# Chapter four

# The Warrumbungle Complex

SYNOPSIS: The Warrumbungle Complex forms an important component of the central New South Wales landscape. The nature of this Complex is described, and general background conditions, such as geomorphology and regional geology are outlined.

## 4.1 Introduction

Volcanoes are responsible for some of the most significant landscape features on the Earth. The geomorphic investigation of these features and their associated sediments provides a wealth of information on a diverse range of topics, from the mechanisms of volcanic emplacement through to the nature of volcanic landscape evolution, including the determination of palaeoenvironmental parameters. Among these features, the Warrumbungle Complex has great potential to yield information which may uncover some 17 million years of landscape evolution. The sequence of evolution in this complex may be explored and unravelled through studies of the location and identification of volcanic vents, remnant volcanic stratigraphy, evidence of updoming of basement rock, denudation rates, and palaeoclimatic and palaeobotanical determinations. In addition, this Complex forms part of a series of volcanic episodes that cover some 70 million years of landscape development in eastern Australia (Section 2.1). Any geomorphic and geological interpretations from the Warrumbungle Complex may aid in the interpretation of the volcanic history of Australia, and perhaps the morphotectonic development of eastern Australia.

The Warrumbungle Complex is composed of multiple layers of interbedded basalt and trachyte lavas, tuffs and breccia. The flanks of the shield (the distal zone) have been dissected by stream incision but still retain their primary constructional form of tiered, outwardly sloping lavas and airfall pyroclastics. Judging by the angle of dip of the major volcanic constructional remnants, Duggan (1989b) suggested that the Complex was originally a reasonably symmetrical low shield reaching a height of about 1000 m above the surrounding basement. However, Wellman (1986) suggested that this apparent height is exaggerated by significant updoming of the basement beneath the central part of the volcano (Section 2.4.1). By contrast, the centre of the shield (the proximal zone) has been deeply dissected by erosion revealing many of the upper conduits which supplied lava to the surface (Plate 4.1a, b).

## 4.2 The Warrumbungle Complex: cultural history

Archaeological evidence suggests that Aboriginal people have inhabited the northwestern slopes region of New South Wales for some 25 000 years BP but no sites older than 5000 years old have been recorded in the Warrumbungles (Central Mapping Authority 1986). Around 2000 to 1000 BP human activity was prevalent around the core of the Warrumbungle National Park (Figure 1.2) with activity around 5000 BP restricted to the margins of the shield. The language spoken was a form of Gamilaroi (or Kamilaroi), yet no ceremonial sites such as bora rings like those in the Nandewar Volcano have been located or identified (Central Mapping Authority 1986). While most organic evidence of aboriginal habitation has rotted away (carved and scarred trees), inorganic evidence in the form of tools/ tool making flakes and grooves, campsites, rock paintings and rockshelters is common (Fox 1996).

The first European to view the Warrumbungle Complex was John Oxley who passed through the area in 1818 and named it the Arbuthnot Mountains, after the head of the British Treasury. Oxley's party, on approaching from the west (cover page) reported: "... *To the east a most stupendous range of mountains, lifting their blue heads above the horizon* ...". Closer to the Complex, the party observed "... *very broken and rugged, detached rocks projecting like pillars and pyramids in various parts of the range* ...". Later, they noted "... *Its elevated points were extremely lofty, and a dark, barren, and gloomy appearance; the rocks were of a dark grey, approaching black* ..." (Oxley 1820).

*Plate 4.1*: (a) The Warrumbungle Complex from the southwest. Note the distinct shield shape of the volcanics preserved as heavily eroded planeze surfaces (Section 3.8.2). The peaks in the centre represent plugs, dykes and domes exposed by the erosion of softer volcanic material and can be seen more clearly in Plate 4.1b. *Photo*: A. Timmers.


*Plate 4.1*: (b). The shield centre, taken from Siding Spring Observatory. A significant volume of softer material has been eroded, exposing the volcanic conduits of Crater Bluff, Belougery Spire, Belougery Split Rock and Bluff Mountain, as well as the underlying Jurassic sediments (right foreground). Differential erosion has also preserved major constructional elements such as Mount Exmouth, which consists of interbedded trachytic and basaltic lavas and pyroclastics. *Photo*: A. Timmers.

As early as 1836 “Warrumbungle” became the preferred name for the area (Fox 1996). Squatters arrived in the area in the 1830s and began producing wool, wheat, and beef in the less rugged areas of the Complex. The first calls to preserve the area came in 1936 when the National Parks and Primitive Areas Council recommended that the "Warrumbungle National Monument" be declared on the grounds that the central Warrumbungle Ranges were one of the few areas in the region that still retained its natural vegetation. In January 1952, 3360 hectares were set aside for public recreation. An extra 2300 hectares adjacent to the Park were declared as a buffer zone. A further 25 hectares were donated in 1959 by local property owner Keith Blackman and by 1967 a further 6235 hectares were added. Since that time more land has been acquired by the National Parks and Wildlife Service such that the Park now covers 20 914 hectares encompassing the main volcanic centre (Fox 1996; Figure 1.2; Plate 4.1b).

Many of the landscape features in the study area have been given names of Aboriginal and European origin, or are extracted from Gaelic mythology. European-labelled features have been largely named after the Blackman and Pincham families and their properties ‘Belougerie’ (a name of Aboriginal origin) and Strathmore, or are derived from, or named by, key persons who established the Warrumbungle National Park and/or built facilities in the Park. Other features have been named for their resemblance to anthropogenic objects (for example, the Breadknife) or natural features (for example, Whitegums Lookout).

