Overview of granite outcrops in Western Australia

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Introduction

One of the objectives of this workshop, and this issue of The Journal of The Royal Society of Western Australia, was to examine the management of granite outcrops from a more applied than academic viewpoint (see Granite Outcrops Symposium, *Journal of the Royal Society of Western Australia*, Volume 80[Part 3], 1997). This paper presents a broad overview of granite outcrops in Western Australia based on the Granite Outcrops Symposium, from a geological, geomorphological and biotic point of view, to provide a foundation for the following papers in this issue on more detailed and specific aspects of management of granite outcrops. Since the Granite Outcrops Symposium, three books pertaining to granites have been published by participants from that symposium, *Rock of Ages* (Bayly 1999a), *Life on the Rocks* (Nikulinsky & Hopper 1999) and *Inselbergs* (Porembski & Barthlott 2000). In addition, Agriculture Western Australia has produced a *Revegetation on Farms Information Kit*, and the Department of Conservation and Land Management has produced two booklets *How to Manage Your Granite Outcrop* (Hussey 1998) and *Exploring Granite Outcrops* (McMillan & Pieroni no date).

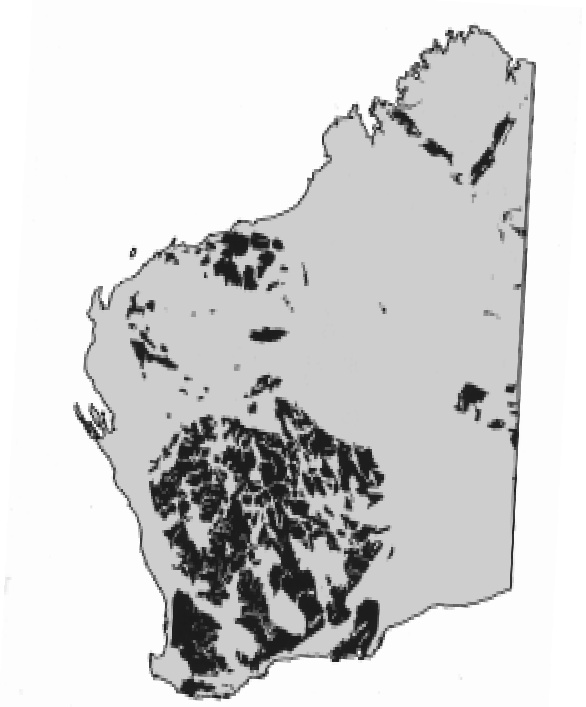

Figure 1. Distribution of granitoid landforms in Western Australia. Redrawn from the hydrogeological Map of Western Australia, Geological Survey of Western Australia (1989).

Granite outcrops form a complex part of the varied ecosystems in Western Australia, although they are often perceived as isolated rock forms jutting out of the surrounding landscape. They have been formed at varying geologic times, by various processes. They have subsequently weathered into differing major landforms (inselbergs, nubbins, koppies, *etc*), and a wide variety of minor structural forms (pits, basins, *etc*). Not only do granite outcrops form a specialised suite of habitats for animals and plants in their own right (*e.g.* rock pools, meadows, exfoliating rock sheets, rock crevices) but they also merge with the surrounding habitats and form specialised edge habitats, the fringing apron. Thus, the flora and fauna associated with granite outcrops are not only those species adapted to survive and persist on the granite rock habitats, but include many species from the surrounding habitats that seek temporary or permanent refuge amongst the granite rocks, or on the fringing apron.

Distribution of granites

Granite rocks are one of the most wide-spread and abundant types of rock on Earth. Granite forms the bulk of the continental crusts as well as uplifted mountain ranges, whereas the oceanic crust is mainly basalt.

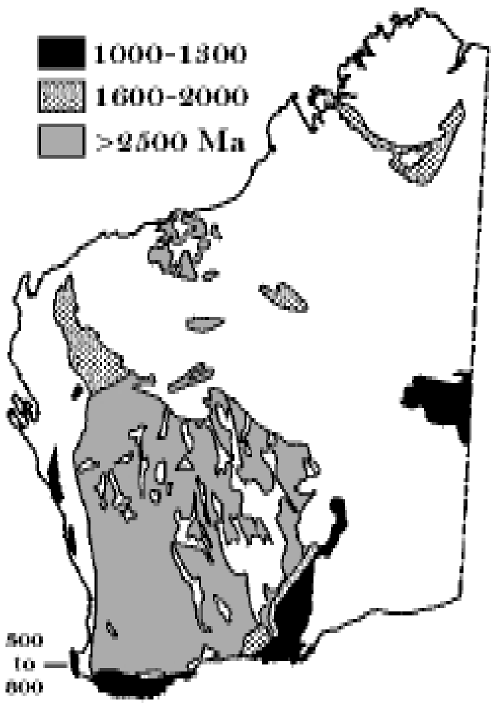

Figure 2. Approximate ages of formation of the main granite outcrops in Western Australia (modified from Myers 1997).

