CHAPTER 1

INTRODUCTION

1.1 AIMS

The main aim of this thesis is to explain the geomorphic history of the Armidale-Uralla region of New South Wales, Australia. Subsidiary aims are to examine the validity in the Armidale-Uralla region and adjacent areas, of several theories and concepts of landscape development; and to set the geomorphic history of the Armidale-Uralla region in the wider context of east Australian landform evolution.

The present landscape of the Armidale-Uralla region is much older than the Pleistocene glaciated landscapes of much of Europe and North America, and the volcanic landscapes of western Victoria and parts of north Queensland. The most recent origins of the Armidale-Uralla landscape are in the Oligocene-Miocene basalt extrusions, and some landforms may be much older than this. There are added difficulties in studying landform evolution in old landscapes. For example the older a landscape, the greater the chance of initially similar forms being modified to different degrees by subsequent processes, and the greater the possibility that landforms that are similar today may have been initially different from each other. Such problems indicate that landscape interpretation must be based on detailed examination of the landforms and geology of the area being studied, so that any conclusions have a solid basis of fact and a minimum of conjecture.

1.2 STUDY AREA AND SCALES OF INVESTIGATION

The main study area is the New England plateau in the Armidale-Uralla region, New South Wales (Map 1; Figures 1, 2). The Armidale-Uralla region consists of undulating plateau country on either side of the Main Divide. The Main Divide is the major east Australian drainage divide between coastal and inland rivers. In the Armidale-Uralla region the Main Divide separates the tributaries of east-flowing coastal streams from the west-flowing tributaries of the Gwydir River (Map 2).

The City of Armidale, with a population of almost 19,000, and Uralla township with a population of just over 5,000 (1981 Census figures), are service centres for a principally rural economy, based on beef and sheep production with some dairy farming and fruit growing.

The study of landscape development undertaken in this thesis is on three main scales.

1. Detailed field mapping of geology and surface materials onto 1:25,000 topographic base maps. This mapping programme covered an area of 420 km^2 between Armidale and Uralla, here referred to as the Armidale-Uralla region.
2. The New England plateau and eastern scarp and gorges beyond the Armidale-Uralla region were investigated by air-photo interpretation, literature search and field trips to selected areas.
3. The east Australian highlands and adjacent coastal plain, and the depositional basins to the west of the eastern highlands, were investigated by literature search.

The modern landscape in the Armidale-Uralla region is a result of past tectonic, volcanic, and fluvial erosion/deposition episodes, not all the evidence for which is preserved within the region itself. The Armidale-Uralla landscape is erosional with only minor areas of deposition. Areas of deposition outside this region, such as the upper Darling basin to the west,

