Chapter one

The geomorphic evolution of the Warrumbungle Volcanic Complex, New South Wales, Australia.

An approach to volcanism may be made through either petrology or geomorphology, a volcano and its mechanism being regarded either as a geological crucible or as a builder of landforms.

C.A. Cotton 1944

1.1 Rationale for the study

Many volcanic studies are written from a geological point of view, concentrating on mechanisms of eruption, geochemistry and petrology. From a geomorphic standpoint, volcanic provinces are characterised by distinctive landforms, mostly constructive in origin, resulting from the emplacement of magma and the eruption of lavas and tephra. This work adopts Cotton's latter approach to volcanism as a builder of landforms, and their geomorphic development, and is specifically concerned with the activity of the Warrumbungle Volcanic Complex (cover page), New South Wales, Australia. This study of the Warrumbungle Volcanic Complex (hereafter called the Warrumbungle Complex) is undertaken as a response to the lack of significant geomorphic studies of this feature compared to other Australian shield volcanoes. The Warrumbungle Complex, along with other central-type shield volcanoes, contributes significantly to the nature of the eastern Australian landscape, and is large enough to have a considerable effect on regional topography, soil development and drainage. It is therefore important to develop a thorough examination of this neglected area, and this thesis is intended to contribute to an ongoing analysis of shield volcanoes and their impact on the development of the eastern Australian landscape. (The term "Complex" is extended in this work for convenience to include all pre-volcanic, volcanic and post-volcanic materials and landscapes of the Warrumbungle study area).

1.2 Australian volcanism

Eastern Australia has been intermittently influenced by intraplate volcanism from about 70 Ma ago to as recently as 4600 BP (Johnson 1989). All volcanic areas are within 500 km of the coast, except for some leucitite centres which occur in central and southern New South Wales and central northern Victoria (Johnson 1989; Figure 1.1). Volcanism has extended from the Torres Strait, along the eastern highlands of Queensland and New South Wales, and extending into Victoria, South Australia and Tasmania. This volcanism has been categorised by Wellman and McDougall (1974a) into central-type (which should not be confused with the Central Province of northern New South Wales), lava field, and leucitite suite provinces (Section 2.2.2). While all three provinces are of significance to Australian geomorphic and volcanic history, it is the central-type (shield) and, more specifically, the mid-Miocene central-type Warrumbungle Complex that is considered in this thesis.

The Warrumbungle Complex forms part of a 750 km long chain of alkaline shield volcanoes which includes, among others, the Main Range, Focal Peak, Tweed, Ebor-Dorrigo, Nandewar, Comboyne and Canobolas Complexes (Figure 1.1). These volcanoes comprise a petrologically distinct group because they all contain oversaturated peralkaline rocks (Middlemost 1981) and were all extruded over the period 25-10 Ma (Wellman and McDougall 1974a, b). More importantly, both the Nandewar and Canobolas Complexes contain material of similar petrology to the Warrumbungle Complex (Middlemost 1981). The origin of this chain of shields has been attributed to a sub-lithospheric heat anomaly (mantle plume or hotspot) that remained more or less stationary as the Indo-Australian plate drifted northward (Wellman and McDougall 1974b; Section 2.4).