## 4.3 Biological diversity

### 4.3.1 Vegetation

Today, the vegetation in the area is dominated by dry sclerophyll (Myrtaceae) woodland with Casuarinaceae gallery forest along valley waterways in response to an annual average rainfall of 600 mm per annum (Freebairn 1993) and seasonal temperature variations of less than 0°C to 15°C in winter and up to the mid- to-high thirties in summer (Central Mapping Authority 1986). Because rock lithology and outcrop varies so widely across the shield, a range of plant communities exist in response to the characteristic terrain associated with these outcrops. Thus, vegetation distribution is controlled as a response to rock type, slope, soil depth and nutrient status, moisture, temperature and exposure. Fairley (1991) defined seven vegetation communities based on these factors:

1. riverine: characterised by reliable water sources in areas cleared for pasture (for example, Wambelong Creek), generally in broad, flat alluvial valleys. Vegetation dominated by gallery forest consisting of *Casuarina cunninghamiana* and *Eucalyptus camaldulensis*.
2. creek: characterised by general lack of surface water, steep valleys and the presence of colluvium. Vegetation dominated by *Angophora floribunda* and *Eucalyptus albens* with an *Acacia decora* understory. Such communities are widespread within the study area, especially around the intermediate flanks of the shield where narrow valleys are protected from dry winds (for example, Spirey Creek).
3. dry eucalypt woodland (type 1): characterised by moderate to steep slopes with northerly and westerly aspects. Soils are dry and skeletal. Vegetation is dominated by *Eucalyptus blakelyi*, *Callitris glaucophylla*, *Callitris endlicheri* and *Eucalyptus dwyeri*. The understory is mostly *Acacia spp.* and *Phebalium* (for example, higher slopes of High Grand Tops).
4. dry eucalypt woodland (type 2): occurs on dry ridges and moderate slopes on sandstone soils that are often enriched by volcanic debris. Slopes are less exposed than type 1. *Eucalyptus rossii*, *Eucalyptus crebra*, *Callitris glaucophylla*, *Callitris endlicheri*, *Eucalyptus blakelyi* and *Eucalyptus macrorhyncha* are common (for example, White Gums Lookout).
5. eucalypt woodland: characterised by damp, cool southerly slopes. Soil derived from tuffs, breccias, trachyte and basalt rocks. Vegetation dominated by *Eucalyptus bridgesiana*, *Eucalyptus macrorhyncha* and *Eucalyptus albens*. Understory includes *Xanthorrhoea glauca* ssp. *augustifolia*, *Indigofera australis* var. *australis* and various herbs grasses and orchids (for example, Mount Exmouth).
6. heathland: occurs on dry, rocky exposed peaks and slopes with skeletal soil. Substrate is exposed to the elements and lack of water is common. Vegetation occurs as low shrubs including *Acacia cultriaformis*, *Cryptandra amara*, species of *Phebalium*,

*Kunzea* and *Platysace*. Native grasses are also present. Localities include summits of Mount Scabilon and Bluff Mountain (Plate 3.2); and

7. trachyte outcrops: vegetation occurs as stunted low shrubs on exposed rock surfaces such as lava flows, plugs and domes where soil occurs in pockets. Exposure to the elements is extreme. Vegetation includes *Acacia cultriformis*, *Phebalium* spp., *Micromurtus sessilis* and *Cheilanthes tenuifolia*.

The level of differentiation of vegetation communities in the present-day Warrumbungle Complex contrasts with the diversity of vegetation communities that existed both prior to, and over the period of, volcanic emplacement (Table A.1). As mentioned in Appendix A, the Tertiary pollen record is largely that of rainforest assemblages (Martin 1978). Despite this, Holmes *et al.* (1982) reported in their study of mid-Miocene fossil *Eucalyptus* and pollen from the Chalk Mountain diatomite north of the main Warrumbungle volcanics, that a suitable environment must have existed for the development of *Eucalyptus*, and other scleromorphic plants, in Early Tertiary time. This conclusion was based on leaf venation and fruit development of *Eucalyptus bugaldiensis* and microflora fossilised in diatomite at Chalk Mountain (Figure 1.2). Given that the preservation of fossil pollen and plant remains usually relies on the presence of lakes, swamp and bogs, and that rainforest species rely on abundant water, it is not surprising that plants adapted to drier and harsher conditions are not well represented in the fossil record. Given the vagaries of pollen preservation, especially in volcanic regions where vegetation may be rapidly destroyed by eruptions, emphasis is placed on the palaeoenvironmental interpretation of diatomite deposits associated with the lavas of the Warrumbungle Complex in an effort to refine the palaeoenvironmental record available for the mid-Miocene in the study area. Such investigations are valuable due to the versatility of diatoms for such studies (Section 3.9.1.2), and the fact that the diatoms were deposited contemporaneously with volcanic activity.

### 4.3.2 Faunal diversity

The study area is a refuge for over 19 native mammal species and more than 50 different reptile species. Over 180 native birds have been recorded, along with a substantial feral animal population including foxes, goats, pigs and cats. Fox (1996) has provided a comprehensive checklist of animal species found in the area including a discussion on preferred habitats and distribution. In addition to the present-day distribution of animal species, regional archaeological evidence (for example, Tambar Springs, 80 km east of Coonabarabran) indicates that populations of megafauna, including diprotodons and various species of giant macropods, inhabited the area until at least 25 000 BP ago.

