formation. Qld. J. Agric. Sci. v.20, p.475-498.

McEwan, T., 1964. Isolation and Identification of the Toxic Principle of Gastrolobium grandiflorum. Nature. v.201, p.827.

McNeilly, T., and Bradshaw, A.D., 1967. Evolutionary processes in populations of Agrostis tenuis. Evolution. v.22, p.108-118.

Mendelsohm, F., (ed.) 1961. The geology of the Northern Rhodesian copperbelt, MacDonald, London, 532 p.

Mestre, H., 1935. The absorption of radiation by leaves and algae. Cold Spring Harbor Symp. Quant. Biol. v.3, p.191-209.

Meyer, M.P., and Calpouzos, L., 1968. Detection of crop diseases. Photogmm. Engng. v.34, p.554-556.

Miesch, A.T., 1964. Effects of sampling and analytical error in geochemical prospecting. Stanford Univ. Publs., Geol. Sci., v.9, p.156-170.

Miller, C.P., 1961. Plant and soil prospecting for nickel. Trans. Am. Inst. Min. Metall. Petrol. Engrs., v.220, p.255-260.

Minguzzi, C., and Vernano, O., 1948. Nickel content of Alyssum bertoloni (Ital.). Atti. Sco. tosc. Sci. nat., v.55, p.49-74.

Mitchell, R.L., 1945. Cobalt and nickel in soils and plants. Soil Sci. v.60, p.63-70.

Miyake, Y., 1965. Elements of geochemistry, Maruzen, Coy., Tokyo.

Moore, R.M., 1960. The management of native vegetation in arid and semi-arid regions. In, Arid Zone Research XV Reviews of Research, UNESCO. Switzerland.

Moore, P.D., 1972. Need for Nickel. Nature v.236, p.265-266.

Mothes and Reuter, (unpubl.) cited in Fowden, L, 1958.

Mulcahy, M.J., 1960. Laterites and lateritic soils in south-seatern Australia. J. Soil. Sci. v.11, p.206-225.

Muth, O.H., (ed), 1967. Symposium, Selenium in Biomedicine, Westport, Cann. Avi. publ., 445 p.

Myers, V.I., Weigand, C.L., Heilman, M.D., and Thomas, J.R., 1966. Remote sensing in soil and water conservation research. Proc. Fourth Symp. on Remote Sensing of Environment, Institute of Science and Technology, Univ. of Michigan, Ann. Aabor., p.801-813.

Nakagawa, H.M., and Thompson, C.E., 1968. Atomic absorption determination of Tellurium. U.S. Geol. Surv. Prof. Paper, No. 600-B. p.B123-B125.

Nature, 1972. Need for nickel. London, April, v.236, p.265-266.

Neish, A.C., 1939, Studies on chloroplasts. II. Their chemical composition and distribution of metabolites between the chloroplasts and the remainder of the leaf. Biochem. J. v.33, p.330-308.

New Scientist, 1972. Mining nickel the easy way. London, 16 March 1972. v.53, No. 787, p.583.

Nicholas, D.J.D., 1961. Minor mineral nutrients. Ann. Rev. Pl. Physiol. v.12, p.63-90.

Nicolls, O.W., Provan, D.M.J., Cole, M.M., and Tooms, J.S., 1965. Geobotany and geochemistry in mineral exploration in the Dugald River area, Cloncurry District, Australia. Trans. Inst. Min. Metall., v.74. p.696-799.

Nielsen, J.H., and Sauberlich, H.E., 1970. Evidence of a possible requirement for nickel by the chick. Proc. Soc. exp. Biol. Med. v.134, p.845-849.

Nielsen, J.S., 1972. The feasibility of biogeochemical and geobotanical prospecting at Spargoville, Western Australia. M.Sc. Thesis, Massey University.

Nielsen, J.S., Brooks, R.R., Boswell, C.R., and Marshall, N.J., 1972. Statistical evaluation of geobotanical and biogeochemical data by discriminant analysis. J. Appl. Ecol. (In Press).