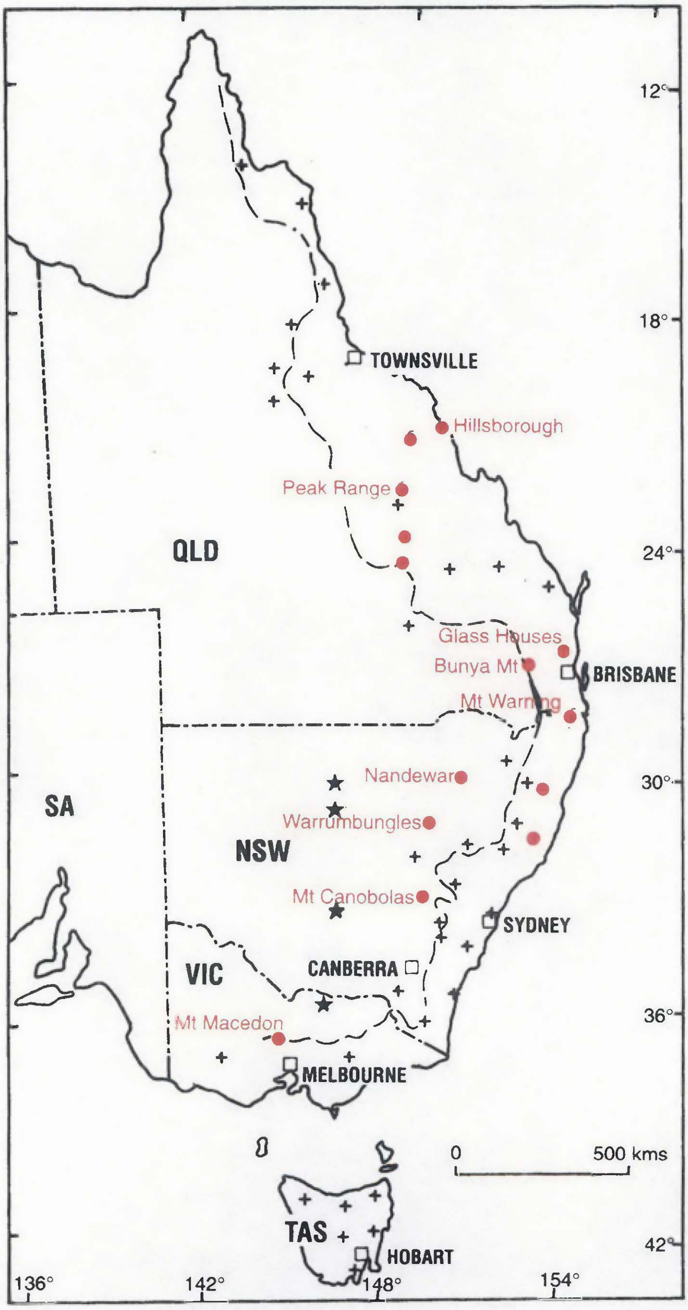


Figure 1.1: Location of the Warrumbungle Complex in relation to the main central-type volcano (red •), lava field (+) and leucitite suite (high potassium-mafic;★) provinces of eastern Australia. Central-type volcanoes are closely associated with the Great Divide (dotted line) in New South Wales and southern Queensland, where they are offset to the east and west of this feature. *Source*: Modified from Duggan and Knutson 1993.