## 4.4 Regional landscape development

The Warrumbungle Complex lies partly on the western edge of the Gunnedah Basin and partly in the Coonamble Basin. The Gunnedah Basin contains up to 1200 m of marine and non-marine Permian and Triassic sediments resting unconformably on Early Permian and ?Late Carboniferous silicic and mafic volcanic rocks (Tadros 1993). Basic intrusions of Mesozoic and Tertiary igneous rocks are associated with the emplacement of the Garrawilla Volcanics complex and the Liverpool, Warrumbungle and Nandewar Complexes in the central, southwest and northwest of the Basin respectively (Figure 4.1). A general history of the Warrumbungle region is presented in Table 4.1 and discussed in the following sections.

### 4.4.1 Pre-volcanic setting

The Warrumbungle Complex was emplaced through the mid-Jurassic Purlawaugh Beds and the Late Jurassic Pilliga Sandstone (Table 4.1). These beds surround the volcanic shield, but are best exposed in the southeast, east and northern flanks. To the west, the Jurassic geology is obscured by Quaternary alluvium (gravel, sand, silt and clay). Jensen (1907) suggested that the Warrumbungle area was probably submerged in Carboniferous times, being the western margin of the sea which stretched to the New England region.

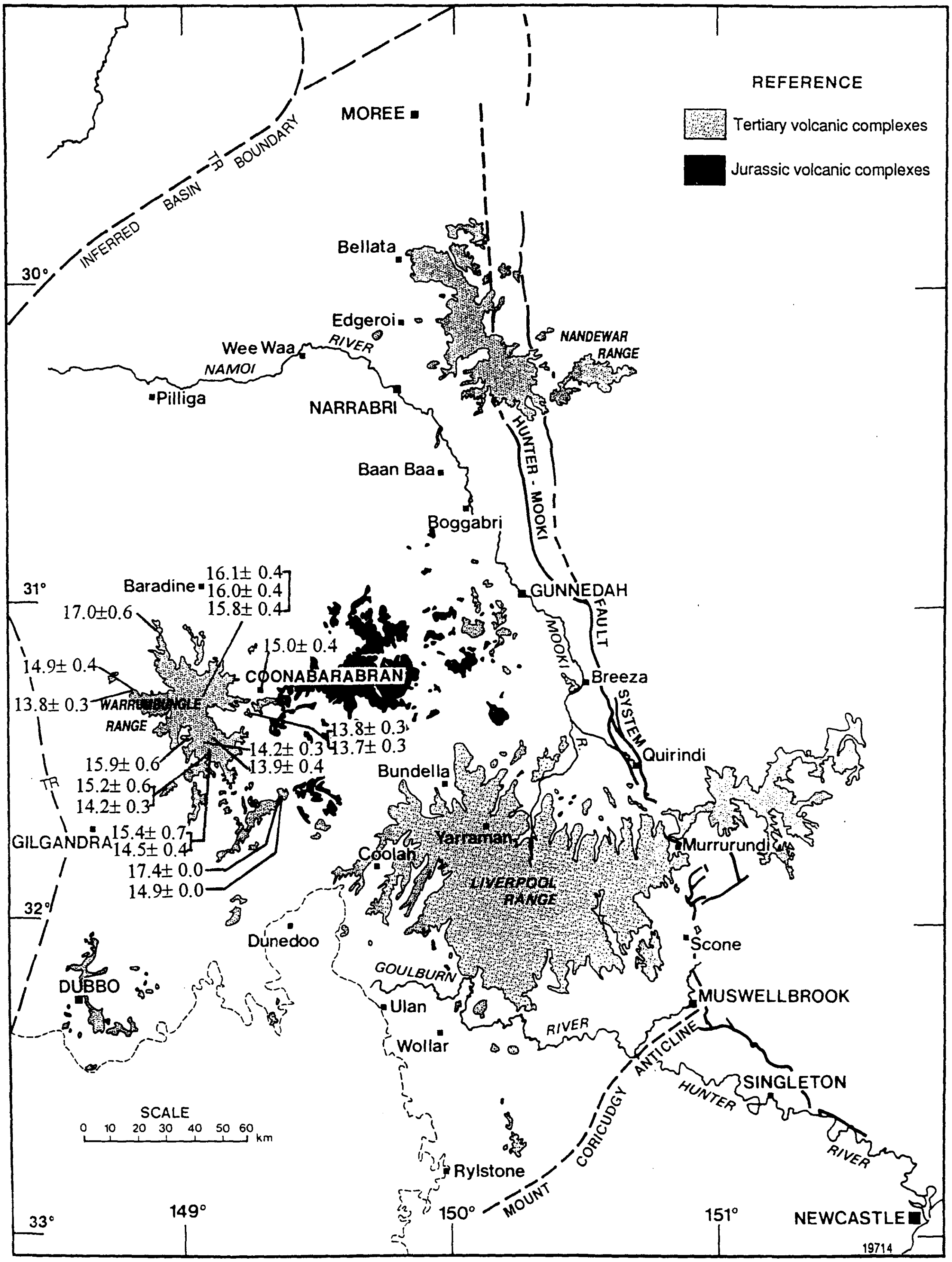



*Figure 4.1*: Tertiary and Jurassic volcanic complexes (shaded) of the Gunnedah Basin (dashed line). Note the broad northeast and/or north-northwest alignment. The location of K-Ar ages for volcanics in the Warrumbungle Complex are also shown. *Source*: Modified from Tadros 1993.