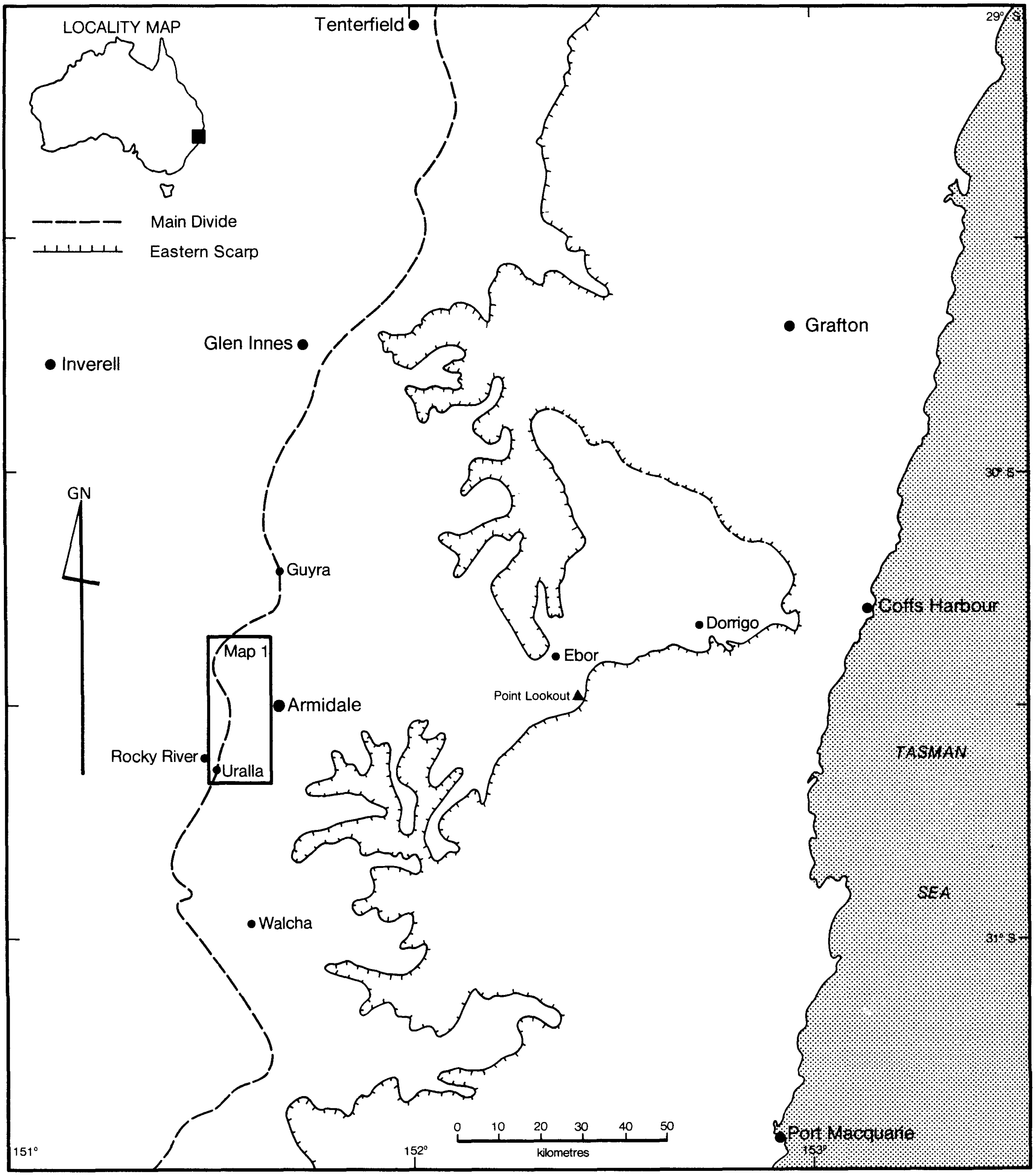

Figure 1. *The New England area, showing the convoluted eastern scarp, the Main Divide, and the location of the Armidale-Uralla study region shown in Map 1.*