1.3 The Warrumbungle Complex study area

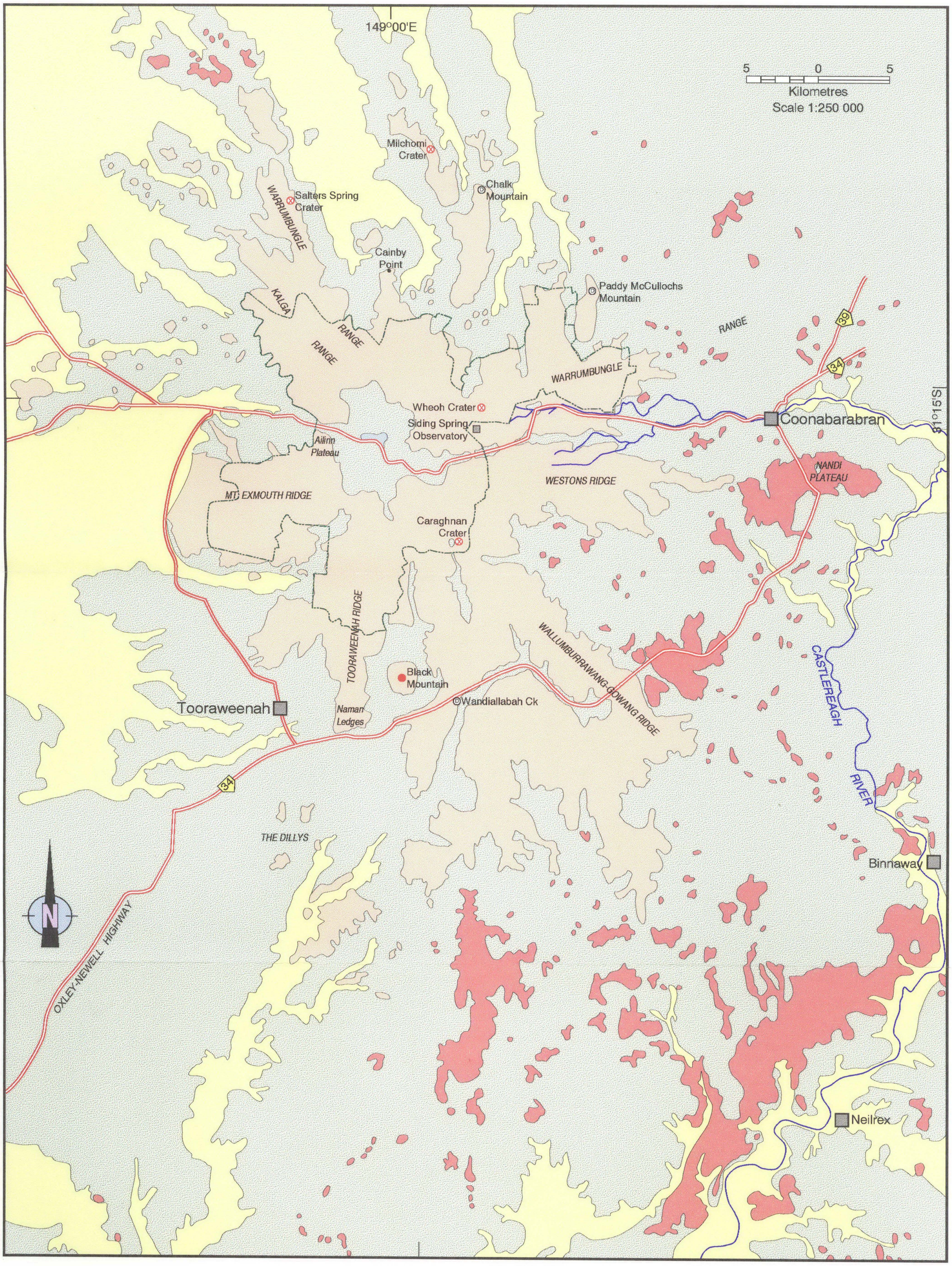
The Warrumbungle Complex is located approximately 350 km northwest of Sydney, in central New South Wales; 110 km northwest of the nearest point of the Great Divide and 37 km west of Coonabarabran (Figure 1.2). The word "Warrumbungle" is aptly derived from the local Kamariloi word meaning "crooked mountains". The Complex is a deeply dissected mid-Miocene continental shield volcano on a basement of maturely eroded Jurassic sedimentary rocks, which occupies an approximately ovoid area about 55 km north-south and 32 km east-west. The central area of this Complex is largely contained within the boundaries of the Warrumbungle National Park, with outliers of basaltic rock extending northwest towards Coonamble and southeast towards the Liverpool Ranges. Maximum present-day thickness is estimated to be 806 m, based on a section of volcanic material between Tonderburine Creek (400 m ASL) and Mount Exmouth (1206 m ASL; Section 6.5.2.1). The shield is largely preserved as a spectacular array of volcanic domes, plugs (necks), dykes and craters interspersed with lavas, pyroclastics, tuffs and breccias occasionally interbedded with diatomite deposits. While a comprehensive account of the present landforms of the Warrumbungle Complex is presented in Chapter 4, these landforms can be conveniently classified into the following groups:

1. *Skeletal areas*: this group encompasses most of the shield centre where volcanic conduits have been exposed by erosion. Soil development is poor due to rocky outcrop, vegetation is sparse, and relief is well defined and rugged. Elevations range from 700 to 1140 m ASL.