Nomoto, M., Narahshi, Y., and Murakami, M., 1960. A proteolytic enzyme of Streptomyces grisens. J. Biochem. (Tokyo), v.48, p.593-602.

Oland, K., 1963. Change in the content of dry matter and major nutrient elements of apple foliage during senescence and abscission. Physiologia Pl. v.16, p.682-694.

Ortiz, D.S., and Carrasquero, A., 1968. Investigations of possible selenium-containing soils in Venezuela. Agronomia. Trop. (Maracay) Venezuela. v.18, p.369-377.

Osburn, R.L., Shendrikar, A.D., and West, P.W., 1971. New spectrophotometric method for determination of submicrogram quantities of selenium. Anal. Chem. V.43, p.594-597.

Parry, J.T., Cowan, W.R., and Heginbottom, J.A., 1969. Colour for Coniferous Forest Species. Photogmm. Engng. v.35, p.669-678.

Pearman, G.I., 1966. The reflectance of visible radiation from leaves of some western Australian species. Aust. J. Biol. Sci., v.19, p.97-103.

Pease, R.W., and Bowden, L.W., 1969. Making colour infrared film a more effective high-altitude remote sensor. Rem. Sensor. Rem. Sens. Envir. v.1, p.23-30.

Pease, R.W., 1970. Colour infrared film as a negative material. Rem. Sens. Envir. v.1, p.195-198.

Peterson, P.J., 1969. The distribution of zinc-65 in Agrostis tenuis Sibth. and A. stolonifera L. tissues. J. Exp. Bot. v.20, p.863-875.

Peterson, P.J., 1971. Unusual accumulations of elements by plants and animals. Sci. Prog., Oxf. v.59, p.505-526.

Peterson, P.J., 1972. NOn-protein aminoacid distinctions between Aspleniaceae and Athyriaceae in New Zealand. N.Z. J. Bot. v.10, p.3-7.

Peterson, P.J., and Butler, G.W., 1962. The uptake and assimilation of selenite by higher plants. Aust. J. Biol. Sci. v.15, p.126-146.

Peterson, P.J., and Butler, G.W., 1967. Significance of Selenocystathionine in an Australian Selenium-accumulating plant, Neptunia amplexicaulis. Nature, v.213, p.559-600.

Peterson, P.J., and Butler, G.W., 1971. The occurrence of Selenocystathionine in Morinda Reticulata Benth, a toxic seleniferous plant. Aust. J. Biol. Sci. v.24, p.175-177.

Peterson, P.J., and Parris, P.S., 1970. An analysis of aminoacids in New Zealand species of Doodia (Blechnaceae). N.Z. J. Bot. v.8, p.647-657.

Poley, J.Ph., 1965. Contrast filtration in photogeology by selective filtering. Photogmm. Engng. v.31, p.368-375.

Pories, W.J., and Strain, W.H., 1971. The functional role of zinc in epidermal tissues. In, Trace Element Metabolism in Animals, ed. C.F. Mills, E and S. Livingstone, London.

Prescott, J.A., and Pendleton, R.L., 1952. Laterite and lateritic soils. Commonw. Bur. Soil. Sci. No.47, 51 p.

Prider, R.T., 1961. The "greenstones" of south-west Australia. J. Proc. R. Soy. West. Aust., v.44, p.1-9.

Quin, B.F., 1972. Analytical and Biogeochemical Studies of Tungsten. Thesis (unpubl.) Massey University, New Zealand.

Rankama, K., 1940. On the use of trace elements in some problems of practical geology. C.r. Soc. geol. Finl., No.14, p.90-106.

Rao, C.R., 1952. Advanced Statistical Methods in Biometric Research. New York.

Ravikevitch, S., and Margolin, M., 1957. Selenium in soils and plants Israel Agr. Res. Sta., Rehovot 1957, Series 145-E, v.7, p.41-52.