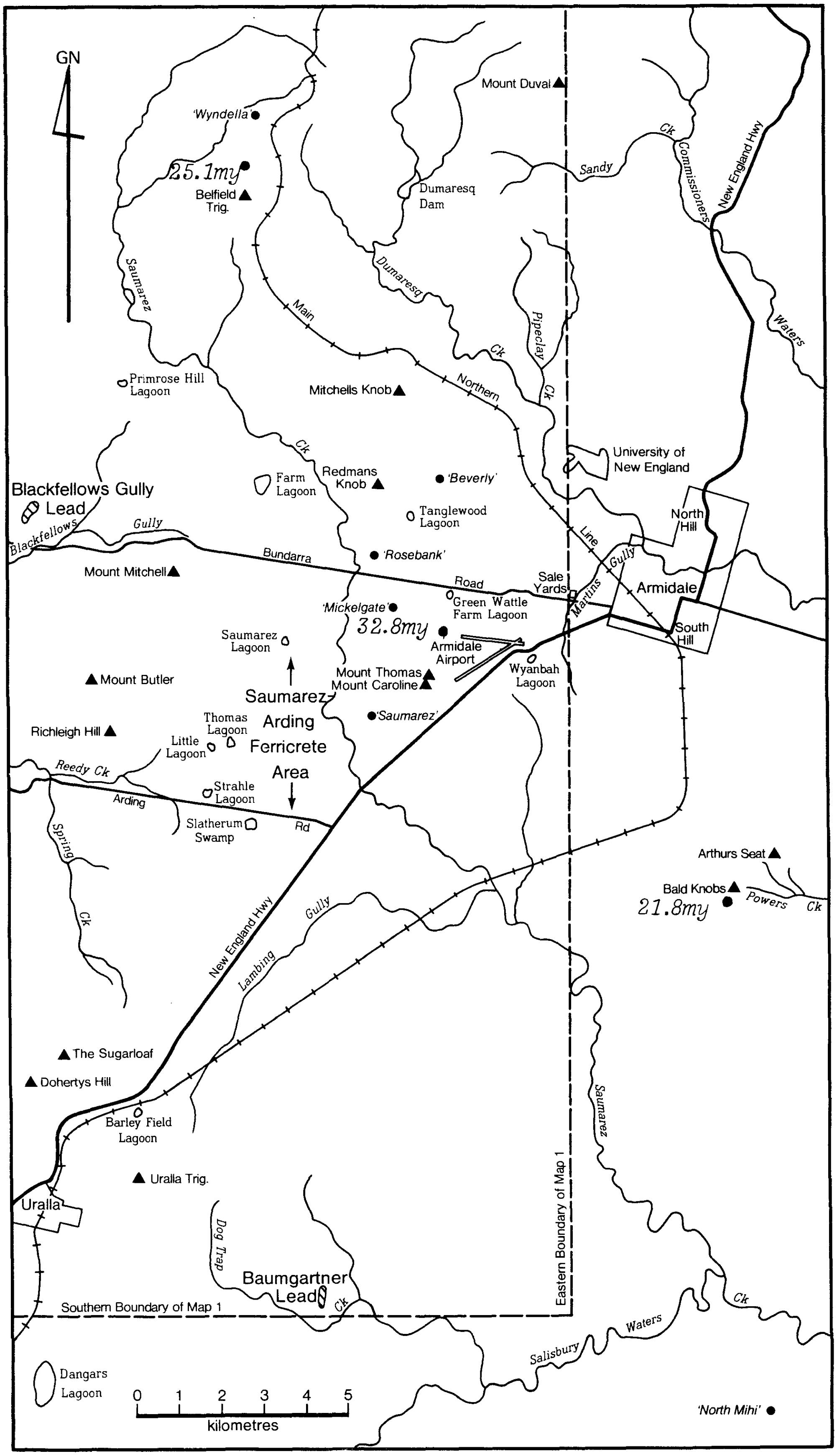

Figure 2. Localities in the Armidale area. Dashed lines show the margins of Map 1. Figure 2 also shows locations and ages of dated basalts along a NW-SE line through Belfield Trig., Armidale Airport and Bald Knobs.

have preserved a sediment record that reflects changes in erosion intensity at the sources of sediment in the eastern highlands. In conjunction with detailed field analysis in the Armidale-Uralla region, these inland sediment records help explain geomorphic development in the Armidale-Uralla region. Conversely, some of the conclusions about landform evolution in the Armidale-Uralla region, based on detailed fieldwork, are applicable to areas outside the immediate Armidale-Uralla region.

1.3 DATA SOURCES AND FIELD MAPPING TECHNIQUES

Subsurface and mining data were obtained from four main sources.

1. Bore logs for water bores. These were supplied by Watermin Drillers Limited, Orange; CRA Exploration Limited, who extracted bore logs from records at the Water Resources Commission, Sydney; and several landholders in the Armidale-Uralla region.
2. From inspection of gold mine shafts and waste heaps identified during fieldwork.
3. By reference to contemporary mining reports and newspaper articles.
4. From discussions with Arnold Goode, Uralla landholder and historian, who has undertaken detailed research into the gold mining era in the Uralla-Rocky River area.

Surface geology data used in compiling Map 1, and information about slope angles, soils and drainage, was collected by detailed field traverses. Air photographs, the 1:250,000 Dorrigo-Coffs Harbour geological mapsheet, and topographic maps at 1:25,000 and 1:31,680 scales were used during the preliminary stages of fieldwork, but all geological boundaries in Map 1 were drawn in the field, following field traverses either on foot or in a 4-wheel drive vehicle.

Field mapping was at 1:25,000 scale. The same scale was used for final presentation (Map 1). To enable field mapping on 1:25,000 scale, the 1:31,680

Armidale (9236-IV-N) and Gostwyck (9236-IV-S) topographic sheets were enlarged photographically, and joined to the 1:25,000 Dumaresq sheet (9237-III-S). Grid references in this thesis use the standard grid numbers for these sheets, as detailed in the margins of Map 1.

Geological outcrops and boundaries were initially located by parallel field traverses. Once located, the boundaries were traced by walking or driving the contact. This method minimised the chance of missing minor geological outcrops, a possibility if boundaries are followed without first traversing the area.

Location of outcrops and boundaries of some geological materials was aided by their characteristic or distinctive form. For example, basalt margin slopes in the Armidale-Uralla region are usually convex-concave, with the slope at the basalt margin being steeper than the slope on the basalt proper, and much steeper than the slope off the basalt. Because basalt margins and summits in the Armidale-Uralla region are often steep and rocky, they are difficult to cultivate for agriculture and have frequently remained more heavily timbered than surrounding areas. This can also assist in their identification.

