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GEOMORPHOLOGY AND THE ENVIRONMENT IN THE NORTHERN JARRAH FOREST OF WESTERN AUSTRALIA

BY

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"The present is the key to the past."

"While man has to learn, mankind must have different opinions. It is the prerogative of man to form opinions; these indeed are often, commonly I may say, erroneous; but they are commonly corrected and it is thus that truth in general is made to appear."

James Hutton, 1788
Father of Modern Geology

It is concluded that present indications favour the cause of death being due to the accumulation of some element in the soil environment....

The degree of permeability to water of any particular rock strata would probably depend to a great extent on the frequency of joint planes in the mass.

H.D. Waring, 1950
Investigation into Jarrah Dieback
[before the cause was known]

"Geologic structure is a dominant control factor in the evolution of landforms and is reflected in them."

"It is perhaps not going too far to say that no variation in rock structure is too slight to have significance over a sufficient span of geologic time"

W.D. Thornbury, 1954

SUMMARY

This paper introduces forest managers, students and other interested persons to the geomorphology of the Northern Jarrah Forest of Southwestern Australia. Using structural geology we interpret landforms and examine how they may affect the ecosystem.

We use structural geology to explain features such as valleys, concave slopes, ridges, spurs, convex slopes, saddles, coves, swamps, springs, monadnocks and granite outcrops. We identify, describe and name a new landform called a "Granitic Sink". The occurrence of Black Gravel is interpreted. We describe the reflection by vegetation of underlying joint patterns in rock. These patterns, which show through soil and other weathered material, we name "Field Joints". The nonconformity at Gracetown, between igneous rocks and sand dunes, is identified and named the "Gracetown Surface."

We use structural geology to explain site characteristics that influence the distribution of vegetation and the spread of Jarrah Dieback (*Phytophthora cinnamomi*).

SECTION I

GEOMORPHOLOGY AND THE ENVIRONMENT IN THE NORTHERN JARRAH FOREST OF WESTERN AUSTRALIA

INTRODUCTION

The Jarrah Forest (*Eucalyptus marginata* Donn. ex Smith) occurs in the Southwest corner of Western Australia (Fig. 1). Although limited by world standards, the Forest covers more than 3 million hectares of land (Dell *et al.* 1989) and is the purest large stand of eucalyptus in Australia (Forests Department of Western Australia 1966). The region has approximately 6000 species of plants, of which 75 per cent are found nowhere else (Hopper *et al.* 1990). This unusually large variety of plants inhabits poor soils and survive hot, dry summers.

FIGURE 1 NEAR HERE

Hopefully, this paper will introduce forest managers, students and other interested persons to the geomorphology of the Northern Jarrah Forest. The forest landscape is not an incomprehensible jumble of separate entities but, rather, an integration of landforms. Using structural geology, we interpret these landforms and show how they may affect the ecosystem.

Most of us understand little about the affect structural geology has on our forest, although, as we will see, its influence on geomorphology and the ecosystem is considerable. The occurrence of soils, landforms (geomorphology), plant communities and the presence of the devastating plant pathogen

GEOLOGICAL SKETCH MAP
OF
WESTERN AUSTRALIA

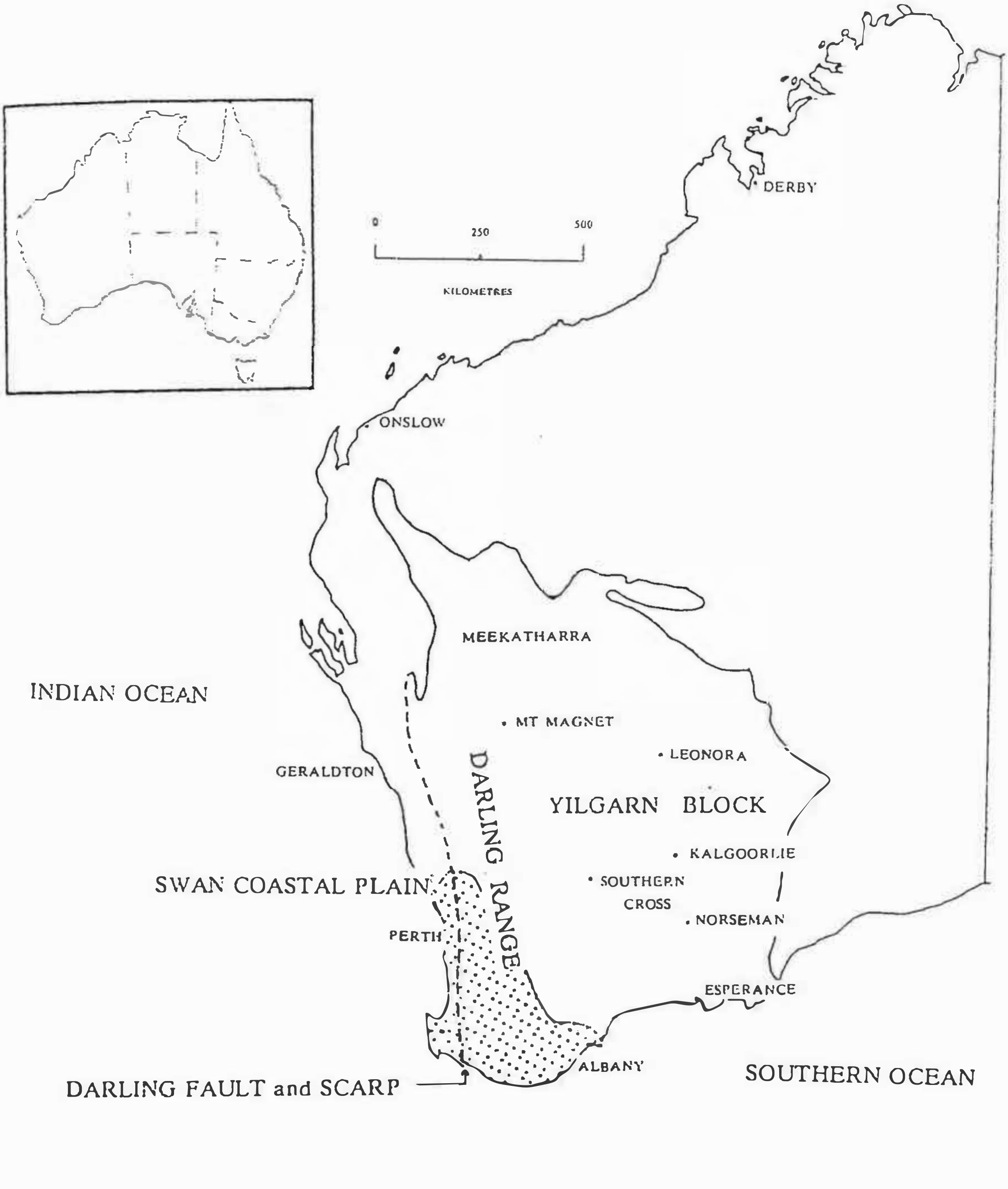

Figure 1. The stippled area is the approximate extent of the Jarrah Forest in Western Australia. Other large scale geomorphic features are: the Darling Fault and Scarp, Darling Range and the Swan Coastal Plain (Perth Basin).

"Jarrah Dieback" (*Phytophthora cinnamomi* Rands) reflect geologic structure. Forest landforms and the ecosystem are not haphazard in their occurrence.

For ease of understanding, the paper is divided into sections. We first describe the *Area* and briefly tell its *Geologic History*. In *Background Information* we define geomorphology and examine two classifications presently used in explaining the forest. Also, the suitability of the geomorphic approach is discussed. Then some *Geologic Concepts* are described and important *Terms Defined*. The concepts are useful geomorphic tools and are basic to our interpretation. Armed with them we can explore Landforms and the Landscape in *Things We See in the Bush*. Finally, the relationship between structural geology and site characteristics that influence the existence and spread of Jarrah Dieback are explained in *Geologic Structure and the Distribution of Jarrah Dieback*.

SECTION II

DESCRIPTION OF AREA

Much of the Northern Jarrah Forest occurs on the Darling Range in the southwest portion of the *Yilgarn Block* of Southwestern Australia (Fig. 1). This is the largest of the Blocks that make up the ancient Precambrian Continental Shield. The area consists mainly of granite and gneiss and, in extent, is about 700 km by 900 km (Giddings 1976).

The *Darling Range* is a chain of hills along the western fringe of the Plateau. Carved by erosion, the Range boarders the Swan Coastal Plain. The hills have an average elevation of around 300 metres and structural geology clearly influences the drainage pattern (Fig. 2). A lateritic duricrust caps the western margin of the range and, in places, forms massive rock on ridges and slopes. Scattered through the region, granitic knolls, called monadnocks, protrude above the general forest level.

FIGURE 2 NEAR HERE

The Yilgarn Block ends abruptly against the *Darling Fault*. This fault, which is about 1000 km long, is a major north - south structure of the Earth's crust. Its maximum downthrow of around 15 km is colossal. Although an impressive structure, the fault is not a distinct feature owing to erosion and a cover of sediments (Biggs & Wilde 1980).