Raymond, R.W., 1887. Indicator Plants, Amer. Inst. Metall. Engineers Trans. v.15, p.644-60.

Reilly, C., 1967. Accumulation of copper by some Zambian plants. Nature v.215, p.667-668.

Reilly, G., 1969. The uptake and accumulation of copper by Becium homblei. (De Wild.) Duvign & Plancke, New Phytol. v.68, p.1081-1087.

Reilly, G., Rowel, J., and Stone, J., 1970. The accumulation and binding of copper in leaf tissue of Becium Homblei (de Wild.) Duvign & Plancke. New Phytol. v.69, p.993-997.

Reith, J.W.S., 1970. Soil factors influencing the trace element content of herbage. In, Trace Element Metabolism by Animals (ed. C.F. Mills). p.410-412. Livingstone, London.

Reinaecker, G., and Toursel, W., 1966. Influence of solid catalysts on solid phase reactions. Mh. dt. Akad. Wiss. Berlin. v.8, p.18-22.

Roach, W.A., and Barclay., 1946. Nickel and multiple trace element deficiencies in agricultural crops. Nature, v.157, p.606.

Robinson, N., (ed) 1966, Solar radiation, Elsevier, Amsterdam, 347 p.

Robinson, W.O., Edgington, G., and Byers, H.C., 1935. Chemical studies of infertile soils derived from rocks high in magnesium. Tech, Bull. U.S. Dep. Agri. n.471, p.1-29.

Rosenfeld, I., and Beath, O.A., 1964. Selenium. Academic Press, New York. 411 p.

Ross, W.D., and Sievers, R.E., 1972. Environmental Air analysis for ultratrace concentrations of beryllium by gas chromatography. Environ. Sc. Tech. v.6, p.155-158.

Sandell, E.B., 1959. Colorimetric determination of traces of metals. New York, Interscience, 3rd ed., 1032 p.

Sayre, J.D., 1952. Accumulation of radioisotopes in corn leaves. Ohio Agric. exp. stn. Ohio. Res. Bull. 723.

Schütte, K.H., 1964. The biology of Trace Elements. Crosby Lockwood, London.

Scott, D., Menalda, P.H., and Brougham, R.W., 1968. Spectral snalysis of radiation transmitted and reflected by different vegetations. N.Z. J. Bot. v.6, p.427-449.

Severne, B.C., 1972. Localisation of water-soluble nickel and calcium in plant tissue by electron microprobe techniques. Proc. Fifth Nat. Conf. N.Z. Soc. Electron Microscropy.

Severne, B.C., and Brooks, R.R., 1972 A nickel-accumulating plant from Western Australia. Planta, v.103, p.91-94.

Severne, B.C., and Brooks, R.R., 1972.b. Rapid determination of selenium by atomic absorption spectrophotometry. Anal. Chim. Acta., v.58, p.216-218.

Severne, B.C., and Brooks, R.R., 1972.c. Rapid determination of selenium and tellurium by atomic absorption spectrophotometry. Talanta, (In press).

Shacklette, H.T., 1964. Flower variation of Epilobium augustifolium L. growing over uranium deposits. Can. Fld. Nat., v.78, p.32-42.

Shear, C.B., and Faust, M., 1971. Value of various tissue analyses in determining the calcium status of the apple tree and fruit. In, Recent advance in Plant Nutrition. v.1 (ed.) R.M. Samish, Gordon and Breach, New York.

Shift, A., 1964. A Selenium Cycle in Nature? Nature. v.201, p.1304-1305.

Shvyryayeva, A.M., and Mikhailova, G.A., 1965. Experiences in the indicator interpretation of geobotanical maps in the North Caspian region. In, Plant in icators of soils, rocks and subsurface waters. New York, Consultants Bureau, 209 p.

Sidgwick, N.V., 1962. The chemical elements and their compounds. v.2. Clarendon Press. London.