2. *Flat-topped lava flows*: these areas are confined to the flanks of the shield where lavas formed stacked flows up to 806 m thick but are generally less than 300 m thick. They are characterised by terraced and dissected margins, or occur as residuals. Flows range in length from several metres to 50 km.

3. *Valleys*: the depth and shape of valleys depend largely on the relief and nature of the underlying lithology. Steeper, narrower valleys occur on basalts and trachytes, with broader, wider valleys confined to sandstone basement areas.

4. *Basement*: basement rock in the area consists of rare outcrop of Triassic Purlawaugh Beds and the widespread Jurassic Pilliga Sandstone. The Pilliga Sandstone is generally flat-lying except where tilted by the emplacement of intrusive bodies such as domes,



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Kilometres
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Milchomi Crater
Chalk Mountain
Salters Spring Crater
WARRUMBUNGLE
Cainby Point
KALGA
RANGE
RANGE
Paddy McCullochs Mountain
RANGE
39
34
WARRUMBUNGLE
Wheoh Crater
Siding Spring Observatory
Coonabarabran
31°15'S
Ailinn Plateau
MT. EXMOUTH RIDGE
WESTONS RIDGE
NANDI PLATEAU
Caraghnan Crater
TOORAWEENAH RIDGE
WALLUMBURRAWANG-GOWANG RIDGE
CASTLEREAGH
Black Mountain
Wandiallabah Ck
Tooraweenah
Naman Ledges
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RIVER
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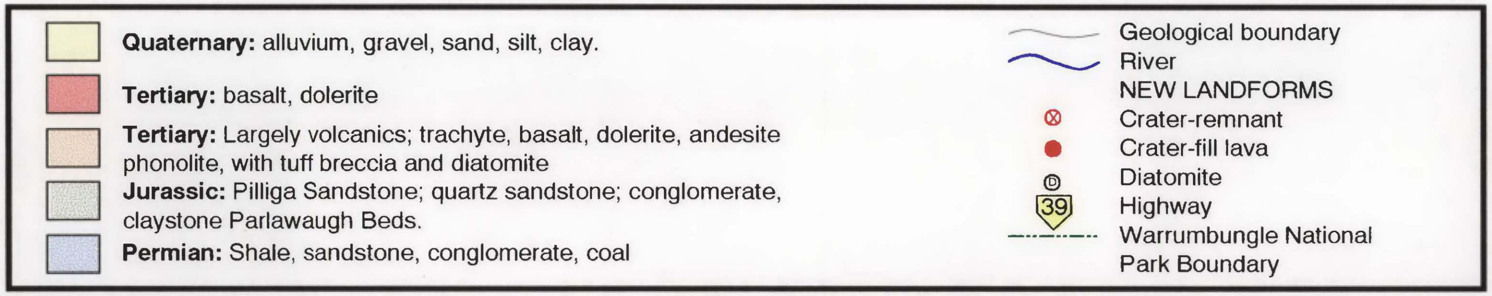

Figure 1.2: Map of the Warrumbungle Complex study area and the principal localities discussed in the text. The dotted line marks the boundary of the Warrumbungle National Park. The distribution of pre-volcanic geology has been determined in this study. General geology has been derived from the Gilgandra 1:250 000 geological map sheet (Geological Survey of New South Wales 1968, Hockley (undated) and Coonabarabran Shire Council (1987).

plugs and dykes. Sandstone basement has been exposed in the shield centre and flanks by erosion.

The present study encompasses the whole of the Warrumbungle Complex, and lies within the Gilgandra 1:250 000 geological sheet (SH 55-16; Geological Survey of New South Wales 1968). Volcanic landforms were interpreted from continuous coverage of the Warrumbungle shield from 1:50 000 scale aerial photographs (Land Information Centre 1979,1992) and field reconnaissance. These landforms were mapped onto the Tenandra (8635-I & IV), Bugaldie (8735-I & IV), Tooraweenah (8635-II & III), Coonabarabran (8735-II & III), Gilgandra (8634-I & IV) and Binnaway (8734-I & IV) 1:50 000 topographic maps (Central Mapping Authority of New South Wales 1979), in order to provide an account of the development of the Warrumbungle landscape. All grid references cited in this thesis refer to the 1:50 000 topographic maps listed above.