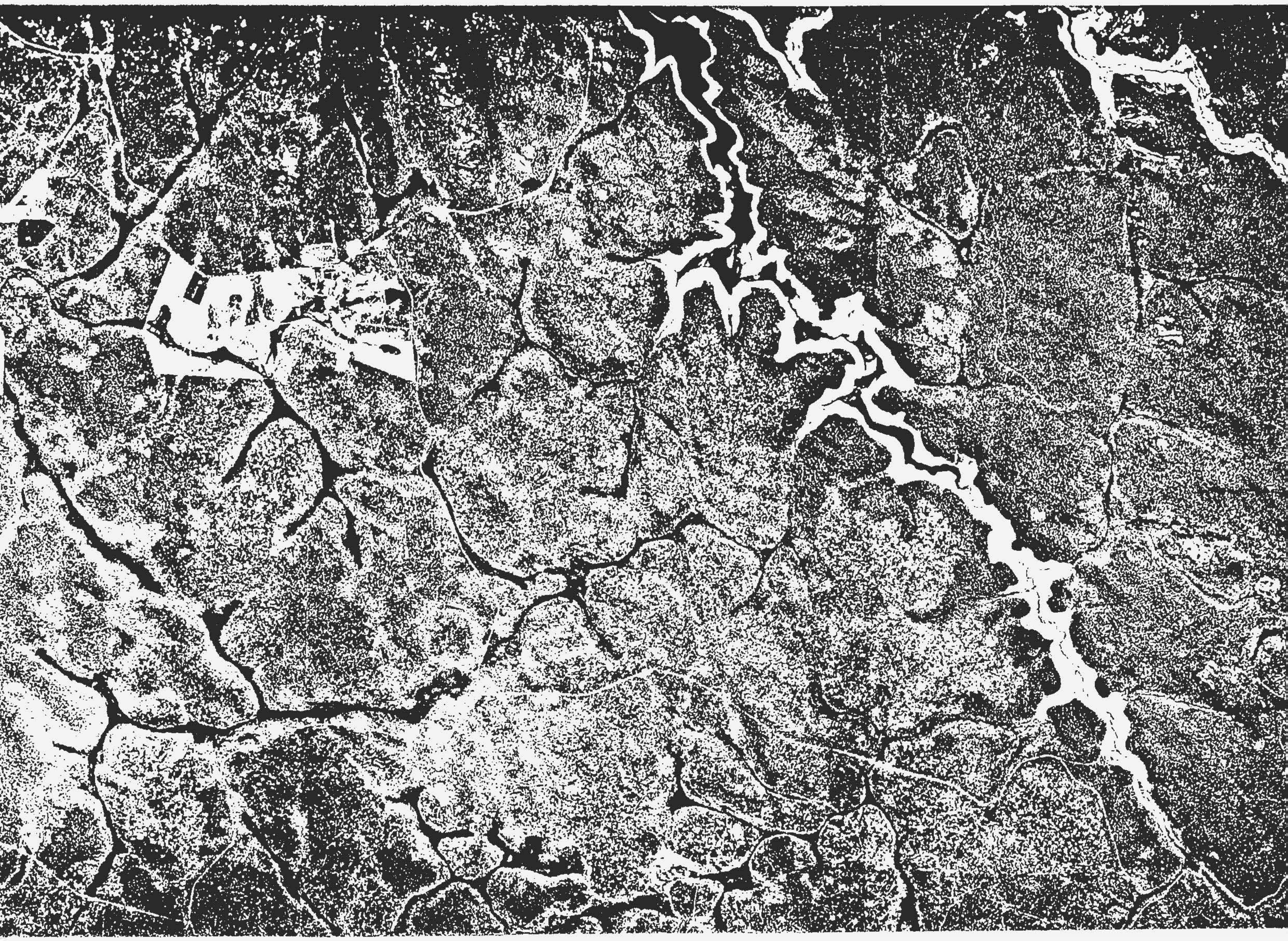

Figure 2. An arm of Serpentine Reservoir (major structural trend) separates two distinct drainage patterns controlled by structural geology. Both patterns are related and show a rhomboid system of joints. The photo shows lineaments formed by drainage (joints) and dieback.

The *Darling Scarp* is, however, topographically prominent. The escarpment forms the western margin of the Darling Range and separates the Coastal Plain and the Darling Plateau. Caused by the Darling Fault, this feature has retreated up to 3 km east of its origin due to erosion (Biggs & Wilde 1980).

The *Swan Coastal Plain* is a belt of wind blown and water laid sediments between the Darling Scarp and the Indian Ocean. It is also called the *Perth Basin* and has, for tens of millions of years, received debris derived from the Darling Range. The basin is about 1000 km long, 65 km wide and up to 15 km deep.

SECTION III

GEOLOGIC HISTORY

Because of its great geologic age, the history of the Northern Jarrah Forest is fascinating. Figure 3 shows the chronology and duration of events in direct proportion to time. This unusual representation is necessary because of the antiquity of the land. Figure 4 emphasizes recent time and is the more conventional way of displaying geologic eras, periods and epochs.

FIGURES 3 AND 4 NEAR HERE

Geologists think the zone occupied by the *Darling Fault* has been a region of intermittent deformation since early time. Roughly parallelling the fault is a belt of gneiss that is, in places, over 10 km wide. These rocks are the oldest in the region; indeed, they are some of the oldest rocks in the world. Some originated as sediments and others as metamorphosed granite. They are testament to ancient sedimentation and then intense metamorphism caused by crustal deformation. These rocks, with origins greater than 3 billion years, reflect the last regional metamorphism to affect the area (Arriens 1971).

Along the *Darling Scarp*, only outliers remain of the old gneissic rocks. This is because granitic rock, which forms most of the *Darling Plateau*, invaded the area next. This occurred during the Late Archean or, perhaps, the Early Proterozoic (2.5 billion y.a.).

GEOLOGIC HISTORY OF SOUTHWESTERN AUSTRALIA

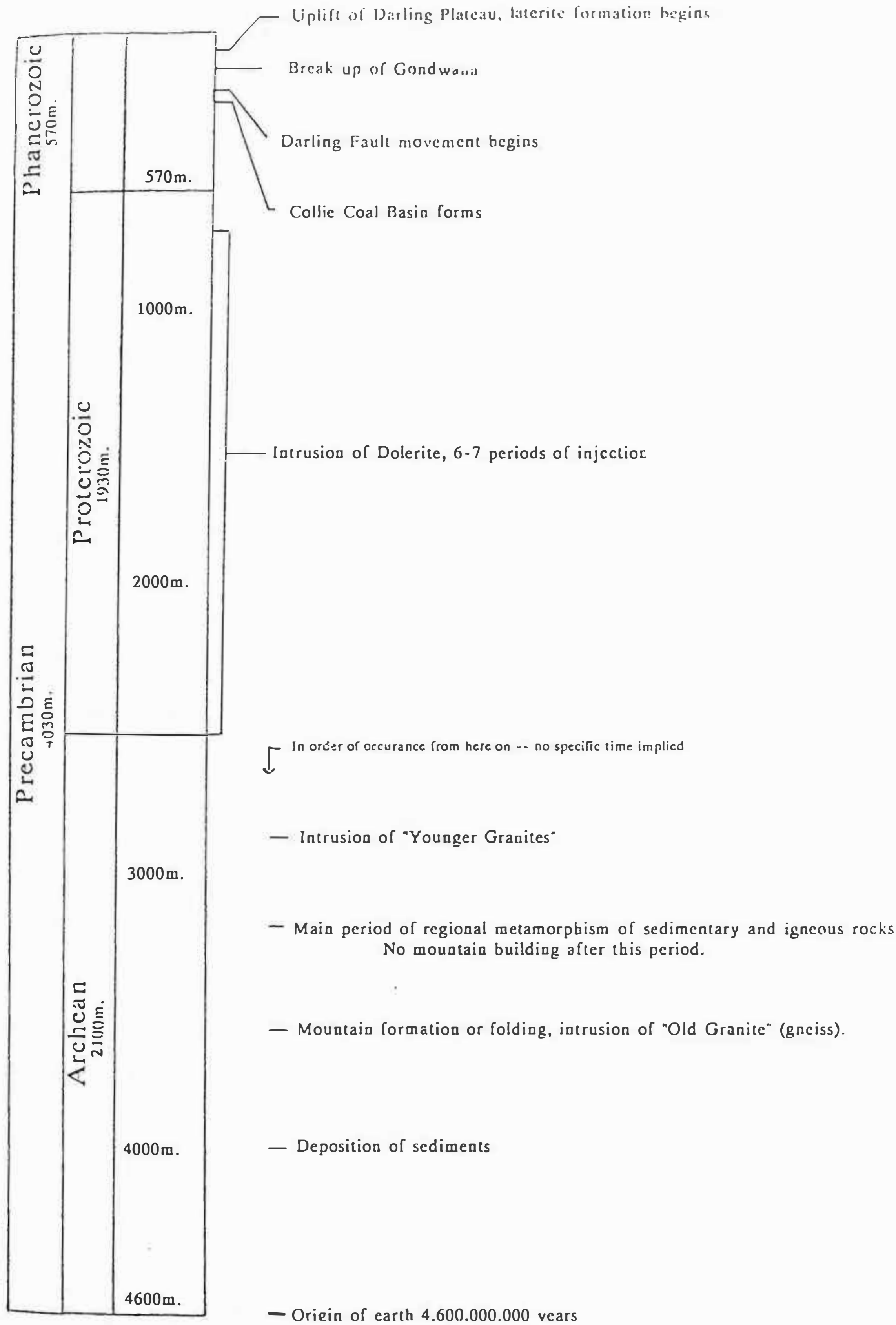

Figure 3. Chronology and duration of geologic events in millions of years and directly proportional to time.

GEOLOGIC HISTORY OF SOUTHWESTERN AUSTRALIA

Eon	Era	Period		Epoch	
Phanerozoic	Cainozoic 65m.	Quaternary 2.5m.		Recent 10,000y.	Rottnest becomes an island. Sea level up 100m.
				Pleistocene 2.5m.	Four major periods of glaciation. Sea level fluxuates.
			2.5		
		Tertiary 63m.		Pliocene 4.5m.	
					Darling Plateau uplift of about 300m.
				Miocene 19m.	Perhaps some renewed movement of Darling Fault
					Main period of lateritization.
				Oligocene 12m.	
				Eocene 16m.	
				Paleocene 11m.	
			65		
	Mesozoic 160m.	Cretaceous 71m.			Gondwanaland breakup Dunsborough Fault Bunbury Basalt
		Jurassic 54m.			Darling Fault - greatest vertical movement. Maximum downthrow about 15 km
		Triassic 35m.			
			225		
	Paleozoic 345m.	Permian 55m.			Collie Coal Basin formed Glacial activity
		Carboniferous 65m.			
		Devonian 50m.			
		Silurian 35m.			Oldest rocks in Perth Basin Displacement of fault may have begun
		Ordovician 70m.			Some faulting around Boddington
		Cambrian 70m.			
			570		
Precambrian	Proterozoic 1930m.				
			2,500		
	Archean 2100m.				
			4,600		

Figure 4. The conventional way of displaying the earth's geologic history emphasizing recent time in Southwestern Australia.