Granite outcrops are distributed widely throughout Western Australia. Although there does not appear to be a specific map of granite outcrops in Western Australia, the distribution of granite landforms clearly indicates a widespread potential distribution of granite outcrop habitats over much of the south-western portion of Western Australia, and to a much lesser extent north-eastern, east-central and northern Western Australia (Fig 1; see also Withers 1997). Much of the western part, particularly the Yilgarn cratonic block (see below), is covered by granite, and there are scattered patches of granite in the East and West Pilbara. There is a pronounced "V"-shaped patch of granite in the Kimberley, and scattered patches of granite along the eastern border of Western Australia, particularly around the Musgrave Ranges.

Origins of granites

The extensive granite outcrops of Western Australia are not of uniform age, but vary widely from over 2500 million years old to less than 1000 million years old (Fig 2; Myers 1997). These varying ages reflect differences in formation of the granite rocks.

The extensive south-western granites are part of the Yilgarn Craton, and were formed 2600 to 2700 million years ago when this craton was generated by assembly of numerous smaller continental crust rafts. The granites of the Pilbara craton are mostly buried by volcanic rocks and the Hammersley banded iron formations.

Other granite outcrops of Western Australia were formed in three major, distinct orogens, representing separate episodes of continental collision of cratons (Fig 3; see Myers 1997). The younger granite outcrops of the Kimberley and Gascoyne regions result from the colliding, about 1600-2000 million years ago, of the Pilbara, Yilgarn and other continents. Two more recent episodes of continental crust collision formed granite in the south of Western Australia. The older of these, the Recherche granite, was intruded about 1300 million years ago by deformation of the Mawson Craton and the West Australian Craton. Even younger Esperance granite, formed about 1180 million years ago, may be largely derived from another episode of compression between the Mawson and West Australian Cratons. The Musgrave granites formed at about the same time through deformation between the Mawson Craton and the North Australian Craton. The granites in the vicinity of Cape Leeuwin are even younger, having formed about 500-800 million years ago.

Figure 3. Schematic of the three independent cratons of continental crust with their main directions of movement (modified from Myers 1997).

Granite landforms

The particular landforms typical of granites are not peculiar to granite rock, but are sufficiently characteristic that the underlying nature of the granite rock can often be discerned from afar (Campbell & Twidale 1995). The development of granite landforms is largely due to patterns of weathering, as well as tectonism (Campbell 1997). Weathering by air and water through physical and chemical effects, as well as biological effects, shape granite landforms.

The major landforms of granites include relatively smooth plains as well as the more obvious positive relief features such as inselbergs (Fig 4; Twidale 1982; Campbell 1997). Bornhardts are the basic form of inselbergs, being rounded dome forms of massive bedrock. Nubbins and castle koppies are derived from bornhardts by partial breakdown below the surface of granite sheets to form blocks and boulders (nubbins) or pronounced weathering of vertical fractures (castle koppies). Granite pillars are blocks or towers from which the surrounding regolith has been removed.

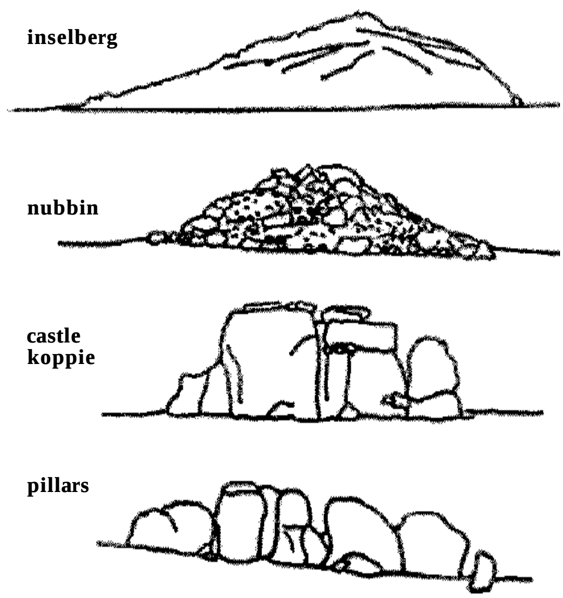

Figure 4. Schematic of major granite landforms (drawn from photographs in Campbell 1997).