1.4 Research objectives

Remarkably, there has been very little work undertaken on the geomorphic development of the Warrumbungle Complex. It has been the Main Range (Ewart and Grenfell 1985; Stevens *et al.* 1989a) and Focal Peak Volcanoes (Ross 1989) in southern Queensland, Tweed Volcano (Mount Warning Complex; Solomon 1964; Ewart *et al.* 1987; Stevens *et al.* 1989b) in northeastern New South Wales, the Ebor-Dorrigo Volcano (Ollier 1982a; Feebrey 1989; Ashley *et al.* 1995) in northeast central New South Wales, the Nandewar Volcano (Abbott 1965, 1967, 1969; Stolz 1983, 1985, 1986) in central New South Wales and the Newer Volcanics (Ollier and Joyce 1964; Ollier 1967) in Victoria, that have received the most academic attention. The bulk of these studies have discussed the age of these features, as well as geomorphic, palaeontologic and stratigraphic aspects, and these have yielded significant data on the geological and geomorphic development of these volcanoes and adjacent landscapes.

The first published mention of the Warrumbungle Complex was produced by John Oxley (1820) and consisted of descriptions of landscape features. David (1896) and Jensen (1906,

1907) were next to describe the area, concentrating largely on geology and petrology, although Jensen did provide some physiographic data and notes on *geomorphogeny* in which he discussed primary stream development, landforms and volcanism within a geological framework. More recently, several authors have discussed aspects of the petrogenesis of the Warrumbungle Complex and provided limited speculative analyses of the geomorphic development of isolated parts of the shield (Hockley 1973, 1974; MacKellar 1980; Loxton 1982; Hubble 1983; Duggan and Knutson 1991, 1993). In addition, the National Parks and Wildlife Service have released short, tourist-oriented booklets (Mullins and Martin 1976; Fairley 1977, 1991; Fox 1996) that cover general aspects of Warrumbungle volcanism, landscapes and biodiversity. Despite these works, geological maps of the Complex are still inadequate, as is a comprehensive petrological and chemical analysis of the shield. Furthermore, there has been little effort to describe the integrated geomorphic evolution of the Warrumbungle Complex. This work aims to fill the gap in the present literature on the geomorphic development of the Warrumbungle Complex by providing an account of the pre-volcanic, volcanic and post-volcanic geomorphic evolution of the Complex.

In filling this gap, this study seeks to address several areas in order to provide a clearer understanding of the geomorphic evolution of the Warrumbungle Complex. Thus, the primary foci of this project are:

1. *to determine the extent of updoming of the underlying and surrounding Pilliga Sandstone associated with the emplacement of the Warrumbungle magma body, in order to determine its impact on regional long-term landscape evolution;*
2. *to determine the location of eruption centres and relate these to crustal fractures and emplacement mechanisms, and to then demonstrate their effect on landscape development;*
3. *to determine whether the general trend of age-latitude progressive volcanism displayed by central-type provinces in Australia is evident in the Warrumbungle Complex and to determine its relevance to age extrapolations across the shield;*

4. *to identify flow units and their eruption centres in order to determine sequences of eruption, so as to determine the influence of multiple flow stratigraphy on landscape development;*

5. *to produce further evidence of the nature of regional climate over the period of eruption (17-13 Ma) through the analysis of contemporaneous diatomite deposits, in order to determine the effects of climatic events on geomorphic agents and their implications for landscape development;*

6. *to investigate the extent of drainage modification caused by the emplacement of the Warrumbungle Complex, especially on its primary stream, the Castlereagh River, and to look at the rate of denudation of the volcano in the context of the whole drainage system of the Darling Basin;*

7. *to use the information obtained in the above points to produce a history of landscape evolution for the elements of the Warrumbungle Complex, from the time prior to volcanic activity to the Present; and*

8. *to compare the morphological development of the Warrumbungle Complex to other Australian shields and place it within the framework of eastern Australian intraplate volcanism and landscape evolution.*

An explanation of the distribution and significance of vent locations, volcanic stratigraphy, the effects of updoming and elucidation of climate parameters is central to the geomorphic interpretation of landscape evolution in the Warrumbungle Complex and its immediate surrounds. Such explanations aid the interpretation of drainage alteration, clarify any age relationships and provide a framework for the interpretation of the geomorphic development of the region.