Dolerite dykes, which are wall like bodies of rock that cut through granite, originated in the Proterozoic Era. They were injected into the "new granite" in six or seven stages ranging from about 2.5 billion to 700 million years ago (Gidding 1976). This was the last igneous activity to occur in the region.

Joints are cracks in rocks. Many joints may have originated in the Archean Era and in the Proterozoic during emplacement of dykes. Also, countless numbers probably formed during the Mesozoic Era when the Darling Fault began to move and later during uplift of the plateau. Precisely when particular joint sets developed is impossible to say. They are difficult to interpret correctly even if one understands the structural geology of an area well (Billings 1960). For us, it is enough to know they exist in large numbers and are, with dykes, important in determining the geomorphic and ecologic character of the landscape.

During the Permian (280-225 million years ago), the Collie Basin formed. Evidence of glaciation lies at its base and on top are the Collie Coal Measures. The only working coal mines in Western Australia are in these seams (Wilde & Low 1979).

About 200 m.y.a., in the Mesozoic Era, the Archean zone of deformation reawakened as the Darling Fault began to move. This fairly recent event lasted for about 75 million years. Following the era, in the Cretaceous Period (65-140 m.y.a.), came the breakup of the supposed continent called *Gondwanaland*. *Gondwana* included India, Africa, South America, Antarctica and, of course, Australia. India is still colliding with South Asia (1 cm/year) and forcing up the Himalayans. It is humbling to note how recent in earth history these momentous events occurred (Fig. 3).

As continents parted, the Darling Fault underwent its greatest vertical movement. For millions of years violent tremors probably reverberated through the region as several huge slabs of Australia slipped down 5 to 10 km forming the Perth Basin. The retreat of the face of the Darling Scarp began as the sea flooded the feature.

The Darling Plateau uplifted about Mid-Tertiary. It was then that streams and rivers began, in earnest, to carve up the plateau and transport it to the basin. In this period, the Darling Range and the predecessor of the Coastal Plain developed simultaneously, and the Darling Scarp formed coastal cliffs against a sea (Playford *et al.* 1976). Owing to this long period of development, the Darling Plateau is called an *ancient erosional surface*.

In the Tertiary (2.5 to 65 m.y.a.) laterite began developing over much of the Western Plateau (Playford 1954; Prider, 1966; Finkl 1971). This fossil soil is the penultimate in surface chemical weathering and leaching. Most of it formed in place on granite; some, however, formed on dolerite, gneiss and even Pleistocene sands of sedimentary origin (Wilde & Low 1978). The laterite contains large deposits of Bauxite, an important ore of aluminium.

In the past 2 million years, four ice ages have occurred. Although in our region no glaciers existed, they significantly influenced the climate. Large amounts of rainfall probably alternated with drier periods (Churchill 1968), and sea level fluctuated. As recently as 17,000 years ago sea level was over 100m lower and Rottnest Island stood as sand dunes (Seddon 1972). Undoubtedly these climatic disturbances affected erosion and transport of material from the plateau to the coastal plain.

The most *recent formations* in the Darling Range are the surfaces of hills, valleys and, of course, river and stream beds. Most unconsolidated sediments date back no more than 10,000 years. Compared with the Swan Coastal Plain that has many types of Pleistocene (glacial epoch) and *Recent* sediments, evidence for recent geologic history in the "hills" is scarce.

Because events in Archean history are so ancient and evidence is so meagre, their interpretation is unclear. The history is fascinating, however, due to its duration and magnitude of events.

SECTION IV

BACKGROUND

Geomorphology

Geomorphology is the science of landforms; it describes and interprets the earth's relief features.

The influence of geologic structure on geomorphology is immense. Most of the great and small landforms of the world are controlled by structure. Thornbury (1954) says this about its presence, even in minutia:

> *"We should not, however, make the mistake of concluding that where the effect of geologic structure is neither obvious nor striking its influence is lacking. The effects are there but we may lack the ability to see them....It is perhaps not going to far to say that no variation in rock structure is too slight to have significance over a sufficient span of geologic time."*

In essence our viewpoint will be that landforms are the result of *regional* and *local climate* working on the *physical* and *chemical geologic structure* through long periods of *time.* Figure 5 summarizes the approach.

FIGURE 5 NEAR HERE

Our regional climate is Mediterranean. The local climate depends on the orientation and placement of the site in the landscape and, for our purposes, the kind, amount and distribution of vegetation. Physical structure refers to joints, dykes, rock bedding planes, rock hardness, faults, folds, permeability or impermeability etc. of rock. Chemical structure refers to weathering and other chemical traits.

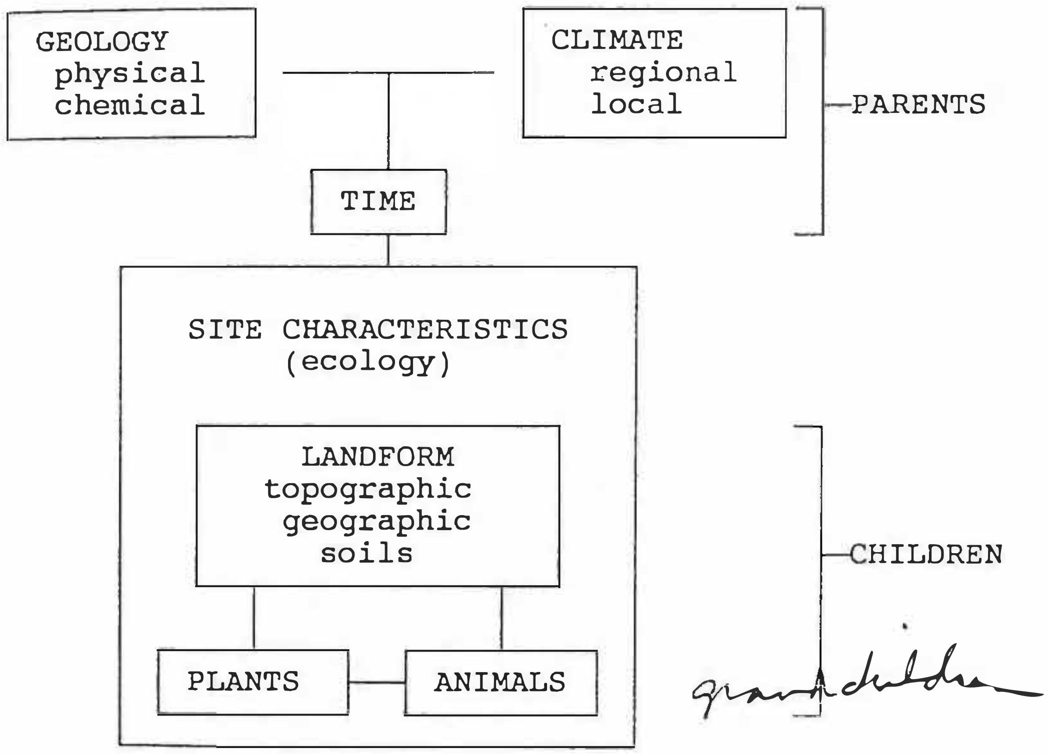

Figure 5 --The ingrediants which most influence the site are its regional and local climate, physical and chemical geology, and time.

Collectively, the physical and biologic characteristics of a site make up its ecosystem and a continuum of environments or sites produce the landscape.

Forest managers presently use two classifications -- one geomorphic the other ecologic -- to help explain the Jarrah Forest. Since they are the basis for our current understanding, we will examine them in the light of structural geology.

Geomorphic Classifications

Geologists describe landforms in three ways: by *stage of development* (valley shape-young, mature and old age), *geomorphic processes* (deposits formed by wind, marine, lake, and river environments), and *geologic structure* (joints, dykes, faults, rock composition etc.).

Soil scientists and forest managers working in the Northern Jarrah Forest use the stage of development method of geomorphic classification. First applied in the region by Mulcahy (Mulcahy *et al.* 1972), this method uses valley shape as its means of appraisal. Steep sided or "V" shaped valleys are young, "U" shaped valleys are mature and broad, shallow valleys imply old age. Mulcahy related soil units to these profiles and gave them names. Some of these units are: the *Helena, Murray, Yarragil, Pindalup, Dwellingup and Goonaping Surfaces*. There are, of course, more (Mulcahy *et al.* 1972; McArthur *et al.* 1977). Table 1 summarizes some of the important surfaces.

TABLE 1 NEAR HERE

TABLE 1

Some Landforms and Soils of the Darling Plateau[3]

Lateritic Uplands

DWELLINGUP SURFACE: Landscape gently undulating; duricrust on ridges; sand and gravel in shallow depressions.

GOONAPING SURFACE: Shallow upland valleys; grey sands and some swamps.

Minor Valleys

PINDALUP SURFACE: Valleys of the central plateau; slopes, gravelly duplex soils; some rock outcrops; broad floors, grey sands and duplex yellow soils and orange earths.

YARRAGIL SURFACE: Valleys of the western plateau; slopes sandy gravels; floors, swampy orange earths.

Major Valleys Combining Slopes and Floors

BALINGUP SURFACE: Incised valleys; slopes, red and yellow earths and duplex soils; narrow alluvial terraces; swampy floors.

MURRAY SURFACE: Deeply incised valleys; slopes, red and yellow earths; narrow alluvial terraces.

HELENA SURFACE: Very deeply incised valleys; slopes, steep rocky and some shallow red or yellow earths.

Scarp

DARLING SCARP: Very steep slopes; shallow red and yellow earths and much rock outcrop.

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3 Summary taken from Pinjarra Sheet, Landforms and Soils Map, Department of Conservation and Environment by H.M. Churchward and W.M. McArthur, Division of Land Resources Management, C.S.I.R.O. Perth, Western Australia.

The problem inherent in the stage of development approach to geomorphic classification is that the name only implies a relative time of formation, position in the landscape and a certain shape - it does not explain the site. For example, a particular *perched catchment* may be called a Goonaping Surface because of its characteristics. The plant pathogen Jarrah Dieback may be associated with the surface; but the mystery remains of why the landform and disease occurs, ~~remains.~~

For soil scientists, a valley form classification is both convenient and useful. For us, it is better to examine forest ecology from a different stand-point -- that of structural geology. This is because structural geology, which dominates in landform development, also explains it.