Another aid in the preliminary identification of basalt outcrops is the fact that certain species of eucalypt such as Yellow Box (<u>Eucalyptus melliodora</u>) and Stringy Bark (<u>Eucalyptus laevopinea</u>), grow preferentially and more vigorously on basalt. Even from a distance of several kilometres, trees on basalt are often appreciably greener and taller than those off the basalt.

Colour of outcrop or soil is another characteristic that aided in locating outcrops in the Armidale-Uralla region. For example silcrete is often highly visible in in the field because of its characteristic white to pale grey colour. Further, because of the drought in the Armidale-Uralla region during much of the period of fieldwork for this thesis, grass cover was usually so sparse that even minor outcrops were visible.

Such aids to field mapping can increase the speed of mapping, but have the disadvantage that over-reliance on them can result in small, unusual or uncharacteristic outcrops being missed during fieldwork. Not all outcrops conform to expected patterns of location, form, colour or size. For this reason generalisations about outcrop characteristics must be used in conjunction with, rather than as a substitute for detailed field traverses.

An example follows of how this worked in practice. Map 1 shows the location of many deposits of ferricrete and silcrete in the Armidale-Uralla region. These deposits were located by field traverses that were not uniformly spaced throughout the study area. Rather, the traverse pattern varied depending on several factors, one important factor being parent rock material. For instance in the early stages of mapping for this thesis it became evident that granitic parent rock did not usually contain inliers of other geological materials. In contrast, basalt parent rock frequently contains minor inliers and margin deposits of ferricrete and silcrete. As a result traverses over areas of granitic rock were spaced more widely than the traverses over basalt areas.

Minor outcrops are more likely to be missed if a coarse traverse pattern is used than if the traverse pattern is fine. To avoid this, even areas of apparent geological uniformity, such as areas on granitic rock, were spot-checked by detailed traverses. This ensured that the recording of geological materials was not biased by preconceptions about where certain geological materials were likely to be found.

Geological boundaries in the Armidale-Uralla region are sometimes obscured as a result of the downslope creep of soil and weathered rock. Where this has happened the geological boundary can sometimes be drawn along the up-slope limit of outcrop of the topographically lower material. This is only possible where there is at least some outcrop. In cases where outcrop was completely obscured by regolith or other weathered material, the site was mapped as colluvium. In these instances it was assumed that the contact between the surrounding geological materials lay beneath the colluvium.

1.4 STUDY OF BASALT, FERRICRETE AND SILCRETE

Description and explanation of the distribution, origin and landscape significance of basalt, ferricrete and silcrete, is central to attainment of the aims of this thesis. These three materials overlie rocks of the Sandon Beds, the basement rocks of the Armidale-Uralla region. The main rock types comprising the Sandon Beds in the region are greywacke, chert, jasper, mudstone and some vein quartz.

The extrusion of basalt, and the development of indurated deposits of ferricrete and silcrete during the Tertiary were the first significant additions of new geological material to the Armidale-Uralla region since the intrusion of the New England Batholith in the late Permian, and possible volcanic activity in the Jurassic. Basalt, ferricrete and silcrete are still widespread, and as basalt has been isotopically dated, its age and present topographic position can be used in explaining landscape evolution. The age of ferricrete and silcrete relative to the Tertiary basalt, and the characteristics, present distribution and field relationships of these two materials, give further evidence about landscape evolution. The remnants of the pre-basalt landscape preserved beneath deposits of basalt and silcrete form the basis of my explanations of changes in drainage and in the location of drainage divides during the Tertiary.

Detailed examination of basalt, ferricrete and silcrete is therefore a necessary pre-requisite to the main aim of explaining the geomorphic history of the area. For this reason discussion of the origin, distribution and landscape significance of Tertiary basalt, ferricrete and silcrete in the Armidale-Uralla region form an important part of this thesis.

1.5 THESIS STRUCTURE

Chapters 2-4 examine the petrography of basalt, and the petrography and classification of ferricrete and silcrete in the Armidale-Uralla region. I have devised classification schemes specifically for the ferricrete and silcrete of the Armidale-Uralla region because there is no generally accepted system of classification for either material, and systematic description and explanation of any geological material can only proceed on the basis of clearly understood terminology.