The finer details, or minor forms, of granite rocks are mainly formed by weathering, although tectonism creates some features such as A-tents and deposition of weathered materials forms features such as speleotherms (Campbell 1997; Table 1). Rock basins (gnammas) are irregular to circular depressions in solid granite rock (Fig 5). They are often initiated at a shallow weathered depression or on fractures or fracture intersections. Hemispherical pits often form in more homogeneous

Table 1.

Summary of modes of formation for minor granite landforms by weathering, tectonism and construction (modified from Campbell 1997). Note that a number of minor forms are probably convergent, being formed in more than one way.

Weathering	**Initiated at weathering front**	pits	flared slopes
		gnammas	caves
		gutters and grooves	clefts
		flakes and spalls	blocks
		polygonal cracks	boulders
	By partial exposure	rock levees	pedestal rocks
		rock doughnuts	plinths
		fonts	
	Initiated at surface	gnammas	flakes and spalls
		gutters and grooves	blocks
		tafoni	boulders
	By crystal strain	Clefts	gutters and grooves
	By gravitational pressure	gnammas	tafoni
	By intrusive veins	clefts	walls
Tectonic		A-tents	fault scarps
		Blisters	orthogonal cracks
		triangular wedges	
Constructional		speleotherms	boxwork ridges

Figure 5. Schematic showing the development of gnammas, pits, pans and arm-chair basins by progressive weathering, indicated by numbers (drawn from Campbell 1997).

granite, and flat pans often form in laminated granite. Arm-chair basins are modified pans or pits, but on steeper slopes. Gutters and grooves develop on recently exposed granite, like gnammas. Flared slopes are often found around the base of hills, and are formed by sub-surface weathering followed by removal of the regolith to expose the smooth sloping weathered front. Tafoni are hollows at the base of boulders, formed at the weathering front or by gravitational force of a large boulder sitting on a granite outcrop. In contrast, A-tents (pop-ups) are arched slabs of granite, caused by permanent expansion of a sheet of granite due to release of compressive load. Finally, construction of granite features from weathered sediment is relatively rare, but precipitation of sediments can form silica flowstone, stalagmites or stalactites, and precipitation in fractures then weathering of the softer granite can form a boxwork pattern of small silica ridges.

Granite outcrop biota

It is clear that the times of formation of the different groups of granite outcrops in Western Australia considerably pre-date the presence of existing species of terrestrial vertebrates and invertebrates. Nevertheless, the current distribution of plants and animals on granite outcrops can reflect relictual isolation of ancient species by continental drift (*e.g.* the breakup of Gondwana) as well as more recent (in geological time) evolutionary and dispersal patterns. Some granite outcrop biota are clearly ancient relictual populations. For example the chironomid insect *Archaeochlus*, which is restricted to the granite outcrops in south-western Australia, has congeners found in the Drakensberg escarpment of southern Africa; these ancient Gondwanan remnant populations have been separated for a minimum of 120 million years (Cranston *et al.* 1987; Withers & Edward, 1997). In contrast, the granite-specialist dragon lizards (*Ctenophorus* sp) are much more recently evolved species, from perhaps a Tertiary radiation of amphiboluroid lizards (Hutchison & Donnelan 1993).

Granite outcrops often appear physically to be “islands” in the surrounding landscape, and they have a profound influence on the local plants and animals (Mares 1997). Important aspects of the physical environment provided by granite outcrops for plants and animals include the nature of the substrate, the shelter provided by rocks, and the sources of water that can accumulate on rocky substrates (Fig 6). Plants and animals which are permanent residents of granite outcrops often have adaptations for adhering, or moving over, the bare surface of granites. Weathering of granite produces many special habitats for plants and animals, including exfoliating sheets of granite, water-retaining depressions, and the talus around the base of weathering rocks (Wyatt 1997). Permanent and partial residents of granite outcrops exploit these habitats. The environmental conditions are often harsher on rock outcrops than in the surrounding habitats, with higher