Although McArthur *et al.* (1977) favoured classifying soils according to stage of development they had this to say about structural control in the Murray River Catchment Area:

> *"The distribution patterns of landscape elements, both in broadscale and detail, are distinctive and may be examined in relation to the physical environment....The landforms and soil patterns have a clear relationship to geological structure with soils, drainage lines, drainage divides, and laterite residuals often aligned with dykes, joints and faults."*

The principal elements of structural geology that influence regional patterns and local topography are the *Darling Fault, joints, dykes*, and *rock types*. Despite this apparent simplicity, few landforms have been described with these elements in mind. This circumstance may be due to a belief that the topography is ancient and complex thereby making it difficult to explain and unexciting to study.

Forest Classification

The Havel (1975) *site-vegetation classification* is a simple and efficient method of forest evaluation. Biological in nature, this tool mainly uses understorey indicator species to characterise the forest for management purposes. The classification is extremely useful for disease management, rehabilitation and silviculture.

Havel bases his site-vegetation classification on the observation that forest characteristics or traits are associated. In his method, vegetation is "the integrator and indicator of environmental conditions" (Havel 1975).

Using multivariate analysis Havel demarcated these associations into "site-types". Some of the traits are: kinds of plants, tree height and density, topographic and geographic position, and physical and chemical properties of the soil. Although site-types (determined by associations of characteristics) characterise forest environments, they do not explain them.

A comparison between the statistical procedures of *correlation* and *regression* may help us to understand why structural geology can better explain forest traits and plant associations. If one plots the height of fathers against sons, a regression results that shows a reasonably predictable relationship. If, on the other hand, we plot the height of brothers against sisters a correlation results that reveals a tendency for tall brothers to have tall sisters (Snedecor 1956). A direct kinship between father and son is stronger than a tendency for likeness between brothers and sisters who are less directly related through common ancestors.

The characteristics used by Havel to classify a site are related like brothers and sisters. To illustrate: Havel (1975) states that there is a tendency for certain kinds of plants and a "tall, dense stand" of Jarrah to occur together. With this, there is a land surface that is "mainly convex" developed on "upper slopes and ridges", a particular soil type, and a "heavy, massive lateritic ironstone." In the field, when we see these traits we call it a *Havel T-Site.* This assembly of traits, however, leaves unanswered how features originate or their affect on the site. To understand this, we must examine the parent -- the geomorphology of the site.

Whereas Havel's *Site Typing* samples the attributes of a site, geologic structure explains it. Geologically, the key to interpreting the habitat is a dolerite dyke embedded in the upper slope of a ridge or hill. The stand is *tall and dense* (more vigorous) because dolerite provides more nutrients than granite. Strewn on the surface, the *massive lateritic ironstone* originated from dolerite as ions of ferrous iron (dolerite has 3 times more iron than granite). As iron precipitated from groundwater, an underground armour of duricrust formed. Owing to its hardness and general resistance to weathering, the site is *mainly convex, forming upper slopes and ridges. Heavy, massive lateritic ironstone rock* (surface boulders) occur where tree roots or erosion has plucked up the armour.

Another explanation that geologic structure offers is the occurrence of a swamp. A swamp does not just happen as a bog with reeds; it can form where a dyke crosses joints in rock.

As weathering proceeds, joints become valleys and water backs up behind dykes. From this geologic offering, soils form, and plants and animals assemble themselves. Tea trees prefer moisture, Jarrah likes upland sites, Blackbutt favours good water and red soils along dykes, dieback occupies joints and frogs are partial to swamps. Hydrologic, physiographic and biologic features reflect the geologic structure.

Also, structural geology largely controls regeneration after logging. In the past, we have misread the signs and explained inferior bush as "heavily logged", "environmentally disturbed" or "mass-disturbed." At one time or other, logging has occurred in nearly all the Northern Jarrah Forest. However, even following this disturbance, most regeneration more faithfully reflects the geologic environment than anything else.

After logging, and depending on geologic circumstances, the bush may regenerate well or poorly. In past times, when an area regenerated poorly or showed signs of "infection", our priority was to salvage what remained as quickly as possible. The scenario went something like this: First we sent in timber cutters, then salvage cutters, pole cutters, rail cutters, post cutters, strainer cutters, and finally we turned loose ~~the~~ firewood cutters and the general public. When next we saw the degenerate patch of bush, all our suspicions were confirmed -- we shook our head and said, "Mass disturbed by past logging".

Environmentally disturbed sites such as horse yards, log landings, and town and mill sites exist. Even these, however, were probably inadvertently selected for certain attributes on geologic grounds by keen eyed "Old Timers".

The general view of forest managers has been that vegetation reflects the climate, topography, soil, and past history of the site. Although legitimate, we will shift slightly from this.

Our viewpoint will be that *topography, geographic position, soils* and *vegetation* (the children) are related principally to *climate, geologic structure* and *time* (the parents). From this stand-point, we can better understand the impact of dieback, vegetation distribution and regeneration after logging in the Northern Jarrah Forest.

The reflection of structural geology in the site's ecosystem is both geomorphic (shape, position in landscape, soil etc.) and biological (plants and pathogens). Whether seen or unseen, geologic control is strong and hydrologic, physiographic and biologic features of the site reflect it. This viewpoint, which explains why traits occur, complements Havel's site classification -- it does not replace it.

SECTION V

GEOLOGIC CONCEPTS

In order to better understand the Northern Jarrah Forest, it will help to be familiar with some geomorphic principles. Most of the principles are from a textbook -- *The Principles of Geomorphology* -- by Dr William Thornbury.

Concept 1.

"The same physical processes and laws that operate today operated through geologic time, although not necessarily always with the same intensity." (Thornbury 1954)

This is the *Principle of Uniformitarianism* proposed by James Hutton in 1785. It states that: "The present is the key to the past" and it underlies modern geology. It means that *geologic agents* such as running water, groundwater, waves, tides, wind and glaciers behaved in the past as they do today. For example: rain, which now falls down, did not previously fall up; and streams have always occupied valleys, not ridges.

We may assume that rivers have been eroding and depositing for a long time; and that sand dunes are structurally the same today as yesterday. Because of their distinct characteristics, we do not normally mix up the products of geologic agents such as an ancient sand dune with a bed of coal or a coral reef.

Through time, only the intensity of physical processes has altered. There were periods when glaciers were more important than now, when more coal, limestone and mountains formed or volcanos erupted. Yet the geologic agents, which tear down or build up the earth, remained unchanged.

If we did not accept Uniformitarianism, our knowledge would be chaos.

Concept 2.

Base level explains the shape of erosional features such as valleys and slopes.

Base level is the level below which a land surface cannot be reduced by running water; it is the lowest level a stream can erode its channel. The major base level of the world is, of course, the sea; but local or temporary base levels exist. Examples of temporary base levels are: a scarp, stream valley, dyke or even a log embedded in a stream.

A log embedded in a stream may cause deposition of material in the area immediately upstream. This temporary base level will influence erosion and deposition of material until it rots away or is otherwise removed. The influence of a dyke in ~~on~~ a hillside is similar.

The rise of the Darling Plateau, relative to the Coastal Plain, produced a clear difference in base levels. Erosion aggressively attacked the higher side trying to reduce it to the level of the plain. Meanwhile, of course, the coastal plain continued to erode slowly toward the sea.

To some extent, all landforms in our forest owe their existence to this process.

Concept 3.

"As the different erosional agents act on the earth's surface there is produced a sequence of land forms having distinctive characteristics at successive stages of their development." (Thornbury 1954)

We previously mentioned three ways of analysing landforms; *stage of development*, *geomorphic process* and *geologic structure*. In its way, each is useful for describing the landscape. Because it is most familiar to us, stage of development is discussed first. Geologic structure, the most important, is last.

In our area the *stage of development* approach to geomorphic classification is especially useful for demarcating soils. Its basis, called the *Geomorphic Cycle*, is the progressive change of valley shape through time; different shapes imply different ages. A *young* valley is "V" shaped, steep sided and has a small flood plain. With time, youth turns to *maturity* and the valley becomes rounded and "U" shaped as its flood plain broadens. Finally, in *old age,* the topography becomes worn down, gently undulating and streams and rivers meander.

Soil scientists, such as Mulcahy studying the Swan- Avon drainage system East of Perth and McArthur in the Murray River Catchment Southeast of Perth, used this method that names "surfaces" according to their shape. While the approach is useful in classifying and generalising about soils, it is inappropriate for interpreting landforms.

A good example of the difference in viewpoint between stage of development and geologic structure is the nickpoint. Using stage of development, Mulcahy *et al.* (1972) defines a *nickpoint* as a "zone of increased gradient and erosional activity" that separates a sequence of valley forms. They view a nickpoint as an erosional face that began during regional uplift. Through time, as it proceeded inland (like a wave), another uplift occurred and another nickpoint began. Thus, nickpoints acting as base levels separate different erosional profiles. .

Interpreted ~~with~~ using geologic structure, nickpoints are generally areas that are hung up on dykes ~~(geologic structure)~~ that cross drainage lines. This different interpretation does not affect soil scientists since their interest is in soils and their ages. It matters to us, however, because our purpose is to interpret the site, not just describe it.

Concept 4.

"Geomorphic processes leave their distinctive imprint upon land forms, and each geomorphic process develops its own characteristic assemblage of land forms." (Thornbury 1954)

Geomorphic processes develop their characteristic assembly of landforms. Streams and rivers make flood plains, alluvial fans and valleys; wind produces sand dunes; and groundwater in limestone forms sinkholes and caves. *"Just as species of plants and animals have their diagnostic characteristics, so landforms have their individual distinguishing features dependent upon the geomorphic process responsible for their development"* (Thornbury 1954).

Geomorphic process includes all the physical and chemical changes that modify the earth's surface. Processes that lower the surface of the earth are weathering, mass wasting by gravity and erosion. Some *geologic agents* that carry out these processes are running water, ground water, waves, currents, tides, wind and glaciers.