In Chapter 5, I proceed from the basis established in Chapters 2-4, and describe in detail the geomorphology and geology of the Armidale-Uralla region. Chapters 2-5 thus comprise the descriptive and factual foundations of my explanation of the geomorphic history of the Armidale-Uralla region.

Chapters 6-8 discuss the origin, age and landscape significance of basalt, ferricrete and silcrete in the Armidale-Uralla region. The analysis in these chapters is based on the data contained in the earlier chapters, and is a foundation for Chapter 9, in which I discuss the geomorphic history of the Armidale-Uralla region.

Chapter 10 sets the explanation of the geomorphic history of the Armidale-Uralla region into the wider context of east Australian landform evolution, and suggests some directions for future research.

CHAPTER 2

PETROGRAPHY OF BASALT

2.1 THE REGIONAL SETTING

The Cainozoic in eastern Australia was marked by repeated extrusions of basalt, particularly along the higher country of the Main Divide (Figure 3; McDougall and Wilkinson, 1967; Wellman and McDougall, 1974a, 1974b; Stephenson *et al.*, 1980). The amount of basalt remaining along the Main Divide is variable, with some areas still carrying thick mantles while others have minor or no basalt outcrops. The New England area between Walcha and Guyra and east to Ebor and Dorrigo illustrates this variability (Figure 4). In the Walcha and Ebor districts basalt is widespread and prominent (Figure 4). The Armidale region, lying on the Main Divide between Walcha and Guyra (Figures 1, 4) is, in contrast, a region of patchy basalt remnants linking the more extensive basalt deposits that lie to the north and south. East of Armidale, basalt is widespread in the arc running from Point Lookout and Ebor to Dorrigo. These basalt extrusions are truncated in the east by the eastern scarp. Ollier (1982b), suggested that the Ebor and Point Lookout basalts may be parts of a large shield volcano centred on The Crescent, a gabbro outcrop in rugged country east of Point Lookout.

The Armidale area is significant because in comparison with adjacent regions it contains little basalt. One of the problems to be considered in this thesis is whether only a small amount of basalt was extruded in the Armidale area, or whether an originally widespread basalt cover was eroded to remnants in the Armidale area, but preserved in areas to the north, south and