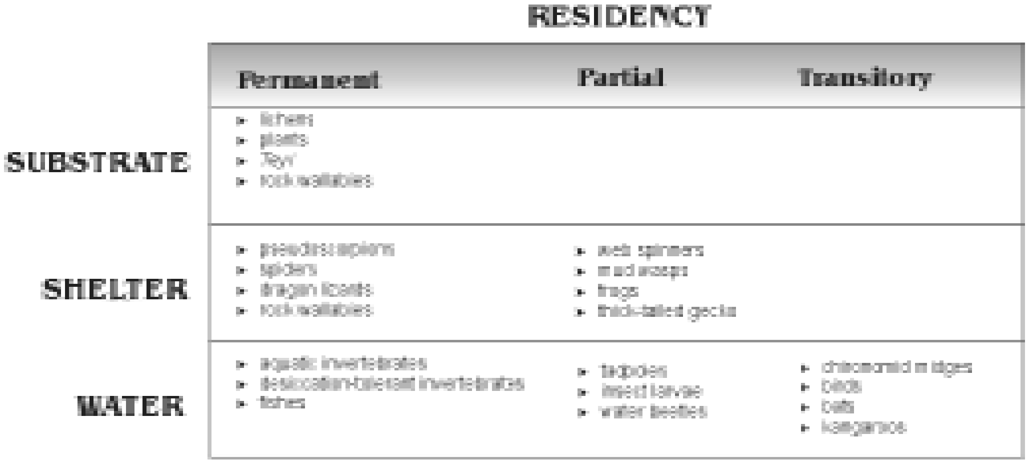

Figure 6. Roles of granite outcrops with respect to substrate, shelter, and water, for permanent, partially permanent, and transitory examples (modified from York Main 1977).

temperatures and lower moisture because of the high runoff of water from rocks; the exposed rock outcrop habitats are essentially desert environments scattered among the more mesic surrounds. However, protected, shaded microhabitats that collect rainwater are much more mesic than the exposed granite surfaces, and often the surrounds, and provide temporary or permanent sources of water for permanent, partial or transitory inhabitants.

Granite outcrops generally have a regional influence on plants and animals, increasing the local species diversity (Mares 1997). The biota of granite outcrops includes species that are permanently resident amongst the rocks, as well as species that are permanent or transitory residents. The common appearance of granite outcrops as "islands" in the surrounding landscape, and their distinctive biota, has led many botanical and zoological studies to examined the plants and animals of granite outcrops from an island biogeography perspective (York Main 1997). Granite outcrops are also commonly refugia for plants and animals that previously were more widespread, or during periods of environmental stress (drought, flooding, *etc*) in the surrounding landscape. So, to a large extent granite outcrops preserve a relictual, contracted and fragmented biota.

For plants, the diverse microhabitats on granite outcrops are refugia for both mesic and xeric plants, during climate change (Hopper *et al.* 1997). However, granite outcrops also act as foci for evolution and speciation of plants and animals specialised for the physical and biotic environment provided by these "islands", and are a potential evolutionary "bottleneck" for small, isolated populations. In Western Australia, the flora of granite outcrops shows biogeographic patterns that mirror the whole flora (Hopper *et al.* 1997). In the south-west and pastoral zone, granite rocks have a higher level of endemism than do rock outcrops of the northern zone. In the south-west, an apparent stochastic dynamism of dispersal and local extinction can result in great variability in the flora (orchids) of adjacent outcrops yet a similar flora of widely-separated outcrops. The species that are endemic to granite outcrops may be relictual with no obvious closely related species and therefore have been isolated on the outcrops for a considerable period, may be sister species derived by speciation from allopatric congeners of surrounding habitats, or may be sister species derived by speciation from allopatric congeners of nearby granite outcrops (Hopper *et al.* 1997). Granite outcrops thus may harbour relict species and preserve a record of evolutionary change; for example, the initial stages of evolution in the genetically complex lineages of *Isotoma petraea* are preserved at Pigeon Rock (Bussell & James 1997).