Other processes build up the surface. The same geologic agents are responsible for building up as for tearing down. Thus, running water may carve valleys and form the Darling Range while simultaneously releasing sediments to build the Coastal Plain.

"Regional uplift" is a type of building up that affected our area. About 20 million years ago a series of regional uplifts simultaneously elevated the coastal plain and the Great Plateau. These uplifts produced the difference in relief between land and sea (base level) that continues to influence the development of our topography.

Concept 5.

"Geologic structure is a dominant control factor in the evolution of landforms and is reflected in them." (Thornbury 1954).

Geologic structure is a major influence on landform evolution. *"It is perhaps not going too far to say that no variation in rock structure is too slight to have significance over a sufficient span of geologic time"* (Thornbury 1954). Geologic structure was, of course, established long before the geomorphic forms that exist on them.

Geomorphologists use the term *geologic structure* in a broad sense that incorporates all physical and chemical traits of the rock. These include joints, bedding planes, faults, folds, rock massiveness, physical hardness of constituent minerals, susceptibility of the minerals to chemical change and permeability of the rock.

Although interactions between biology and the physical environment exist, the influence of geologic structure predominates. Because it dominates over stage of development and geologic process, the focus of this paper is on geologic structure. Structure is important; sites differ because of it.

Concept 6.

"Little of the earth's topography is older than Tertiary and most of it no older than Pleistocene." (Thornbury 1954)

Our landscape fits nicely with this concept. Its geomorphic form and the development of laterite began in the Tertiary (about 40 m.y. old) (Playford 1954; Prider 1966; Finkl 1971). Naturally, the rocks and structure of the Yilgarn Block are far older than the topographic surfaces. Other processes were, no doubt, at work earlier, but more recent events have destroyed evidence of them.

Almost the entire Coastal Plain, comprising sand dunes, swamps, lakes, estuaries and beaches, is of Pleistocene Age.

SECTION VI

TERMS DEFINED

The *Darling Fault*, *joints*, *dykes*, and various *rock types* are the four elements of structural geology that most influence the character of the Northern Jarrah Forest. These ingredients interact with *climate*, over *time*, to create the landscape. To better understand this, let us define some terms.

Lineaments

Many interpretations in this paper originated from lineaments on photographs.

In geology the term *lineament* means significant lines in the landscape that reveal the hidden architecture of the basement rock. The growth of vegetation, that appears as dark areas highlighting valleys (joints) and dykes, reveals this architecture (Figure 2).

Because dieback kills trees and follows valleys and depressions, it also traces linear patterns across air photos. Its presence can be verified in the field and with Department of Conservation and Land Management dieback maps. Section VIII examines this in more detail.

Regional joints and dykes usually form straight lines as they cross the landscape. This is because they intersect the earth's surface almost vertically. If the angle was other than vertical, the lineament would appear to weave back and forth as it crossed hills and valleys. Beard (1967) noted rectilinear patterns formed by lineaments of vegetation on aerial photographs near Ravensthorpe, Western Australia.

The Fault

A *fault* is a break or crack in the earth's crust where one side has moved relative to the other. The *Darling Fault* is the only fault in the Northern Jarrah Forest that concerns us (Figure 1). It is a *normal fault* because the western block, underlying the coastal plain, has slipped down along the face of the eastern block. Tension or pulling apart of the earth's crust causes this type of fault. The eastern block, which has risen relative to the west, has been dissected by erosion and now forms the Darling Range.

Joints

Joints and dykes are important structures that influence the appearance of the Darling Range. Together, they account for landforms such as ridges, valleys, spurs, saddles, convex and concave slopes, coves, granitic sinks, granite outcrops, monadnocks and the major structural trends. In addition, they explain the occurrence of ~~where~~ swamps, springs and probably black gravel sites. ~~occur~~.

A *joint* is a brittle fracture in rock that is generally vertical and along which no movement has occurred. Cracks in granite outcrops are examples of joints. Groups of joints that are more or less parallel form *joint sets*. Two or more joint sets, intersecting at angles that are reasonably predictable, form a *joint system*. Joint sets and systems are visible on most granite outcrops. They also appear on a larger regional scale (Fig. 2).

Local joints are individual joints that normally riddle the basement rock. Local joints quicken weathering and thereby aid in laterite formation. The presence of laterite suggests that weathering is proceeding more rapidly than erosion. In a location where the basement rock has fewer joints (e.g., more massive), the lateritic profile is shallower. Granite outcrops are, of course, areas of few joints where erosion outstrips weathering ~~and~~ to expose~~s~~ bare rock.

Jarrah Dieback may inhabit local joints. This explains why, in the past, we have noticed dieback spreading along contours. This type of micro joint, which we call a "Field Joint", is more fully described in *Things We see in the Bush*. ? Author date

One can best see local joints on granite outcrops or as subtle lineaments on aerial photos. Contour maps do not show these features.

A *regional joint* is a concentration or cluster of local joints that, because of their intensity and persistence, establish a major regional pattern (Fig. 2). They may show directional preferences over a wide area. Regional joint patterns look similar to local patterns found on granite outcrops; the two differ only in scale. Therefore, the terms "joint set" and "joint system" are applied here to both regional and local joints.

In the Darling Range, valleys evolve because regional joints allow water easy access to rock. Water speeds chemical weathering and decomposition which, in turn, accelerates erosion. Erosion forms valleys. Valleys are, therefore, where the earth's crust has decayed due to joints. Twidale (1976) describes this type of joint-controlled stream dissection in the development of inselbergs (like monadnocks).

Regional joints are obvious on aerial photos because they are the drainage.

On aerial photos, lineaments caused by vegetation reveal regional joints. Valleys usually have a more dense plant assembly that appears darker whereas up slope vegetation is generally more sparse and lighter coloured.

In some areas, regional joints, embedded in the landscape, produce concave slopes and saddles. These would ordinarily go unnoticed were it not for infection by dieback. The subject of structural control affecting plant pathogens is examined in Section VIII.

One can best see regional joints as valleys in the field or as lineaments on aerial photographs. They are also obvious on contour maps.

Rock Types

The five most common rocks types in the region are *granite*, *dolerite*, *gneiss*, *migmatite* and *duricrust*. Duricrust may form from any of the other rock types.

Granitic rocks predominate on the Darling Plateau in the area from the Helena River Reservoir to Mt. Keats. *Granitic* is a general term use to describe rock compositions ranging from granite through adamellite to granodiorite. Most rock is an even grained adamellite (Wilde and Low 1980) that is closely related to granite but with a slightly darker colour and a chemical composition slightly toward dolerite. The major constituents of adamellite are plagioclase, orthoclase (both feldspars) and quartz with minor biotite and hornblende. An increase of orthoclase and a matching decrease in plagioclase shifts the rock toward granite (Spock, 1962). The age of this rock is around 2.5 billion years.

Dolerite is a medium textured rock comprised of dark and heavy minerals high in iron and magnesium. As with granite, the definition is broad and includes some chemical and textual variation. Around the world, the chemical compositions of dykes vary. Those in the Darling Range are similar to the Precambrian doleritic dykes of India (Sujatna 1979). This evidence is a small portion of that which supports the theory of continental drift.

Depending on its texture, dolerite may be called gabbro, dolerite or basalt. A lava flow forms *basalt*. It has the same chemical composition as dolerite but is fine grained because it cooled quickly. *Gabbro*, also, has the same composition but it has a coarse grain size. Gabbro occurs in some dykes of the Darling Range and ancient basalt flows occur near Bunbury.

Gneiss is a coarse grained rock with bands of granular minerals alternating with bands of micaceous minerals. It looks like a granite that has had its light and dark minerals aligned. The name refers to rock texture and not composition.

Gneiss is a metamorphic rock frequently found outcropping along the scarp. The width of the belt of outcrop varies up to 10 km, and the parent material may be either sedimentary or igneous rocks. Metamorphosis of parent rock results from deformation caused by extreme pressure and temperature (high grade regional metamorphism).

Migmatite is a metamorphic rock formed by injecting granitic rock into gneiss. Migmatite is found beneath granite and is exposed in the deeply eroded Murray River Valley and along creeks incised through the scarp. This deep-seated pattern of rock outcrop is consistent with migmatites around the world. In our region, because of erosion, it peeks through openings carved by creeks and rivers in overlying granitic rocks.

The term duricrust originated in Australia and describes a type of massive lateritic cap rock that is widespread in the Jarrah Forest. It may form over any of the major rock types and is most common and best developed near the scarp where rainfall is highest.

Duricrust is a hardened rocklike crust, formed in the soil by salts precipitating from solution. In our region, the salts usually come from weathered granite. Under moist conditions when these salts diffuse surfaceward, precipitation of aluminium, iron and silica may occur. Factors involved in duricrust formation are the mobilization, migration and concentration of ions.

The dominant *soil* of the region is a nutritionally poor lateritic gravel that occurs in a matrix of yellow sand. In places, this soil can be greater than 5 metres thick.

Laterite is widespread in the area and is a geologic formation that, in places, is more than 50 m deep (Bettenay *et al.* 1980). The lateritic profile includes the near surface duricrust, gravels and sands (ferruginous surface horizons) as well as underlying mottled and pallid clays. The pallid zone may be up to 30 m thick. At the bottom, weathered country rocks grade into parent material. Parent rock is usually granitic; but it can be dolerite, migmatite or gneiss.

Much of our deeply weathered and leached laterite contains bauxite. *Bauxite* is an extremely stable substance made up of iron and aluminium oxides that are derived mainly from granite weathered in place. It is the chief ore of aluminium and is of great economic importance to the region.

Dykes

A *dyke* is a wall of igneous rock that cut through other /s rocks (Fig. 7 and 9). There are several kinds of dykes affecting the region, but, for us, the most common and ? important type is a dark intrusive rock called dolerite. In the Darling Range, sub-parallel sets of dolerite dykes cut massive granitic and metamorphic rocks at nearly vertical angles. They form relatively straight lines and may appear and disappear throughout the landscape.