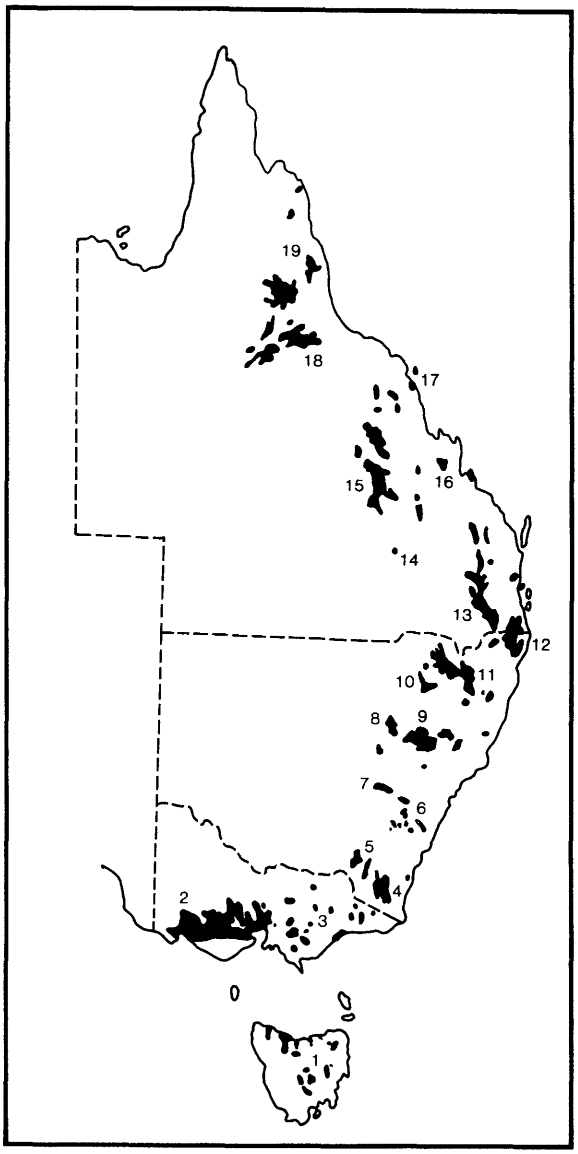

Figure 3. Areas of Cainozoic volcanism in eastern Australia: 1 Tasmania; 2 Newer Volcanics of Victoria; 3 Older Volcanics of Victoria; 4 Monaro; 5 Snowy; 6 Abercrombie; 7 Orange; 8 Warrumbungle; 9 Liverpool; 10 Nandewar; 11 Inverell (Central Province); 12 Tweed; 13 Toowoomba; 14 Roma; 15 Springsure-Clermont; 16 Rockhampton; 17 Hillsborough; 18 Nulla; 19 McBride-Quincan. These volcanic provinces approximately correspond to the eastern highlands of Australia (from Ollier, 1978a).

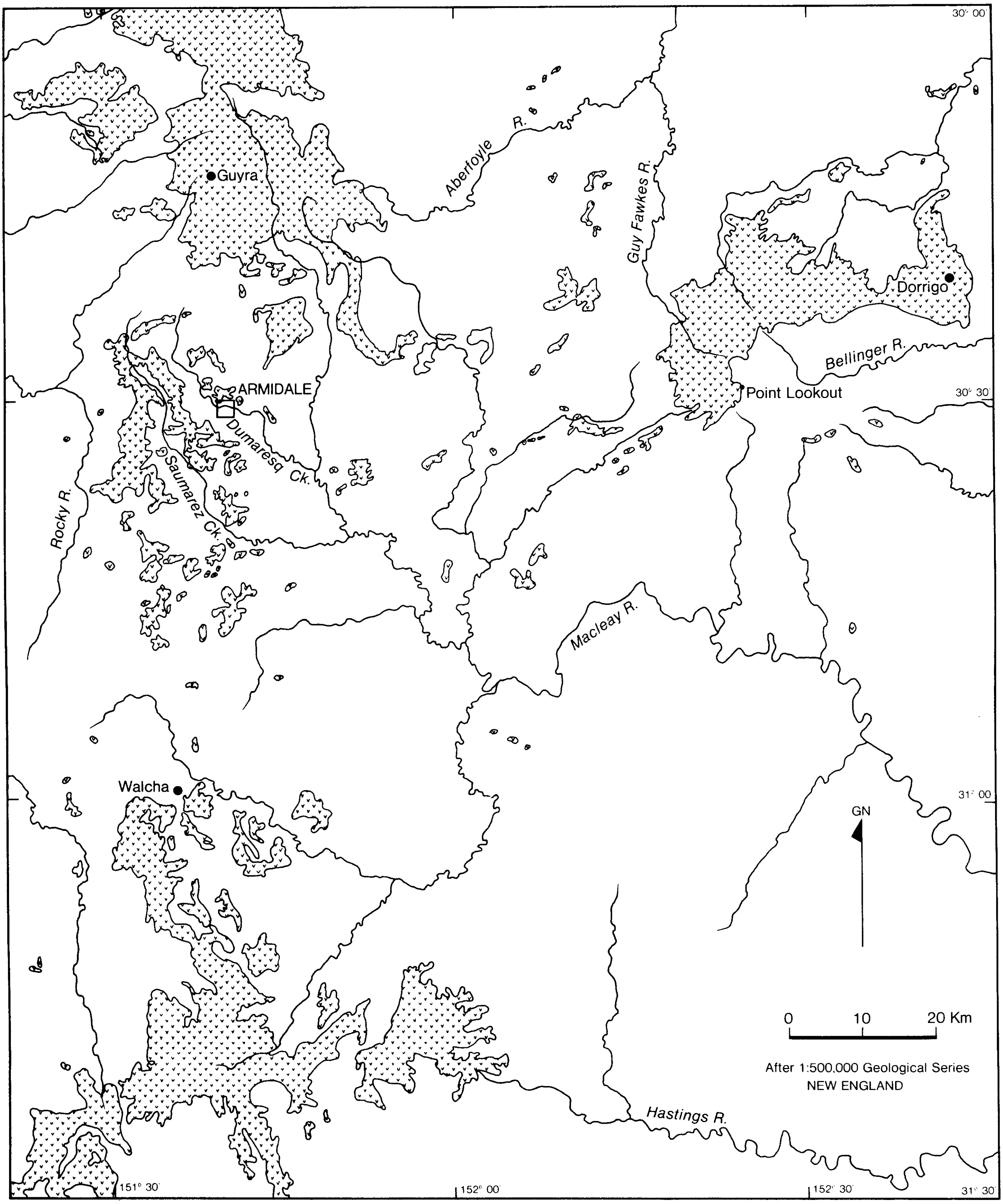

Figure 4. Distribution of Tertiary basalt in southern New England. The basalt in the Armidale area is much more patchy in coverage than basalt in the Walcha, Point Lookout and Guyra regions. The map shows the preferential location of basalt on interfluves in the Armidale area.

east.