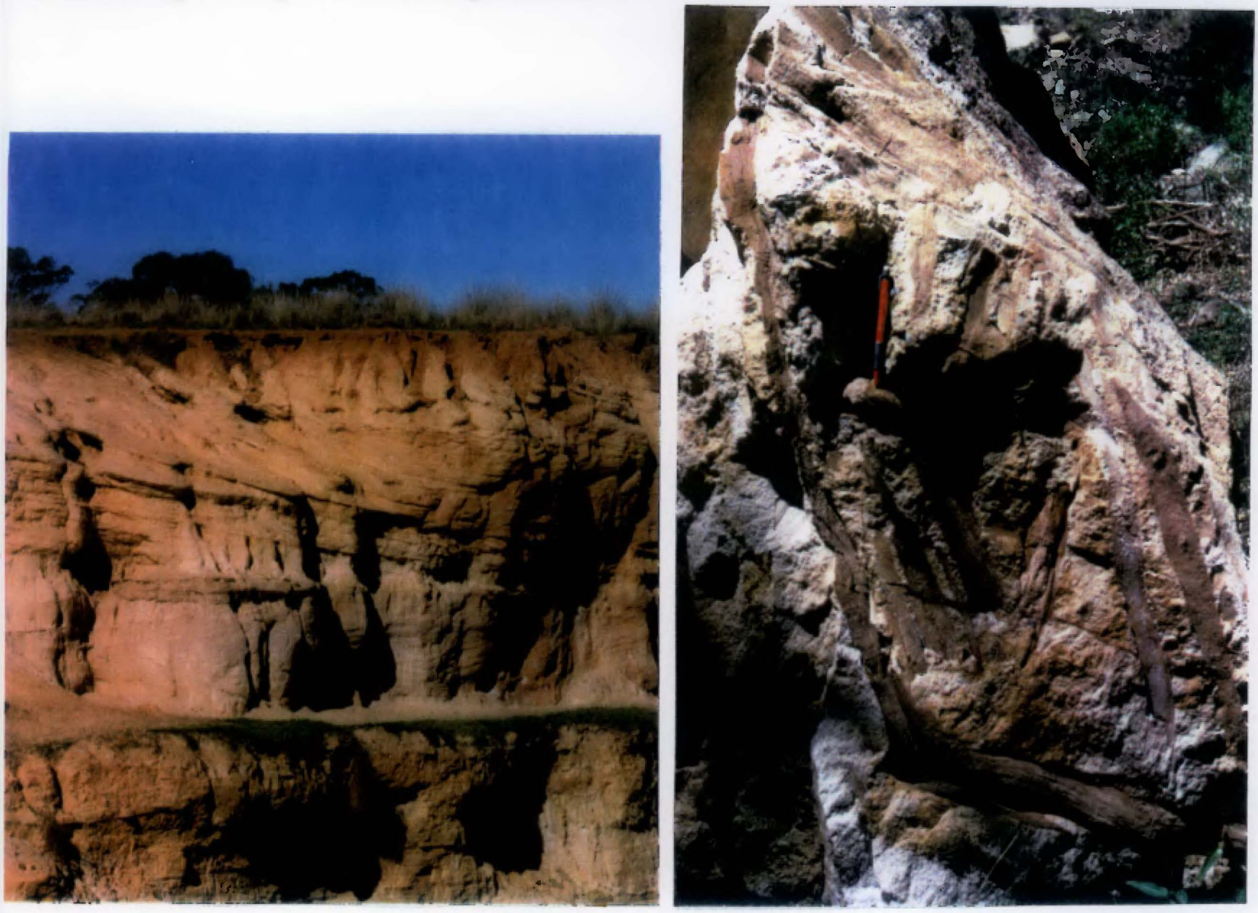
*Table 4.1*: General geological and geomorphological history of the Warrumbungle Complex and surrounding area.