1.5 Landscape evolution

Given the remarkable age of many Australian landforms (the main features of the landscape are of the order of 10^7-10^8 years old; Gale 1992), studies of palaeoforms need to challenge the traditional assumptions of the relative youth and the largely transient nature of the physical landscape (for example, W.M. Davis's Cycle of Erosion). Much of the landscape has been shown to have developed over similar time scales to that of the tectonic evolution of the continent itself (Twidale 1976, Ollier 1978; Young 1983; Ollier 1991). Thus, evolutionary studies of landforms will be lacking unless undertaken within the framework of continental morphotectonic evolution. In addition to investigations of long temporal scales, analysis of ancient landscapes should also contain elements of investigation over large spatial scales in order to provide a complete understanding of landscape development in context. Applications of such an approach to geomorphic studies show that there are strong links between the morphology of Australian landscape features, plate motions and processes. Given the nature and location of the Warrumbungle Complex, the study of this feature has the potential to unravel some 17 Ma of landscape evolution and may provide some inferences as to the morphotectonic development of the eastern Australian highlands.

1.6 Nomenclature

There is some confusion in the literature as to the description of the products of volcanic activity. This confusion has occurred as a result of attempts to infer, through the use of certain terms, either a descriptive or genetic relationship for materials and landforms of volcanic origin. For example, the general descriptors of volcanic landforms such as volcanic domes, cones and shields, fall into this category. Cotton (1944) drew little distinction between the terms volcanic (basalt) dome and shield volcano. Both terms were used by Cotton to denote the build-up, by relatively quiet eruptions, of basic lavas with little explosive activity and consequent fragmental or tuffaceous outpourings. By contrast, Williams (1932) defined volcanic domes as steep-sided viscous protrusions of lava forming more or less dome-shaped masses around their vents. He used the term shield volcano for much larger, dome-like structures formed exogenetically by the outpourings of fluid lavas, such as those volcanoes of the Hawaiian Island group. Kear (1957) used the term volcanic cone to denote all types of central eruptions. On the other hand, Cotton (1944) used the term volcanic cone to indicate the build-up of low broad lava hills of flatly conical or dome shaped outpourings, emitted with varying intensity, from a central vent. To avoid the confusion caused by this conflict between genetic and descriptive relationships for landforms and materials of volcanic origins, I will use the definitions provided in Table 1.1

throughout the text. These definitions are further embellished upon in the chapters following.

Table 1.1: Nomenclature used for the description and classification of major volcanic landforms as relevant to the Warrumbungle Complex.