Siegel, S., 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, Tokyo, 312 p.

Sinclair, R., and Thomas, D.A., 1970. Optical properties of leaves of some species in arid South Australia. Aust. J. Bot. v.18, p.261-273.

Sinclair, T.R., 1968. Pathway of solar radiation through leaves. M.S. Thesis, Purdue Univ., Lafayette, Ind.

Sindeeva, [illegible], 1964. Mineralogy and Types of Deposits of Selenium and Tellurium. Interscience, New York.

Skertchy, S.B.J., 1897. The copper plant (Polycarpea spirostyles, F.V. Mueller.) Pub. Geol. Surv. Qd, n.119, p.51-53.

Smith, H., 1970. Determination of Trace Elements in Biological material by Neutron Activation Analysis. In, Trace Element Metabolism by Animals. (ed. C.F. Mills), p.512-521. Livingstone, London.

Smith, I., 1960. Aminoacids, amines and related compounds. In, Chromatographic and Electrophoretic Techniques. v.1. Heinemann Medical Books., London.

Soane, B.D., and Saunder, D.H., 1959. Nickel and chromium toxicity serpentine soils in Southern Rodesia. Soil Sci., v.88, p.322.

Sofoulis, J., and Mabbutt, J.A., 1963. Geology of the Wiluna-Meekatharra Area. In, Lands of the Wiluna-Meekatharra Area, Western Australia, 1958. C.S.I.R.O. Land Research Series, No. 7. p.93-106.

Stanton, R.E., 1966. Rapid methods of trace analysis for geochemical applications Arnold, London, 96 p.

Stanton, R.E., and McDonald, A.J., 1965. The determination of Selenium in Soils and Sediments with 3,3-Diaminobenzidine. Analyst, v.90, p.497-499.

Stebbins, G.L., 1942. The Genetic Approach to rare and endemic species, Madrono, v.6, p.241-272.

Steiner, D., and Guterman, T., 1966. Russian data on spectral reflectance of vegetation, soil, and rock types. Final Technical Report, United States Army European Research Office.

Stephens, C.G., 1971. Laterite and Silcrete in Australia. Geoderma, v.5, p.5-52.

Stern, H., 1968. Fractionation of plant cells. In, Biochemists Handbook, London, p.1192.

Stocking, C.R., and Ongun, A., 1962. The intracellular distribution of some metallic elements in leaves. Amer. J. Bot. v.49, p.284-289.

Storozheva, M.M., 1954. The influence of copper and boron on yields of forage grasses and on the cold-resistance of clover in the Northern Trans. Urals. Dokl. Akad. Nauk. SSSR, 95, p.1341-1342.

Swaine, D.J., 1955. The trace-element content of soils. Commonw. Bur. Soil Sci., Rothamsted Exp. Sta., Harpended, England, Tech. Comm. 48.

Takimoto, K., Minato, T., and Hiroko, S., 1958. On the distribution of selenium in some sulphide minerals showing the relations of intimate paragenesis. J. Japan, Assoc. Mineral., Petrologists, and Econ. Minerals, v.42, p.161-170.

The National Times, 1972. Mining nickel-the easy way. Australia, March 27, 1972, p.42.

Thomas, J.R., Myers, V.I., Heilman, M.D., and Wiegard, C.L., 1966. Factors affecting light reflectance of cotton. Proc. Fourth Symp. Remote Sensing of Environment, Institute of Science and Technology, Univ. of Michigan, Ann. Arbor, p.305-31 2.

Thurstone, L.L., 1947. Multiple-Factor Analysis. Chicago Press. Illinois, 535 p.

Timperley, M.H., 1971. Biogeochemical Studies of Nickel and Copper in New Zealand. Ph.D. Thesis, Massey University, New Zealand.

Timperley, M.H., Brooks, R.R., and Peterson, P.J., 1970. The significance of essential and non-essential trace elements in plants in relation to biogeochemical prospecting. J. appl. Ecol. v.7, p.429-439.