| Period | Processes/ geology/ geomorphology | Reference |
|---|---|---|
| Late Miocene-Present | Subsequent erosion of volcanic landscape under increasingly semi-arid and later, an oscillating Quaternary climate. Alluvium is deposited west of the shield and along stream courses in response to major eustatic fall in sea-level during the Late Miocene. | Chapter 6; Vail *et al.* 1977. |
| | Erosional unconformity | Arditto 1982. |
| Mid-Miocene | The Warrumbungle Complex becomes active around 17.4 Ma, with constructive volcanism the dominant process. Regional geomorphic adjustments ensue. Eruptions cease after 3.6 Ma of activity. | Wellman and McDougall 1974a, b; Jones 1986; Chapter 6. |
| | Erosional unconformity | Arditto 1982. |
| Late Jurassic-mid-Tertiary | The Pilliga Sandstone formed in the shallow lakes of the Eromanga Basin which now forms the Great Artesian Basin and consist of claystone, quartzitic sandstone and conglomerate. These beds developed into a series of broad valleys and flat-topped ridges. A break in drainage regime during the Late Cretaceous, resulted from the warping in the vicinity of the Great Divide (Figure 1.1). The Liverpool Volcano was active 50 km to the east from 40-38 Ma and 35-32 Ma. During the Cretaceous, the sea invaded from the north, affecting base level. | Jensen 1907; Vail *et al.* 1977; Wellman and McDougall 1974a; Ollier 1986. |
| | Erosional unconformity | Arditto 1982. |
| Mid-Jurassic | Purlawaugh Beds deposited. Dinosaurs roam freely. Shale, lignite, conglomerate, claystone, lithic sandstone accumulate as the Purlawaugh Beds. Mullaley area affected by Garrawilla Volcanics. | Kenny 1929. |
| Early Jurassic | Coonamble Basin, Oxley Basin. Area dominated by shallow freshwater lakes containing sands and muds which later form the basal part of the Purlawaugh Beds. Garrawilla Volcanics erupted. | Bean 1969; Duggan and Knutson 1993. |
| | Erosional unconformity | Dulhunty 1965. |
| Triassic | Napperby Beds and Digby Formations. | Tadros 1993. |
| Permian | Black Jack and Watermark Formations are interbedded with coal deposits. | Tadros 1993. |
| Carboniferous | Gunnedah Basin develops. Region formed the west coast of a Paleozoic landmass. Numerous crustal fractures. | Jensen 1907; Martin and Tadros 1990. |
| | Erosional unconformity | Arditto 1982. |
| Early Paleozoic | Undifferentiated Early Paleozoic metasedimentary basin with associated granites. | Arditto 1982. |

Between Carboniferous and Jurassic times, a period of uplift occurred and by Jurassic time much of the eastern portion of Australia was covered by large expanses of shallow, freshwater lakes (Duggan and Knutson 1993). In the Warrumbungle area, these lakes formed in what is now known as the Coonamble Basin. By the end of mid-Jurassic time, the Purlawaugh Beds were deposited. These beds are composed of conglomerate with white quartz pebbles, fine, well sorted sandstones, sandy shales and clay shales. Calcareous beds are present within these groups but form a very small portion of the Purlawaugh Beds (Kenny 1929). Outcrop of Purlawaugh Beds are infrequent in the study area, and those that are present have been tilted by the emplacement of mid-Miocene volcanics (for example, West Spirey Creek).

By the end of the Jurassic the quartzitic Pilliga Sandstone had been deposited. These beds unconformably overlie the Purlawaugh Beds and are composed mainly of lenticular beds of quartz-rich sandstone, the majority of which are characterised by planar, low angle crossbedding, although massive units are also evident. Plate 4.2 shows bedding characteristics. Cross-bedded units (Plate 4.2a) are cut by massive units that commonly contain pebble layers above the lower scour surface. Plate 4.2b shows fossil branches found by the author, preserved within the sandstone.

The Pilliga Sandstone was formed as the shallow Jurassic lakes were cut by deeper channels carrying pebbles, sand and mud eroded from surrounding areas of higher elevation. Arditto (1982) suggested that the environment immediately preceding the deposition of the Pilliga Sandstone was one of relatively low energy conditions which resulted in channel fill, floodplain and backswamp deposits of fine grained sandstones, shales and flint associated with the kaolinitic 'flint clays', carbonaceous shales and coal of the Purlawaugh Formation (Arditto 1982). In some areas (for example, Mullaley, 65 km east-northeast of Coonabarabran), volcanic outbursts (such as the products of the Garrawilla Volcanics) through the Purlawaugh sediments were not uncommon. Martin and Tadros (1990) postulated that the Jurassic breakup of Gondwana re-initiated activity in crustal fractures which formed in the Late Carboniferous to Early Permian and provided conduits for the Jurassic eruptions of the Garrawilla Volcanics and associated intrusions. These eruptions appear to have been similar to those that formed the Warrumbungle Complex and its neighbours the Nandewar and Liverpool Ranges.



(a) (b)

*Plate 4.2:* (a) Planar crossbedded Pilliga Sandstone exposed in sunken quarry on the western flank of the Warrumbungle shield (GR785272). (b) Fossilised branches or logs replaced by silica or ?siderite-goethite in a sandstone boulder in the Warrumbungle National Park (GR888342). The red pencil is 14 cm long. *Photos*: A. Timmers.

By Late Jurassic time, the Pilliga Sandstone was uplifted to form a low tableland (Jensen 1906). This tableland was dissected to form flat topped mountains and deep gorges, probably by humid landform processes. Evidence of this humid environment is preserved by macrofossils of rainforest flora (Mullins and Martin 1976), fossil fish (Hills 1946), eucalypt leaf impressions, pollens (Holmes *et al.* 1983) and diatomite (David 1896; Fairley 1977; Thomas and Gould 1981a) sandwiched between the Jurassic sandstone and lavas and pyroclastic materials of mid-Miocene age. By contrast, Jensen (1906) suggested that this erosion was caused by arid agencies. Support for the proposition that the climate was becoming increasingly seasonal and semi-arid may come from evidence of the existence of gallery rainforest and widespread sclerophyll vegetation found through diatomological and palynological investigations undertaken in this study (Section 6.7).