2.2 PETROGRAPHY

Cainozoic volcanic rocks in eastern Australia have been classified by Wellman and McDougall (1974a) into three main province types:

1. Lava field provinces, consisting almost entirely of basaltic lavas, and ranging in age from late Cretaceous to early Oligocene.
2. Central volcano provinces, usually consisting of large volcanoes built up olivine basalt with common felsic flows and felsic and mafic intrusions. These provinces range in age from Holocene to Miocene.
3. One mafic, K-rich province.

Tertiary basaltic rocks in the Armidale-Uralla region (hereafter called basalts), belong to the Central Province, one of the lava field provinces of Wellman and McDougall (1974a). The Central Province consists of about 8,000 km^2 of flat-lying basaltic lavas, stretching from south of Armidale, northeast to beyond Inverell (Figure 1).

Basalts in the Armidale-Uralla region are mainly alkali olivine basalts, grading in some areas to analcime basanite where the nepheline or analcime content increases about 10% (Cronk, 1972; Francis, pers. comm.). There are also some tholeiitic andesites (Francis, pers. comm.). This classification follows Wilkinson (1967) who distinguished basaltic and doleritic rocks by grain size, not by whether origin was intrusive or extrusive. Fine grained rocks (average grain size less than 1 mm) are classified as basalts or basanites.

Most of the basaltic rocks are holocrystalline, with olivine usually visible in hand specimen (Plates 1, 2). Wilkinson (1967) gave the percentage composition of normal alkali olivine basalts as 'olivine 10-20, clinopyroxene 20-25, plagioclase 50-60, opaques 5-10, with accessory alkali feldspar, nepheline and/or analcime.'

Some basalts in the Armidale-Uralla region fracture into characteristic blocky fragments, and unbroken hand specimens of these samples exhibit very blocky fracture surfaces (Plate 4). The cause of this blocky fracture, and of the characteristic zoned weathering which results in small grey spots on the fractured blocks (Plate 4), is not known.

Basalts in a railway cutting at 'Wyndella', 13 km northwest of Armidale (Plate 6), show some vertical variation in structure . These basalts are exposed to a depth of 14 m, and extend over an area of 6 km2. From the surface to a depth of 2 m the basalt is massive with few vesicles. This basalt overlies highly vesicular basalt that extends to a depth of about 6 m, at which depth vesicles are no longer apparent. The vesicles are preferentially oriented approximately north-south, and may indicate lava flow along this orientation.

The top of this vesicular basalt, at its contact with the overlying massive basalt, is uneven, with rounded peaks up to 0.6 m high extending into the overlying massive basalt. The sharp junction between the two basalt layers is marked by the undercutting of the surface basalts as the more weatherable vesicular basalts are removed by erosion (Plate 6).

It is likely that at least two flows are represented at the site. The first consisted of at least 12 m thickness of lava that was progressively more vesicular towards the top of the flow. The second flow, of which a 2 m thickness remains, consisted of almost vesicle-free lava.

The microrelief on the top of the vesicular flow is unlikely to be the result of physical drag caused by the succeeding lava flow moving over it, as there is no evidence of mixing along the contact zone. The microrelief is more likely to be preserved relief from the top of the vesicular flow.

There is no evidence of a fossil soil profile at the top of the vesicular flow, and this, in conjunction with the preserved microrelief, suggests that the period between the two flows was far too short for either significant erosion or soil formation to take place.