A dyke is a joint that has been filled with dolerite. Granite, the backbone of our continent, floats like a cork on the a dark and heavy rock. When stresses fracture the granite, tremendous pressure injects the underlying rock through the crack forming a dyke.

Theoretically the constituents of dolerite are less stable than granite and should weather faster (Spock 1962). However, weathering is a complex process and, depending on climate and other factors, the opposite is sometimes true (Twidale 1976). In our region dolerite dykes are more resistant and stand out in the landscape (Bettenay *et al.* 1980; Baker 1980). This resistance may be explained in three ways - each dependent on water.

One factor contributing to durability may be the nature of the clay to which dykes weather. Because the clay is dense and sticky, it inhibits water and air movement and discourages root penetration (Johnson *et al.* 1983). This may help protect /t the dyke from decay. Another reason is that dolerite has a smaller crystal size. Coarser material like granite is more easily penetrated by air and water and, therefore, weathers faster. A third factor is that dykes frequently have along their flanks an outcrop of what appears to be a zone of tempered duricrust (Mulcahy & Hingston 1961). This remarkably hard duricrust may be caused by the movement of ionic iron (ferrous iron) from the dyke into weathered and more permeable granitic material. On precipitation (oxidized to ferric iron), it creates a rugged duricrust (Twidale 1976) that, in our region, has a red baked appearance ~~in our region~~.

Dykes frequently emerge in swarms. A *swarm of dykes* is a group of dykes with parallel alignment. In the landscape, dykes may appear and disappear and line up over long distances.

Photos and field observations show that dykes and dyke swarms form regional patterns. Bettenay *et al.* (1980) notes that in a catchment east of Collie "dolerite dykes underlie most divides and spurs where their resistance to weathering is a major topographic control." Baker (1980) says that significant topographic control is exerted by dolerite dykes that have a principle regional trend of about 330 degrees. Where they cross joints, dykes may form swamps, perched catchments and coves. Because of their influence on hydrology, dykes frequently affect the quality of the bush, vegetation type and the distribution of Jarrah Dieback.

The widths of dykes range from a few centimetres to 200 metres; however, widths in the vicinity of 2 to 10 metres are most common (Wilde and Low 1978). Dykes are most frequent near the scarp where they make up about 15 percent of the landscape (Biggs and Wilde 1980). Further east in the wheat belt, their numbers lessen but they are still an important influence.

One can recognise dykes most easily in the field and, to a varying extent, identify them on aerial photos. Their whereabouts are not determinable from contour maps.

Summary

In brief: Joints are cracks in rock; a fault is a joint that has moved; and dykes are joints filled with a rock type.

SECTION VII

THINGS WE SEE IN THE BUSH - AND WHY

Landforms, although entities, are part of a geologic continuum. Figure 6 shows the relationship that exists between structural geology and landforms. Dykes and joints display different physical and biological characteristics as they occur in different locations on the earth's surface. A dyke may create a ridge, convex slope, spur or swamp depending on where it ~~appears~~ is. It may also channel water, form a black gravel site or produce a tall dense stand of good quality bush. As dykes pass through different locations new relationships exist. In this way dykes tie together seemingly unrelated landforms.

FIGURE 6 NEAR HERE

LANDFORMS AND OTHER FEATURES

Valleys and Concave Slopes

Valleys are concave slopes but not all concave slopes are valleys. A *valley* is low lying land, bounded by hills and usually occupied by a stream or river. In our region, they /which result from weathering of regional joints.

The regional drainage pattern, which is rectilinear, reflects geologic structure. Field and experimental data show that joint systems frequently form a rectilinear pattern (Beard 1967; Badgley 1965; Suppe 1985). This pattern occurs just east of the South Branch of the Serpentine Reservoir in the form of rhomboids (Fig. 2).

Ronson Formation Dieback Ulcer

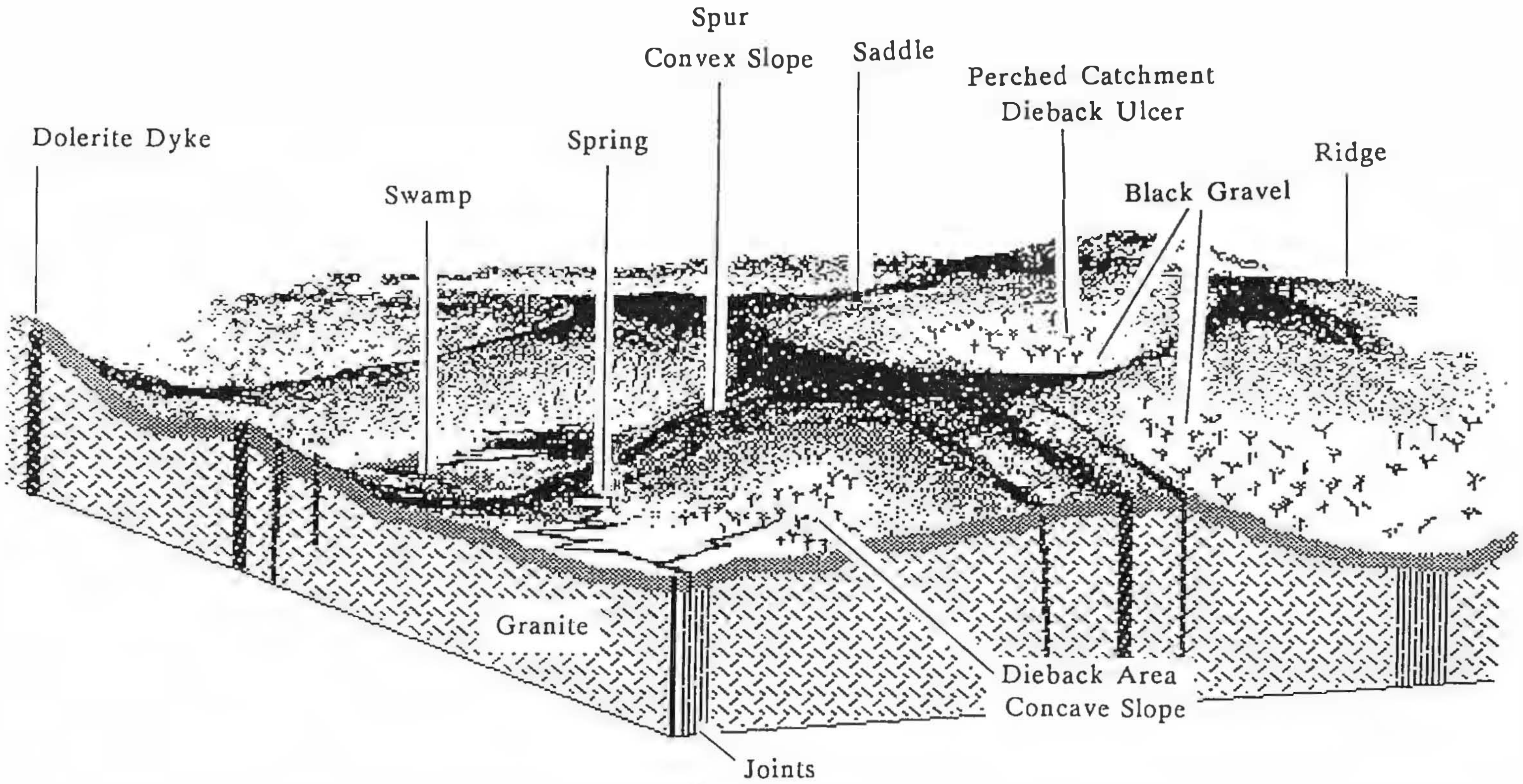

Figure 6. At Ronson Formation near vertical dykes and joints display distinct physical and biological characteristics as they occur in different locations on the earth's surface. Dykes may form a ridge, convex slope, spur or swamp. Joints may form valleys, swamps, concave slopes, saddles, depressions and perched catchments. Here, dieback occurs in a perched catchment and on the slope below.

A *concave slope* is where the angle of a slope is hollow or curves inwards (Fig. 6). It is most frequently found on the lower slopes of hills but it may also occur as a perched catchment or depression caused by joints. Dykes, which are generally more resistant and form convex slopes, may hold up a concave slope higher in the landscape. Concave slopes often determine vegetation type and Jarrah Dieback frequently inhabits them.

Ridges, Spurs and Concave Slopes

Ridges are convex slopes but not all convex slopes are ridges. A *ridge* is a long, narrow elevation of land whose boundaries, in our region, are determined by dykes and joints (Fig. 6). Dykes are generally more resistant to weathering and stand up as divides (Bettenay *et al.* 1980).

A *convex slope* occurs where the angle of the land curves outward. Embedded in the country rock, dykes and their weathered products often create convex slopes. Convex slopes may be fertile (Havel "T" type, Havel 1975) and may form a concave slope further uphill.

A *spur* is a subordinate ridge that extends from a hill crest or ridge (Fig. 6). It forms where a dyke or dyke swarm is deminishing in importance. In the Collie area, Bettenay *et al.* (1980) notes that dykes underlie spurs. Along old railroad formations, many cuttings through spurs expose chunky weathered dolerite and red clays.

Saddles

A *saddle* is a low point on a ridge between heads of drainage flowing in opposite directions (Fig. 6). Joints cause them as they climb hills and form concave surfaces both across and along the contour. High in the landscape, joints may form saddles that have characteristics somewhat similar to valleys. Even when the structure is subtle, it may stand out on aerial photos because of its vegetation or a dieback infection. Section VIII investigates this in more detail. There are examples of saddles infected with dieback in Figure 2.

An unusual type of saddle, that may have been part of an ancient river valley formed in a previous erosion cycle, occurs near the North Dandalup River. On its surface, rounded, water-worn pebbles and boulders occur. Regional uplift during the Tertiary (2.5 to 65 m.y.a.) may have left the saddle perched high in the landscape.

Granitic Sinks

We will describe a *granitic sink* in detail since, to our knowledge, the interpretation and naming of this landform is new.

Many landforms of the world evolve due to erosion or deposition. One sort, however, drains into itself. Logic tells us that such a shape would not usually occur, because it would fill as it ~~formed~~ eroded. In this category of landforms are sinkholes, kettles, meteorite craters, bomb craters, stump holes and others.