In general, the upper layer of the Pilliga Sandstone forms the present day surface of erosion to the east and north of the Complex, as well as in the centre of the complex, where volcanic material has been eroded to expose basement rock. To the west, the sedimentary basement is largely obscured by Quaternary alluvium. Little is known of the thickness variation in surface exposures of sandstone, although Kenny (1929) recorded a maximum thickness of 153 m in the Coonabarabran area. Arditto (1982) has reported a general subsurface trend in thickening to the northwest as the unit extends into the Surat Basin. By Early Miocene time, the Warrumbungle area was possibly a mature sandstone landscape with a relief of 30 to 60 m, similar to the type of present-day sandstone landscape that occurs to the north of the Complex (Duggan and Knutson 1993).

During the Late Eocene (40-38 Ma), volcanic activity formed the eastern Liverpool Ranges and Early Oligocene activity (35-32 Ma; Wellman and McDougall 1974b) formed the western Liverpool Ranges. Topographic and geochemical differences suggest two distinct volcanic sources may have existed for these groups. The Liverpool Range volcanics, like the Warrumbungle Complex, rest on the Jurassic Pilliga Sandstone. The western part of the Liverpool Range forms a plateau surface with a present height of 800 m ASL, rising 300 m above the surrounding plain. This plateau joins the eastern end of the Warrumbungle Range (Schön 1989; Figure 1.2).

### 4.4.2 Mid-Miocene volcanism

Volcanism began in the Warrumbungles 17.4 ± 0.0 Ma and continued until 13.7 ± 0.6 Ma (Jones 1986; Figure 4.1). Duggan and Knutson (1993) suggested that early eruptions consisted of numerous explosive eruptions throwing out huge volumes of trachytic and pyroclastic rocks from numerous centres that blanketed the landscape (for example, Plate

3.4) and formed several short, thick trachyte flows. In addition, thick blankets of coarse tuffs and breccias were deposited over large areas around their vents. Deeper piles of tephra interbedded with lavas formed the flanks of the shield and were responsible for damming and altering drainage (Section 3.8.1). Minor volcanic activity probably preceded the formation of the shield; and geomorphic evidence obtained in this study supports this probability that this may be the case (Section 6.3.3). Further detail on eruptive sequences and shield development in the literature is lacking. There is no accurate estimate of original shield height, volume, structural development or drainage evolution, because no geomorphic study of the shield has been undertaken. As such, this study is designed to fill this gap in the evidence for the eruptive and geomorphic (and to some extent, the structural) development of the Warrumbungle Complex during and after emplacement.

#### 4.4.2.1 Rock types and distribution, geochemistry and petrogenesis

Duggan and Knutson (1991) have summarised the available information on rock types and distribution in the Warrumbungle Complex, reporting that the abundance of rocks is strongly bimodal with maxima in the hawaiite-mugearite and trachyte ranges. Alkali and benmoreite are extremely rare. Hawaiite and mugearite dominate the outer flanks of the shield, particularly the northern and southern areas. Relatively more mafic rock occurs in shield building sequences in the central eastern and western areas. Duggan and Knutson (1991) also reported the major and trace element analysis for the full spectrum of rock compositions, concluding that the mafic rocks of the Warrumbungle Complex are broadly similar to equivalent rocks in other eastern Australian central-type volcanoes.

Trachyte is the dominant rock type in the shield centre and the composition of the leucocratic peralkaline trachyte is to some extent reflected in the mode of outcrop which forms most of the major domes, plugs and dykes (Duggan and Knutson 1991). The crustal configuration, as interpreted through the location and distribution of volcanic vents in the Warrumbungle Complex, is explored in Section 6.4 for the purpose of determining constraints on the structural control of geomorphic evolution.

Hockley (1973, 1974) investigated the spectrum of salic magmas from the Warrumbungle Complex and defined three distinct rock lineages, these consist of:

1. a sodic undersaturated alkali basalt-hawaiite-mugearite-trachyte lineage;
2. a mildly potassic hypersthene normative trachybasalt-trachyandesite-tritanite-trachyte lineage; and
3. a mildly potassic nepheline normative trachyandesite-high iron trachyandesite-nepheline bearing trachyte-phonolitic trachyte lineage.

Such differentiation trends are not uncommon in volcanoes. Parícutin Volcano in Mexico provides evidence of differentiation trends, although over a much shorter time span than the Warrumbungle Complex. Over nine years, continuously erupted lavas at Parícutin changed progressively from olivine basalt to pyroxene andesite (Williams and McBirney 1979). In the Warrumbungle Complex, Hockley (1973, 1974) attributed the above rock lineages to high level, low pressure crystal fractionation high level magma chambers. The number of high level magma chambers envisaged by Hockley is not clear, but it is difficult to see how both oversaturated and undersaturated trends could be produced in a single magma chamber at essentially the same time (MacKellar 1980). While Hockley used differentiation trends to account for the diversity of rock types, Flood (1996 pers. comm.) and Wilkinson (1996 pers. comm.) have indicated that these trends be treated cautiously. This is because new geochemical data do not support the concept of differing petrogenetic lineages in the volcano (Duggan 1997 pers. comm.). For example, only subtle differences exist between nepheline and quartz normative mafic rocks and no evidence has been found to support the concept of differing petrogenetic lineages as proposed by Hockley (1973, 1974). Instead, "... a concept of a continuous spectrum of rock compositions straddling the thermal divide represented by the critical plane of silica undersaturation with no .pm0 systematic variation among K/Na ratios, Mg/Fe ratios and the level of silica saturation is favoured ..." (Duggan and Knutson 1991). Obviously, more geochemical data is required to define the petrological development of the Warrumbungle Complex, with studies now in process (Duggan 1997, pers. comm.).