Tiffin, L.O., 1971. Translocation of nickel in xylem exudate of plants. Plant Physiol. v.48, p.273-277.

Tkalich, S.M., 1959. Practical Instructions in the Biogeochemical Method of Prospecting. Gosgeoltekhizdat, Moscow.

Trescases, J., 1969. Preliminary observations on the weathering of peridotites. New Caledonia. Cah. ORSTOM Ser. geol. v.1, p.27-57.

Tukey, H.B., 1970. The leaching of substances from plants. Ann. Rev. Pt. Physiol., v.21, p.305-324.

Turekian, K.K., and Wedepohl, K.H., 1961. Distribution of the elements in some major units of the earths crust. Geol. Soc. Am. Bull. v.72, p.175-338.

Turek, A., 1966. Rubidium-strontium isotope studies in the Kalgoorlie-Norseman area, Thesis (unpubl.). Australian National University, Canberra.

Turner, R.G., 1969. In, Ecological Aspects of the mineral nutrition of plants (Ed. by I.H. Rorison). Blackwell Scientific Publications Oxford.

Underwood, E.J., 1956. Trace elements in Human and Animal Nutrition. Academic Press, New York.

Underwood, E.J., 1971. Trace elements in Human and Animal Nutrition. 3rd Ed. Academic Press, New York. 530 p.

Vassilaros, G.L., 1971. Determination of arsenic and selenium in steel by an x-ray technique utilizing chemical preconcentration. Talanta, v.18, p.1057-1061.

Vergnano, O., 1958. The inorganic elemental contents in plants of the Impruneta ophiolitic formation (Florence). Nuovo G. not. Ital. v.65, p.133-162.

Viktorov, S.V., Vostokova, Y.A., and Vyshivkin, D.D., 1964. Short guide to geobotanical surveying. Oxford, Pergamon, 158 p.

Vinogradov, A.P., 1959. The geochemistry of rare and dispersed chemical elements in soils. 2nd ed.. Consultants Bureau, New York.

Virtanen, A.I., and Linko, P., 1955. The occurrence of free ornithine and its n-acetyl derivative in plants. Acta. Chem. Scand., v.9, p.531-554.

Virupaksha, T.K., and Shrift, A., 1965. Biochemical differences between selenium accumulator and non-accumulator Astragalus species. Biochem. Biophys. Actm. v.107, p.69-80.

Vogel, A.I., 1966. A text-book of quantitative Inorganic Analysis. p.798-800.

Vogt, T., 1939. Chemical and botanical prospecting at Kuros (in Norweg.) K. norske Vidensk. Selsk. Forh., v.12, p.82-83.

Vostokova, Y.A., and Khdanova, G.I., 1961. Utilisation of geobotanical indicators in aeromagnetic mapping in Western Kazakhstan. Int. Geol. Rev., v.3, p.412-416.

Walker, R.B., 1954. The ecology of serpentine soils. II, factors affecting plant growth on serpentine soils. Ecology, v.35, p.259-266.

Walsh, T., and Fleming, G.A., 1952. Selenium levels in rocks, soils and herbage from a high selenium locality in Ireland. Trans. Intern. Soc. Soil. Sci., Comm. II and IV, v.2, p.178-185.

Walsh, T., Fleming, G.A., O'Connor, R., and Sweeney, A., Selenium toxicity associated with Irish Soil series. Nature, v.168, p.881.

Warren, H.V., 1972. Biogeochemistry in Canada. Endeavour, v.31, p.46-49.

Warren, H.V., and Delavault, R.E., 1948. Biogeochemical Investigations in British Columbia. Geophysic v.13, p.609-624.

Warren, H.V., and Delavault, R.E., 1949. Further studies in biogeochemistry. Bull. geol. Soc. Am., v.60, p.531-560.