Sinkholes form in association with caves and are a feature of limestone terrain. Unlike a valley with flow-through drainage, a sinkhole results from the chemical weathering of rock. Rain, instead of eroding the surface, percolates underground and is channelled along joints. As it leaves the underground catchment, it carries with it dissolved minerals from weathered rock. Owing to this exodus of material, a sinkhole forms as the earth's surface subsides.

A *granitic sink* is a subtle, inward draining depression that forms in granite. The feature has the shape of a shallow saucer and an area of about 3-5 ha. From its centre, sides slope gently upward in all directions and no drainage out of the landform is visible. Figure 7 shows the shape and structure of the feature. Note how closely it resembles a perched catchment (Figure 6); only the incline is different.

FIGURE 7 NEAR HERE

Field evidence suggests granitic sinks are islands of weathered granite that are isolated and bounded by dolerite dykes on three or more sides. Dykes, and the clays to which they weather, are less permeable to water than material weathered from granite (Johnson *et al.* 1983; Nulsen 1985; Engel *et al.* 1987). This pattern traps rain. Joints, which shatter both granite and dolerite alike, gather the water underground and slowly conduct it through the dyke and from the catchment. As it leaves, the water carries minerals from decaying rock. Due to this leaching, the earth's surface slowly subsides over tens of millions of years.

Owing to the inward draining character of Granitic Sinks, ponding may occur in winter when rainfall exceeds the ability of ground water to escape. After heavy rain there is ponding in "Dillon's Lake" along the Del Park Road on the north side of Dwellingup. The timber industry used another sink, the "Old Dwellingup Oval", as a log dump. In winter, due to water

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Granitic Sink

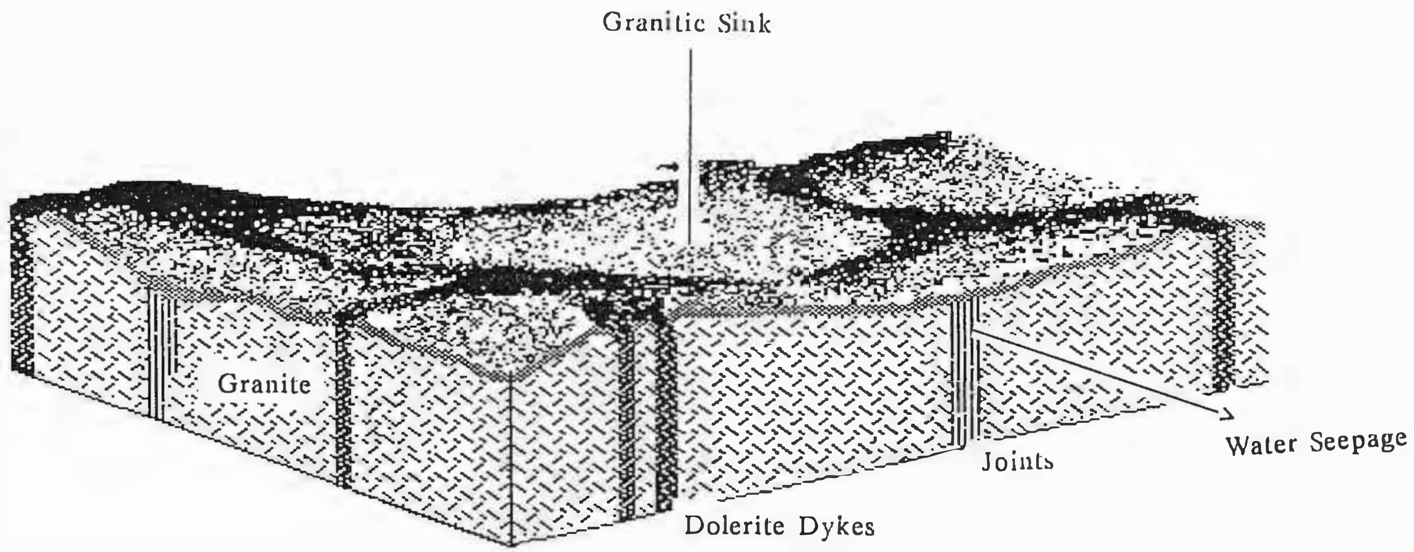

Figure 7. A Granitic Sink is a subtle, inward draining depression that forms in granite. No drainage out of the landform is visible. Ponding may occur in ~~late~~ winter when rainfall exceeds the ability of groundwater to escape the structure.

rising among the logs and movement of heavy equipment, the area became a quagmire and was abandoned.

The plant community and disease condition of sinks reflects its inclination for wetness. Moisture loving sedges as well as Paperbarks (*Melaleuca*) and Swamp Banksia (*Banksia littoralis*) live in the area. In Giles' Sink, along Pindalup Road high in the landscape, Flooded Gum (*Eucalyptus rudis*) and Tea Tree also occur. This sink is unusual in that it is free of dieback, whereas most sites are a virtual graveyard due to the disease.

Appendix A lists the locations of four granitic sinks; many more probably exist. One can best recognise them in the field and on aerial photos. They do not show up well on contour maps due to their low relief.

Coves

A *cove* is a steep walled semi-circular area that looks like an amphitheatre and occurs at the head of some gullies (Fig. 8). It forms as erosion creeps up a joint and abuts against a dyke or swarm of dykes.

FIGURE 8 NEAR HERE

A peculiarity of this feature is its alignment with other coves over numbers of kilometres; one line may contain six or more coves. Where two lines cross, they share one head of gully (Fig. 9).

FIGURE 9 NEAR HERE

Cove

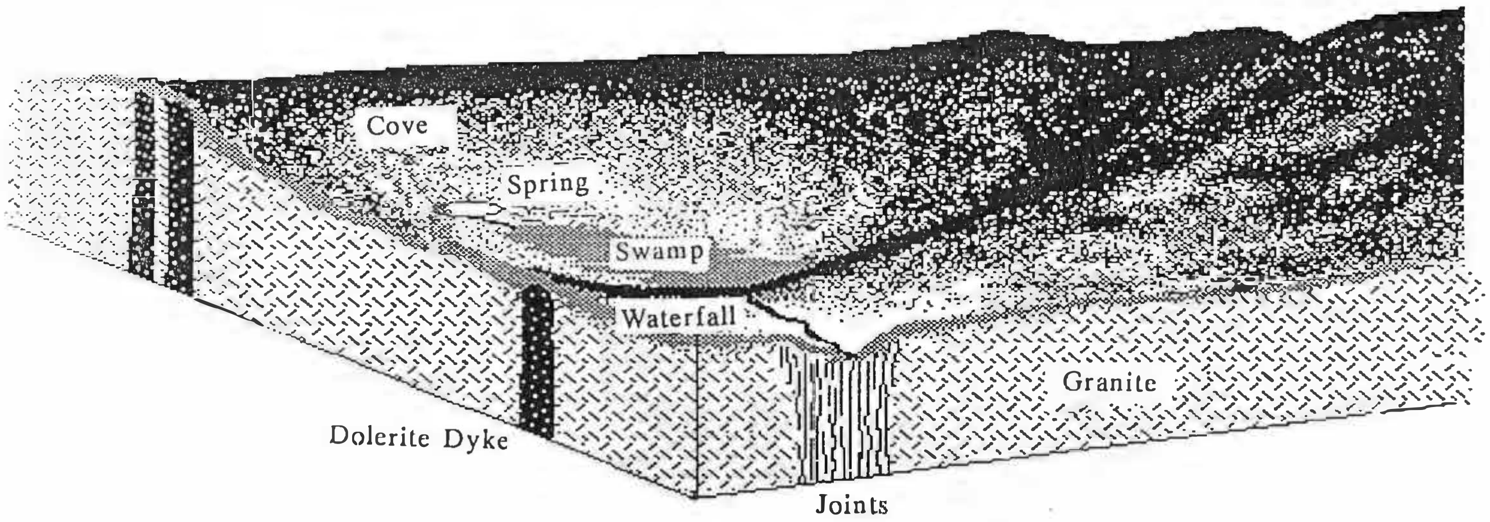

Figure 8. A cove at the head of Waldeck Brook on Stawell Road. A cove is a steep walled semi-circular area that looks like an amphitheatre and forms at the head of a gully. Note how intersecting ~~a~~ joints and dykes make the features.

--------- Power Line

Figure 9. White lines indicate the alignment of coves in the Nanga Region caused by weathered and eroded joints abutting against dykes. The arrow points to the Waldeck Brook Cove pictured in Figure 8.

Using the stage of development method of landform classification, a cove~~s~~ would be the "ultimate nickpoint~~s~~". It is unlikely, however, that coves align themselves so well due to their time of origin being the same. Geologic structure in the form of dykes is a far better explanation and more likely cause of alignment.

One may find bits of dolerite, red soils, lush vegetation, and springs (some developed as water points by CALM) on the lower slopes of coves. This, with Blackbutt (*Eucalyptus patens*), Bracken (*Pteridium esculentum*), *Clematis aristata* and *Leucopogon verticillatus* suggest the presence of dykes.

Swamps and Springs

A *swamp* is a low, spongy land, generally saturated with water that may be here and there studded with trees. In the Northern Jarrah Forest, dykes crossing valleys cause swamps. Since dykes and their clay derivatives create underground dams, water may back up behind them until the water table and ground surface intersect, forming a spring or swamp.

Dykes crisscross almost every valley in the bush. Some dykes, which now make swamps, may previously have formed coves. As erosion breached the dyke and progressed upward along the joint, a swamp developed.

A good example of the dyke-swamp-cove relationship exists along Waldeck Brook parallel to Stawell Road in Park Block (Fig. 9). Here clay, weathered from a dyke, forms a waterfall that is over three metres high. The clay lip holds back a swamp, and at the head of the swamp is a cove. This cove is one of six that fall on a line bearing NNE.

A *spring* is where water flows naturally from rock or soil. In moving downhill, if ground water meets a dyke it may either spill over or move along its face. Swamps and springs occur where topographic conditions force water to emerge. Dolerite is not always visible because weathering of material may go deep.

Along Waroona Road and at Ronson Formation good water flows from springs all year. Many examples of "soaks" and springs fed by dykes exist.