The petrogenetic evolution of the Warrumbungle Complex has traditionally been based on fractional crystallisation processes, with the evolution of volcanic rock series extending from mafic to felsic compositions. Duggan and Knutson (1991) reported that there are many mineralogical and geochemical features consistent with such fractional models in the Warrumbungle Complex, including the close geochemical coherence of many incompatible elements, from mafic through to felsic rocks, and the chemical variation trend among the major, minor and trace elements in the rocks and their component minerals. However, recent studies of other eastern Australian central-type volcanoes question the importance of the traditional role of crystal fractionation. In the nearby Nandewar Complex (Figure 4.1), Stolz (1985) questioned the importance of such processes, because he found it inadequate to explain the spectrum of compositions observed. Similarly, Middlemost (1985) found that fractionation alone was not suitable as a process for the rock lineages in the Canobolas Complex, instead preferring a degassing concept; and Ewart (1981) considered that many of the peraluminous rhyolites of the Tweed Volcano were products of crustal melting.

The difficulties of applying crystal fractionation processes to the evolution of rocks in the Warrumbungle Complex include the following aspects which are discussed by Duggan and Knutson (1991):

1. parent magma;
2. relative rock volumes;
3. fractionation modelling; and
4. isotope data.

#### 4.4.2.2 The age of the Warrumbungle Complex

Jensen (1907) suggested that the earliest eruptions in the Warrumbungle area occurred in the Eocene and continued into the Pliocene. However, isotopic dates indicate that volcanic activity in the Warrumbungle shield commenced and ceased in the Miocene period. Several workers have undertaken isotopic dating on the Warrumbungle Complex.

Potassium-argon dating of the shield give a mid-Miocene age with dates ranging from 16.6 ± 0.6 Ma to 13.5 ± 0.4 Ma. These dates have been recalculated by Jones (1986) based on new decay constants and give an age range of 17.4 ± 0.0 to 13.7 ± 0.3 (Table 4.2). For comparative purpose, all ages referred to will be those of Jones (1986; although it is unusual for K-r ages to contain no error. A discussion on the limitations of isotopic dating appears in Appendix C, along with the results of attempts to undertake dating in this study).

Wellman and McDougall (1974a) have suggested a possible southerly migration with time within the Complex (Section 2.2.2), and this element is investigated with the view to placing an age constraint on volcanic processes and materials across the shield. However, it must be remembered that volcanic landscapes do not necessarily obey the laws of superposition and stratigraphic continuity. Nevertheless, isotopic dates can be useful in the interpretation of landscape elements by placing an age constraint on processes and materials. While isotopic dating was unsuccessful in this study (Appendix C), the ages supplied here will be used to place the evolution of parts of the Warrumbungle Complex in a chronological framework.

The oldest dated flows in the Warrumbungle Complex occur at the northern and southeastern extremities of volcanic outcrop. At Toogolan (Figure 4.1), basalt has been dated at 17.4 ± 0.0 Ma and occurs in association with the valley of the Castlereagh River. A nearby outcrop of similar lithology has been dated at 14.9 ± 0.0 Ma. This suggests that volcanism occurred over almost the total time span in the southern part of the shield. In the north, at Looking Glass Mountain, hawaiite basalts have been dated at 17.0 ± 0.6 Ma. In the central part of the shield, three flows at Mount Woorut give ages of 16.1 ± 0.4 to 15.8 ± 0.4 and a plug 15 km to the south gives a similar age of 15.9 ± 0.6 Ma (Jones 1986). Measurements on alkali olivine basalts from the eastern part of the shield on the Oxley Highway between Coonabarabran and Gilgandra at Jack Halls Creek give ages of 13.8 ± 0.3 and 13.7 ± 0.3 Ma. Outcrop of the same age occurs at Twin

*Table 4.2*: Potassium[40] -argon[40] ages of the Warrumbungle Complex.