In contrast to the plants, relatively few animals are restricted to granite outcrops but many species use them as a seasonal resource or for temporary refuge during climatic fluctuations (Withers & Edward 1997). The fauna of temporary aquatic habitats on granite outcrops is poorly documented but there is generally a positive correlation between species diversity and volume of temporary pools (Bayly 1997). Such temporary pond fauna may include permanent residents of pools (with passive and poor dispersal capabilities), animals that actively disperse but are still present during the dry season as dormant life stages, actively disperse but have a discontinuous presence in pools (emigrate before pools dry up), or have an exceptional dispersal capacity and rapidly recolonise temporary waters. Some insects, such as the dipteran *Archaeochlus*, lichen-consuming moth larvae and certain grasshoppers, a pseudoscorpion *Synsphyronus elegans*, and some species of the mygalomorph spider *Teyl*, may be restricted to granite outcrops (York Main 1997; Withers & Edward 1997). No fishes or amphibians are restricted to granite outcrops in Western Australia, although many use them as refugia for shelter during dry periods, or for breeding during wet periods (Withers & Edward 1997). Four reptiles appear to be restricted to granite outcrops, three *Ctenotus* dragon lizards and a gecko *Gehyra montium* (Figure 7). No birds are restricted to granite outcrops, although a number of species frequent them in appropriate seasons (Hopper 1981). No mammals are restricted to granite outcrops, although a number of species that are specialised for rock environments (rock wallabies *Petrogale*, long-tailed dunnart *Sminthopsis longicauda*, rock rats *Zyzomys*, rock ringtail possum *Pseudochirus dahli*) frequent granite outcrops (Withers & Edward 1997).

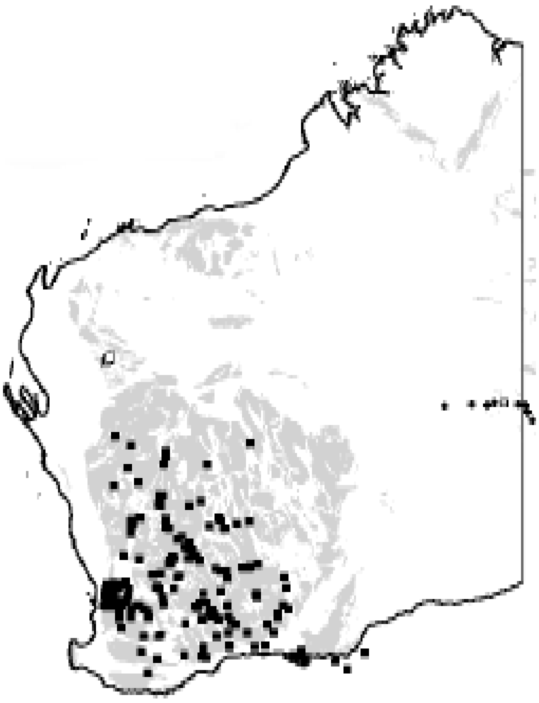

Figure 7. Distribution of three *Ctenophorus* dragon lizards (*C. ornatus* n; *C. rufescens* ©; *C. yinnietharra* ®) and a gecko (*Gehyra montium* :) with respect to granite landforms (dark gray shading) in Western Australia (modified from Withers & Edward 1977). Locality data from Western Australian Museum.

Although relatively few animals appear to be restricted to granite outcrops, many other species have been recorded on granite outcrops and it is clear that granite outcrops and their aprons are important as a seasonal resource or temporary refuge during environmental extremes.

Granite outcrops as a human resource

Granite outcrops would undoubtedly have had an important role in the settlement and occupation of Western Australia by Aboriginal inhabitants, as they provide shelter as well as water and food (Bindon 1997; Bayly 1999b). They also are focal points for cultural activities

Early European settlers recognised the value of granite outcrops as a source of water, and since about 1890 approximately 200 locations have been used to collect water runoff (Laing & Hauck 1997). Currently, the Government, the Water Corporation and the farming community continue to use rock catchments as a water source. Some of these may be surplus in areas with piped water, but several rock catchments are connected to the piped water scheme and supplement the total scheme supply.

Conservation

The granite outcrops of Western Australia occupy a very small proportion of the total area of the State, and are rare habitats that are likely to contain rare species of especially plants but also some animals (Hopper *et al.* 1997). Many species also use the fringing apron zone around granite outcrops. Most granite outcrops require management if their local biota is to survive. Physical degradation by rock removal, clearing, invasion by disease, weeds and feral animals, excessive grazing pressure, altered fire regime, and progressive salinisation are but some of the ongoing processes that are likely to affect the long-term survival of granite outcrops and their biota. These diverse problems associated with managing granite outcrops and their apron habitats cannot be reduced to simple recipes (Main 1997). Conflicts between use of granite outcrops by different groups with disparate values for the granites require that adequate management involve both government and public cooperation.

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