Landform	Nomenclature	Reference
Shield volcano	A *shield volcano* is a succession of wide sheets of volcanic rock, built by repeated outpourings of basaltic lava, with slopes less than 7° and convex outlines.	Ollier 1988
Intrusions	Intrusive basic rocks are commonly feeders to volcanoes, and occur in a few well-defined forms. Vertical fissures eventually become vertical sheets of igneous rocks called *dykes. Necks* or *plugs* are cylindrical feeders of volcanoes.	Ollier 1981a
Volcanic cone	Central vent, or pipe eruptions form two of the most distinctive volcanic features- *cones* and *domes.* Cones may be built of lava alone, scoria, or a combination of lava flows and scoria. The term volcanic cone may be used to indicate the build up of low broad lava hills of flatly conical or dome shaped outpourings, emitted with varying intensity, from a central vent.	Cotton 1944; Selby 1985
Domes	A volcanic *dome* is a steep-sided viscous protrusion of lava forming a more or less dome-shaped mass around a vent. Domes that grow by extrusion and piling up of multiple viscous lava flows are *exogenous*; domes that grow primarily by expansion from within are *endogenous* and domes that rise as simple pistons from a conduit are *plug domes.*	Williams 1932
Craters	A *crater* is a funnel-shaped depression from which gases, fragments of rock and lava are ejected. Craters form the summits of most volcanoes and are partly the upper end of the vent up which the lava rises and overflows, and partly the result of collapse of the vent walls as the magma sinks in the vent after an eruption.	Selby 1985; Skinner and Porter 1987; Duggan and Knutson 1993
Lava flows	*Lava flows* result from the eruption of fluid lava, and are generally confined to basaltic eruptions. Stacked flows and their boundaries may be defined by tiering of flow margins.	Ollier 1981a
Pyroclastic fall deposits	*Pyroclastic fall deposits* are made up of fragments that have fallen through the air after a volcanic eruption. The term *tephra deposit* applies to all airborne pyroclastic ejecta whether loose or consolidated, but excludes fragmental debris produced or laid down under water or in volcanic vents. Tephra is a term not normally used for pyroclastic flows.	Williams and McBirney 1979; Ollier 1988
Pyroclastic flow deposits	*Pyroclastic flow deposits* result from sudden and large eruptions of volcaniclastic or hydroclastic material together with large amounts of gas.	Ollier 1988; McPhie *et al.* 1993
Volcaniclastic material	*Volcaniclastic material* refers to clastic rock containing volcanic material in any proportion without regard to origin or environment.	Bates and Jackson 1980

1.7 Thesis outline

Before proceeding to describe the findings of this study, Chapter 2 discusses the volcanic geomorphology of eastern Australia and the effects that tectonic and associated volcanic activity have had on landscape development. The chapter highlights the problematic nature of developing a dynamic model to account for all volcanism in eastern Australia.

Chapter 3 discusses the development of volcanic landforms, including summarising the influence of endogenic and exogenic factors on these landforms, and emphasising the role of volcanic emplacement, erosion and lithological control on subsequent landscape development. Following the theme of volcanic landform development, Chapter 4 provides an overview of the Warrumbungle Complex, outlining biological diversity, basic geology, ages and the main volcanic formations. A discussion on interbedded diatomite sequences is included with a view to utilising palaeoecological investigations of fossil diatoms to reconstruct environmental conditions over the period of deposition (which occurred contemporaneously with volcanism).

Chapter 5 describes the field and laboratory methods used in this study. Emphasis is placed on aerial photographic interpretation, mapping and fieldwork. The objective of the fieldwork was to clarify apparent relationships observed in the aerial photographs between landform features, and to collect diatomite to reconstruct the palaeoenvironmental conditions which operated during shield formation. Where appropriate, the reader is referred to existing published accounts of the techniques used, with detail provided on any modifications to these techniques. Modifications were required because many diatom extraction techniques were developed to suit Quaternary sediments, rather than those of mid-Miocene age which are examined in this study. Further details on methodology appear in the Appendices.

Chapter 6 begins the account of the geomorphic evolution of the Warrumbungle Complex, with a description of pre-volcanic topography. This is followed by the results from investigations of present shield morphology and a reconstruction of shield morphology at cessation of activity. Evidence of subsequent landscape development is then provided. However, before synthesising these results, some discussion of the apparent correlation of certain features within the Complex is required, as is a discussion of premises and possibilities regarding their evolution, before the broader picture can be presented. These preliminary discussions are therefore necessarily intermingled to some extent with results because a degree of correlation must be determined before the broader picture can be presented.

Chapter 7 then develops the themes of Chapter 6 into a wider discussion. Arguments based on the integration of geomorphic evidence are developed, and Chapter 8 discusses the findings of this study within the wider context of the development of other Australian shield volcanoes and the development of the eastern Australian landscape. Finally, in Chapter 9, the conclusions are drawn in the context of the morphotectonic development of eastern Australia. Bibliographic data follows; along with appendices providing information ancillary, but important to, the main research objectives.