Black Gravels

Black gravel is a soil type, not a landform. It appears that black gravel is associated with dykes but forms on laterite of granitic origin.

Black gravel consists of dark red to black ironstone gravel. As well as quartz grains embedded in the gravel, a matrix of loose, fine, white quartz sand is generally present, sometimes in large amounts.

Black gravels are found on and near the soil surface in a topography that may be convex or concave, on hilltops or slopes. They seem to occur most frequently near the scarp, with the number of sites decreasing inland. Forest Managers link black gravel to poor soils and "graveyard dieback sites".

No one knows their origin. In the past, black gravel has been explained as a relic of ancient swamps (Clifton 1973) or perhaps caused by bush fires. The following is our interpretation of their development and why they harbour dieback.

Both black gravel and ordinary laterite have a fine quartz matrix with a similar grain size and shape (but not necessarily surface colour). Because of this, both appear related to laterite derived from granite, not dolerite (dolerite lacks quartz). However, black gravel differs in colour, angular shape and density from the common pisolite. This suggests that at least the gravel constituent has a different origin.

The arrangement or configuration of dykes appears to be an important factor in the formation of black gravel. Their pattern may trap water, causing it to stagnate and become mineralized. In an oxygen deficient environment, iron, which is three times more abundant in dolerite than granite, can occur in ground water as ions of ferrous iron (Spock 1962). As they diffuse surfaceward through permeable granitic laterite, the prevailing conditions in later environments control what these ions will become.

Another sign that black gravels form in association with dykes comes from the presence in the gravel of vanadium, a mineral that may be scavenged by iron. Baker[1] (personal communication) has found vanadium in black gravels that he concludes comes from dolerite. He points out that vanadium is used to harden steel and may contribute, with maghemite, to the unusual hardness of black gravels.

Winter rain (or perhaps heavy rain during the Pleistocene Epoch) probably causes welling up of moisture and may produce favourable conditions for ionic transfer, thereby forming black gravel.

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1 Gordon F.U. Baker, Mines Geologist, Alcoa of Australia Ltd., Booragoon, Western Australia.

Black gravel is found on convex slopes and a ridge in Park Block on Stawell Road, East of Waroona. The area is probably underlain by a swarm of dolerite dykes that trap water (like bathtubs) and form a graveyard dieback site of black gravel, dead Jarrah stags and scrub. Because of weathering, it is difficult to assess this. However, dolerite outcrops in places and several coves butt onto the area.

Another black gravel "graveyard dieback site" occurs on the concave slope of a *perched catchment* at Ronson Formation (Fig. 6). The concavity and saddle is the result of a regional joint that climbs the hill and fractures two dykes. The concavity lies between the dykes; the upper dyke forms a saddle and the lower forms a convex lip.

The dykes, which behave as underground catchment boundaries (Engel *et al.* 1987), confine rain in the area. Joints gather the water and channel it toward the lowest point - the break through the bottom dyke. In the lower portion of the concavity, where the dyke forces moisture up, black gravel occurs.

Just below this area the same water again appears. Demarcated by dieback, a wedge of dark gravel points uphill toward the perched catchment.

In summary, black gravels may occur in various topographic locations that include ridges, depressions and hillsides. The link between black gravel and dieback is the hydrology of the site. Due to moisture, black gravel areas at both Ronson Formation and Park Block have the disease.

Monadnocks and Granite Outcrops

Thought to be left by erosion, monadnocks are hills that rise conspicuously above the general landscape. In our region they often have bare rock on some side. Examples of monadnocks are Mt. Dale, Mt. Solus, Mt. Wells, Mt. Cook, and Mt. Saddleback.

A *granite outcrop* is an exposure of granite projecting through the overlying cover of debris and soil. There are many granite outcrops, especially along the scarp.

In the Northern Jarrah Forest, rock outcrops show that granite usually protrudes through laterite due to a relative lack of local or regional joints. On them it is obvious that the portion of granite that stands out most has the fewest joints and is more solid. The number of joints determines the speed of deterioration and if joints are few, erosion outstrips weathering and bare rock results. Monadnocks or granite outcrops may form depending on the size and location of the block or the arrangement of its joints.

Lichens, mosses, shrubs and stunted trees inhabit rock outcrops. Many exist in weathered joints called *crevices*.

Field Joints

Local joint patterns in basement rock appear to influence overstory and understory plant distribution. We have called these patterns in vegetation "field joints". A *field joint* is a reflection by the vegetation of an underlying joint system through soil and other weathered material. This alignment of plants may appear on laterite, sand, swamps or other material. Its exact ~~cause~~ origin is unknown but it is probably caused by moisture collecting in joints or some physical property of the soil in response to the weathering.

On aerial photos, the vegetation alignment is subtle. Once recognised, however, one can see great numbers (Figure 10). In the past, these lineaments were either overlooked or mistaken for relics of logging such as snig tracks.

FIGURE 10 NEAR HERE

At Gracetown, Western Australia, which overlooks the Indian Ocean, lines of vegetation can be traced from joints in rock outcrops onto the Pleistocene sand dunes. Here, the field joints reflect the joint patterns of an ancient topographic surface buried below the dunes. This surface[2] and the joints associated with it, probably influence the occurrence and spread of dieback.

Some of the trees that reflect subsurface joints are Marri, Jarrah, Blackbutt and Tea Tree. The alignment occurs about 10 to 50 metres apart and shows on aerial photos of 1:25,000 scale.

THE LANDSCAPE

Regional Structure

Two major structural trends appear to influence the Northern Jarrah Forest; one is due to dykes, the other to joints (see Section VIII).

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2 Geologists call this type of surface a *nonconformity*. A nonconformity exists where sedimentary rocks overlay an eroded igneous surface. It is an ancient topographic surface (paleogeomorphic surface) buried by encroaching sand. This type of surface occurs between Cape Leeuwin and Cape Naturaliste and along our South Coast. For ease of reference to this important feature in our dieback work we have named it the *Gracetown Surface*.

Figure 10. Field joints, Sampson Dam Area. Subtle patterns in the Jarrah Forest and other vegetation are caused by sets of local joints. Some alignments are marked with paired white arrows. These lineaments are everywhere; the more you look the more you see. If you have trouble seeing them hold the page at an oblique angle, looking along the arrow. In the past, these lineaments have either gone unrecognised or been mistaken for snig tracks.

Dykes, have an average strike of about NNW (345) and forge the topography into ridges, spurs and hills. In addition, the region has a series of major valleys that strike about NNW (330). The South Branch of the Serpentine Reservoir (Fig. 2) and the average course of the Murray River exemplify this type of structure.

One explanation for these major valleys may be the overlapping and abutting of joint networks from two adjoining regions. This intermingling could cause concentrated zones of cracking that would intensify weathering and erosion. The existence of different joint networks might be explained by regional differences of stress on rock types or by geographic location.

At the Serpentine, seemingly different joint patterns face each other across a major structural valley (Fig. 2). The drainage to the west is typical of that found throughout the region. Both areas, however, have a drainage pattern related to rhomboids.

Some of the western drainage intersects at unexpected angles (right angles). This can be explained by the mixing of limbs of three or more different rhomb systems (Fig. 2). Any particular portion of drainage may be related to the set it joins or to another set some distance away. In Figure 2, notice how many segments of drainage parallel one another or intersect at angles of about 70 and 110 degrees.

The Murray River Valley is another major structural feature. Although its average course is about 330 degrees, it meanders frequently. One usually associates meandering with old age, not steep sided, deeply incised, and actively eroding rivers. The river, however, does not wander due to old age but because of deflection caused by the underlying geologic structure. As it erodes downward, joints and dykes capture leave ~~it~~ the ~~river~~, directing it like a serpent across the landscape.

If overlapping joint patterns are responsible for alignments, then, as with a checker board, secondary or weaker directions of alignment, may exist. Evidence of a secondary alignment might be the Northern Branch of the Serpentine that approximately parallels the South Dandalup Reservoir and a lineament along Yarragil Brook - Wallace Road. These alignments are evident on CALM maps of the area (Appendix A).

CONCLUSION

Landforms in the Northern Jarrah Forest result from weathering, erosion and time attacking geologic structure. As they blend together, landforms create the landscape. Like landforms, the major trends of the landscape reflect the interaction of joints, dykes and rock types. Geologic characteristics also control the type and distribution of vegetation, and the impact of Jarrah Dieback.

The main purpose of this paper is to reveal how the earth's structural geology creates landforms in the Northern Jarrah Forest. It is also intended to introduce readers to a more vast subject - geologic structure as the basis for the ecology of a site. In seeking answers through understanding, the structural geology of the site will usually be the question.

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APPENDIX A

GRANITIC SINK LOCATIONS

The known locations are given using the West Australian Department of Conservation and Land Management Grid References on the Dwellingup Map (1:50 000), Western Australia, National Map Reference 2132 IV & I.

1) "Old Dwellingup Oval", Ref. CU 62--8 East 5 North
2) Dillon's Lake, Ref. CS 62--4 East 2 North
3) Giles' Sink, Ref. CX 75--8 East 1 North
4) Scarp Road, Ref. CG 60--2 East 1 North

CONSERVATION AND LAND MANAGEMENT MAPS.

Jarrahdale, Western Australia, 1:50 000, National Map Reference 2132 III & II

Dwellingup, Western Australia, 1:50 000 National Map Reference 2132 IV & I

Murray, Western Australia, 1:50 000 National Map Reference 2132 III & II

CONSERVATION AND LAND MANAGEMENT AERIAL PHOTOS.

Photos of Serpentine Dam Area:

Title: Pinjarra; Project No. 800032; Scale 1:50 000; Film No. WA 1975; Run 7; Photos No. 5537-38-39; Date 25/02/81.

Photos of Nanga Area:

Title: Pinjarra; Project No. 800032; Scale 1:50 000; Film No. WA 1977; Run 12; Photo No. 5068; Date 26 /03/81.

PHOTO MOSAICS

The photo mosaics, used for statistical studies in Section VIII, were compiled for the National Topographic Map Service, photographed in February 1981 from Project No. 800032 aerial photos.

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