Warren, H.V., and Delavault, R.E., 1950 a. Gold and silver content of some trees and horsetails in British Columbia. Bull. Geol. Soc. Am., v.61, p.123-128.

Warren, H.V., and Delavault, R.E., 1955 a. Variations in the nickel content of some Canadian trees. Trans. R. Soc. Can., v.48, p.71-74.

Warren, H.V., and Delavault, R.E., 1956. History of biogeochemical prospecting in British Columbia, Trans. Can. Inst. Min. Metall., v.53, p.236-242.

Warren, H.V., and Delavault, R.E., 1960. Observations on the biogeochemistry of lead in Canada. Trans. R. Soc. Can., v.54, p.11-20.

Warren, H.V., Delagault, R.E., and Barakso, J., 1964. The role of arsenic as a pathfinder in biogeochemical prospecting. Econ. geol. v.59, p.1381-1389.

Warren, H.V., Delavault, R.E., and Barakso, J., 1968. The arsenic content of Douglas Fir as a guide to some gold, silver and base metal deposits. Can. Min. Metall. Bull., v.41, p.1-7.

Watkinson, J.H., 1962. Soil selenium and animal health. Intern. Soc. soil, Sci. Joint Meeting comm. IV. and V, p.149-154.

Watkinson, J.H., 1966. Fluoremetric determination of selenium in biological material with 2,3-diaminonaphthalene. Anal. Chem., v.38, p.92-97.

Watkinson, J.H., 1967. Analytical Methods for Selenium in Biological Material. In, Selenium in Biomedicine, Avi, Westport, Conn., p.97-117.

Watts, D., 1971. Principles of Biogeography, McGraw-Hill, London, 401 p.

Webb, J.S., and Atkinson, W.J., 1965. Regional geochemical reconnaissance applied to some agricultural problems in Co. Limerick, Eire. Nature, v.208, p.1056-1059.

Webb, J.S., and Millman, A.P., 1951. Heavy metals in vegetation as a guide to ore. Trans. Inst. Min. Metall., v.60, p.473-504.

Webb, J.S., Thornton, I., and Fletcher, K., 1966. Seleniferous soils in parts of England and Wales. Nature, v.211, p.327.

Webb, J.S., Thornton, I., and Fletcher, K., 1968. Geochemical Reconnaissance and hypocuprosis. Nature, v.217, p.1010-1012.

Webber, G.R., 1965. Second report of analytical data for CAAS syenite and sulphide standards. Geochim. Cosmochim. Acta. v.29, p.229-248.

Weber, F.P., and Olson, C.E., 1967. Remote sensing implications of changes in physiological structure and function of tree seedlings under moisture stress. Annual Progress Report. Remote Sensing Applications in Forestry, National Resources Program, National Aeronautics and Space Administration.

Wellenreiter, R.H., Ultrey, D.E., and Miller, E.R., 1970. Nutritional Studies with Nickel. In, Trace element metabolism in animals. ed. C.F. Mills, p.52-58. E & S. Livingstone. Lond.

Wells, N., 1965. Selenium Content of Soil-forming Rocks, N.Z. J. Geol. Geophys. v.10, p.198-208.

West, T.S., and Williams, X.K., 1969. Atomic absorption and fluorescence spectroscopy with a carbon filament atom reservoir. Part 1., Construction and operation of atom reservoir. Anal. Chim. Acta., v.45, p.27-41.

Whitehead, N.E., 1970. Aspects of radiobiogeochemistry. Ph.D. Thesis, Massey University.

Wilcox, D.G., 1963. The pastoral industry of the Wiluna-Meekatharra Area. In, Lands of the Wiluna-Meekatharra Area, Western Australia. Land Research Series No.7. CSIRO.

Wild, H., 1965. The flora of the great dyke of Southern Rhodesia with special reference to the serpentine soils. Kirkia, v.5, p.49-86.