| Sample | Age (Ma) | Age (Ma) Jones 1986 | Rock type | Locality/altitude | Latitude °S | Longitude °E | Reference |
|---|---|---|---|---|---|---|---|
| GA1374 | 13.8 ± 0.3 | 14.2 ± 0.3 | Basalt/olivine | Belar | 31° 27.5' | 149° 00.5' | Dulhunty and McDougall 1966 |
| GA1375 | 13.5 ± 0.4 | 13.9 ± 0.4 | Basalt/olivine | Wallamburrawang | 31° 23.0' | 149° 15.5' | Dulhunty and McDougall 1966 |
| GA1957 | 15.5 ± 0.6 | 15.9 ± 0.6 | Trachyte | ?Mt. Naman | 31° 22.16′ | 148° 57.2′ | McDougall and Wilkinson 1967 |
| GA2910 | 14.8 ± 0.6<br>14.1 ± 0.4 | 15.2 ± 0.6<br>14.2 ± 0.3 | Basalt<br>Basalt | Parramatta Mountain | 31° 46.3' | 149° 05.5' | Wellman and McDougall 1974b |
| GA2912 | 15.0 ± 0.7 | 15.4 ± 0.7<br>14.5 ± 0.4 | Basalt | Below GA2910 | 31° 26.2' | 149° 05.4' | Wellman and McDougall 1974b |
| GA2931 | 13.3 ± 0.3 | 13.7 ± 0.3 | Andesite | Near Jack Halls Creek | 31° 23.0′ | 149° 17.0′ | Bennett *et al.* 1974 |
| GA2932 | 16.6 ± 0.6 | 17.0 ± 0.6 | Basalt | Looking Glass Mountain | 31° 05.7' | 148° 52.2' | Wellman and McDougall 1974b |
| GA2933 | 14.5 ± 0.4 | 14.9 ± 0.4<br>15.0 ± 0.4 | Trachyte<br>Basalt | 900 m northwest of Twin Peaks. 1.25 km south-west of Coonabarabran Post office | 31° 18.0′<br>31° 17.0′ | 148° 52.0′<br>149° 17.0′ | Bennett *et al.* 1974 |
| GA2934 | 13.4 ± 0.3 | 13.8 ± 0.3<br>13.8 ± 0.3 | Basalt<br>Trachyte | Near Jack Halls Creek. 900 m NW Twin Peaks | 31° 23.0′<br>31° 18.0′ | 149° 17.0′<br>148° 52.0′ | Bennett *et al.* 1974 |
| GA3457 | 15.6±0.4<br>13.8±0.3 | 16.0 ± 0.4 | Trachyte | Woorut Mountain 970 m | 31° 16.8' | 149° 04.2' | Wellman and McDougall 1974b |
| GA3458 | 15.7±0.4 | 16.1 ± 0.4 | Basalt | Woorut Mountain 1120 m | 31° 16.3' | 149° 04.8' | Wellman and McDougall 1974b |
| GA3459 | 15.4±0.4 | 15.8 ± 0.4 | Trachyte | Woorut Mountain 1200 m | 31° 16.5' | 149° 03.8' | Wellman and McDougall 1974b |
| K6 | 17 | 17.4 ± 0.0 | Basalt | Toogolan | 31° 42.27′ | 149° 17.35′ | Dulhunty 1972 |
| K7 | 14.5 | 14.9 ± 0.0 | Basalt | Piambra | 31° 37.45′ | 149° 22.58′ | Dulhunty 1972 |

Peaks at a similar latitude, but on the western side of the shield. In the south, three basaltic flows at Belar and Wallumburrawang Creeks yielded ages of 14.2 ± 0.3 and 13.9 ± 0.4 Ma respectively. Slightly older ages of 15.4 ± 0.7 to 14.2 ± 0.3 Ma are given by two flows from the Parramatta Mountains further to the south. Similar ages of 15.0 ± 0.4 and 14.9 ± 0.4 Ma occur to the east near Coonabarabran and on the western side of the shield near Twin Peaks respectively (Jones 1986).

### 4.4.3 Subsequent erosion of the Warrumbungle Complex

Volcanic activity ceased in the Warrumbungle Complex about 13 ± 0.3 Ma ago. Subsequent erosion has removed much of the softer basaltic rock and pyroclastic materials, exposing evidence of earlier phases of volcanism in the form of resistant trachytic constructional remnants such as lava flows, domes, plugs and dykes (Figure 4.2; Plate 4.1b). The material eroded from the shield was re-deposited on valley floors and reworked onto the plains surrounding the shield to the west, producing rich, dark basaltic soils onto the plains and deep alluvial deposits along water courses.

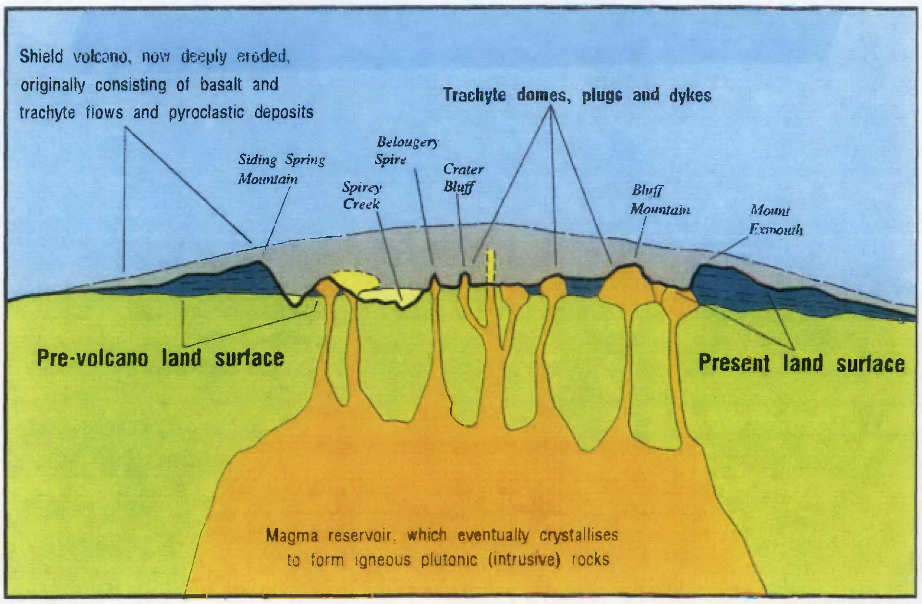



*Figure 4.2*: Schematic cross-section of the Warrumbungle Complex, showing how erosion has stripped away a large part of the original shield. *Source*: Duggan and Knutson 1993.