Wild, H., 1968. Geobotanical Anomalies in Rhodesia. 1, The vegetation of copper-bearing soils. Kirkia, v.7, p.1-71.

Wild, H., 1970. Geobotanical anomalies in Rodesia. 3. The vegetation of nickel bearing soils. Kirkia. v.7, p.1-62. Supplement.

Wild. H., 1971. The taxonomy, ecology and possible method of evolution of a new metallíferous species of Dicoma cass. (Compositae). Mitt. Bot. Staatssamml. München, v.10, p.266-274.

Wild, H., and Heyting, A., 1966. An analysis of leaf dimensions in Becium homblei (de Wild.) Duvign & Plancke and B. obovatum (E. Mey.) N.E. Br. Bot. Notiss. v.119, p.308-317.

Wild, H., and Wiltshire, G.H., 1971. The problem of vegetating Rhodesian mine dumps examined. Sth. Afr. Cham. Mines J. v.13, p.26-03.

Wild. H., and Wiltshire, G.H., 1971 a. The problem of vegetating Rhodesian mine dumps examined. II: Suggestions for future research and practical trials. Sth. Afr. Cham. Mines J. v.13, p.35-37.

Wilding, I.G.P., 1965. Investigation of the secondary dispersion of nickel in Rhodesia and Zambia. Ph.D. Thesis, University of London.

Williams, C.H., 1969. The ecology of Becium homblei Duvign. et Plancke. Thesis, M. Phil. Univ. of London.

Williams, I.R., 1968. Structural layering in the Archaean of the Kunalpi 1:250,000 sheet area Kalgoorlie Region. Geol. Surv. Ann. Rept. 1968. p.40-41.

Williams, K.T., and Byers, H.G., 1936. Selenium compounds in soils. Ind. Eng. Chem. v.28, p.912-914.

Williams, X.K., 1967. Statistics in the interpretation of geochemical data. N.Z. J. Geol. Geophysics., v.10, p.771-797.

Willis, 1966. Cited in Bennett, E.M., 1069.

Willstatter R., and Stoll, A., 1913. Untersuchungen über die Assimilation der kohlensaure. Springer, Berlin.

Wilson, A.F., Compston, W., Jeffery, P.M., and Riley, G.H., 1960. Radioactive ages from the precambrian rocks in Australia. J. geol. Soc. Aust. 6, 179-95.

Wilson, N.L., 1969. The determination of selenium in agricultural materials. West. Aust. Govt. Chem. Lab. Report. No.6. (Final Report), 12 p.

Woodall, R., 1965. Structure of the Kalgoorlie goldfields. In, Geology of Australian Ore Deposits (ed. J. McAndrew), 2nd Ed., p.71-79 (Eight Commonw. Min. Metal. Congr., Melbourne).

Woodall, R., and Travis, G., 1969. Kambalda nickel deposits, Western Australia. Proc. Ninth Commonw. Min. Met. Congr., Paper 26. London., p.1-17.

Woolnough, W.G., 1927. The duricrust of Australia. J. Roy. Soc. N.S.W., v.61, p.24-53.

Ziegler, T.R., Scott, M.L., McEvoy, R.K., Greenlaw, R.H., Huegin, F., and Strain, W.H., 1962. Radiographic studies on skeletal parts of zinc deficient pullets. Proc. Sco. exp. Biol. Med. v.109, p.239.

ACKNOWLEDGEMENTS

I should like to thank my supervisor Dr. R.R. Brooks for inviting me to undertake this project with his biogeochemical research group at Massey University, and for his guidance throughout the course of this thesis.

I also owe a debt of gratitude to Richard Mazzucchelli and Roy Woodall for encouraging this project and for arranging the extensive financial and logistic support of Western Mining Corporation. The valuable assistance and advice given by innumerable company officers is gratefully acknowledged and, especially Peter Bottcher who also provided the facilities of the geochemical laboratory.

The staff of the Perth, Adelaide, and Sydney Herbaria are thanked for plant identifications and especially Dr, Mary Tindale, Eleanor Bennett, Bruce Maslin and Mr. Royce, for helpful discussions.

Thanks are also due to Dr. Peter Ozanne of CSIRO Wembley laboratories for arranging the freeze-drying of plant samples.

I am grateful to both Professor Peter Peterson for assistance in the initial stages of the plant chemistry work and Dr. Graham Butler for providing the laboratory facilities of Applied Biochemistry Division, DSIR. It is also a pleasure to acknowledge the stimulating effect of discussions with Dr. Peter Reay and Bill Bennett. Dr. Alva Challis and Allan Craig, also of DSIR, kindly carried out the electronprobe and electron microscope analyses.

I thank Jill Morrison and Jill Severne for typing services and my wife, Kay, for assistance with the diagrams. I am also grateful to my parents for financial assistance in the preparation of this thesis.

BOTANICAL INDEX

Acacia lineolata Benth.
A. linophylla W.V. Fitzg.
A. loderi Maiden.
A. aff. merrallii F. Muell.
A. oswaldii F. Muell.
A. pachyacra Maiden et Blakely
A. pruinocarpa Tindale
A. quadrimarginea F. Muell.
A. ramulosa W.V. Fitzg.
A. resinomarginea W.V. Fitzg.
A. resinostipulea W.V. Fitzg.
A. salicina Lindl.
A. sclerosperma F. Muell.
A. sibirica S. Moore
A. sowdenii Maiden.
A. stenophylla A. Cunn.
A. stowardii Maiden.
A. subangularis Maiden et Blakely
A. tetragonophylla F. Muell.
A. victoriae Benth.
Astragalus pattersoni A. Gray.
A. preussi A. Gray.
Bossiaeea walkeri F. Muell.
Cassia artemisioides Gaud.
C. cardiosperma F. Muell.
C. chatelainiana Gaud.
C. aff. desolata F. Muell.
C. helmsii Symon.
C. manicula Symon.
C. nemophila A. Cunn. ex Vogel.
C. nemophila var. platypoda (R. Br.) Benth.
C. occidentalis Linn.
C. sturtii R. Br.
Chorizema aciculare (DC) C.A. Gardner
Crotalaria cobalticola Duvign. et Plancke
Daviesia sp.
Gastrolobium laytonii J. White
Neptunia amplexicaulis Domin.
Onobrychis viciifolia Scop.

Leguminosae (cont.)

Psoralea leucantha F.Muell.

Sclerothamnus helmsii (F.Muell. &Tate) Melville

Sesbania aculeata Poir. Encyc.

Swainsona canescens F.Muell.

Templetonia egena (F. Muell.) Benth.

Liliaceae

Dianella revoluta R.Br.

Malvaceae

Sida corrugata Lindl.

S. aff. *calyxhymenia* J. Gay

Menispermaceae

Leichardtia australia R. Br.

Myoporaceae

Eremophila caerulea (S. Moore) Diels.

E. clarkei F. Muell.

E. dielsiana (Kraenzlin.) C.A. Gardn

E. duttoni F. Muell.

E. exilifolia F. Muell.

E. aff. *exilifolia* F. Muell.

E. fraseri F. Muell.

E. granitica S. Moore

E. interstans (S. Moore) Diels.

E. ionantha Diels.

E. latrobei F. Muell.

E. leucophylla Benth.

E. longifolia F. Muell.

E. macmillaniana C.A. Gardn.

E. oldfieldii var. *augustifolia* S. Moore

E. oppositifolia R. Br.

E. pachyphylla Diels.

E. pantoni F. Muell.

E. platycalyx F. Muell.

E. spathulata W.V. Fitzg.

E. spectabilis C.A. Gardn.

E. youngii F. Muell.

Myrtaceae

Baeckia crassifolia Lindl.

Calytrix sp.

Chamelaucium ciliatum Desf.