There are other vesicular basalts in the Armidale area (Plate 5), but they are not widespread. Vesicular basalts are sometimes amygdaloidal, usually with calcite amygdales, but more commonly are not. Amygdaloidal basalt is exposed in a rail cutting at Exmouth 17 km north of Armidale, and at the 'Wyndella' site, discussed above, there is also vesicular basalt in the Doherty's Hill area 3 km north of Uralla. The basalt here forms weathered surface deposits. The vesicles in basalt in the Armidale-Uralla region are generally lenticular. Turner and Verhoogen (1960) reported apparently similar flow-induced alignment of vesicles in pumice. The paucity of vesicular basalt in the Armidale-Uralla region, and in particular the absence of 'frothy' vesicular basalts, suggests that most basalts in the Armidale-Uralla region area were extruded effusively rather than violently. The apparent absence of pyroclastics in the modern Armidale-Uralla region supports this conclusion. No volcanic bombs, breccia, lapilli or tuff are evident. Neither are there weathered materials suggestive of pyroclastic origin incorporated in the Tertiary basalts. There are several cuttings in the Armidale area where basalt up to and exceeding 14 m in thickness is exposed (Plate 6). No pyroclastics are visible in these exposures.

Despite the absence of preserved pyroclastics in the Armidale region, there have been suggestions that pyroclastics were once present. Francis and Walker (1978a) suggested that ferricrete near Armidale has developed from weathered pyroclastics. Schafer (1973) has made a similar claim for ferricrete and soils in the Arding area, between Armidale and Uralla. The validity of these claims cannot be tested, as the soil and ferricrete considered to have developed from the pyroclastics contain no recognisable pyroclastic remnants. There are pyroclastics elsewhere in New England. C.D. Ollier (Bureau of Mineral Resources, Canberra, *pers. comm.*) found volcanic ash, agglomerate and breccia interbedded with lava flows at Point Lookout 75 km east of Armidale. He also reported fine ash fall deposits in the Comboyne area of southern New England, 140 km southeast of Armidale.

Basalts in the Armidale area are not known to contain any flow tubes. lava caves or similar structures. There are several strong outcrops of columnar basalt in the Armidale-Uralla region (Plate 7). Columns are about 60 cm in diameter and are commonly near-vertical. Basalt columns form as the lava cools and contracts progressively inwards from the surface (Longwell _et al._, 1969; Green and Short, 1971). The common near-vertical attitude of basalt columns in the Armidale area suggests that the original basalt flow surfaces were fairly horizontal, though such a conclusion can be only tentative.

There is some evidence for successive lava flows in the Armidale-Uralla region. This evidence consists of weathered horizons between flows (Section 6.3.1)

The base of basalts is rarely visible in sections in the Armidale-Uralla region, as road and rail cuttings are usually too shallow to expose the basalt base. Sites where the basalt base are exposed in section are: Salisbury Waters, 19 km south of Armidale (Figure 2; Section 8.3); at 'Rosebank', 8 km west of Armidale (Figure 2); and at The Sugarloaf, 4 km north of Uralla (Figure 2). At these sites the weathered nature of the basalt makes it difficult to draw conclusions about basalt fluidity and distance capability.

At sites where the basalt base is exposed in section, the surfaces underlying the basalt are highly weathered, with a depth of weathering extending below the section. As the overlying basalt is also well-weathered, and as the sub-basalt contact has been blurred by weathering processes, sub-basalt material at the contact contains a weathering contribution from the overlying basalt.

At Salisbury Waters, the sub-basaltic sandstone and argillite is well-weathered to the base of the road cutting, a depth of up to 2 m. The top of the sub-basaltic sandstone and argillite horizons is sandy clay loam in hand specimen but the degree of weathering and post-exposure disturbance in this cutting makes it impossible to establish whether this material comprised a sub-basaltic fossil soil.

The basalt at the base of The Sugarloaf overlies highly weathered ferricrete (Section 6.3.1; Plate 60). The base of the basalt at this site is again well-weathered, though the basalt is visibly vesicular. Although the ferricrete underlying the basalt is highly weathered, the depth of weathering is unknown, but it certainly extends to below the bottom of the 2 m deep dam excavation. The immediate sub-basaltic horizons at The Sugarloaf are clay to clay loam in hand sample.

In the road cutting at 'Rosebank', basalt overlies shales of the Sandon Beds. The basalt is spheroidally weathered, and a clay to clay loam soil had developed between spheroids almost to the base of the 2.5 m cutting. The contact with the Sandon Bed shales are visible at the western margin of the basalts, but there is no evidence of a preserved sub-basalt soil.

2.3 ABSOLUTE AGE OF BASALT

Absolute ages have been determined for three basalts in the Armidale area. Where necessary I have recalculated K-Ar ages using the constants in the critical tables compiled by Dalrymple (1979). At Bald Knobs 7 km south of Armidale an age of 21.8 ± 1.0 my was obtained (McDougall and Wilkinson, 1967). Basalt at Armidale airport has been dated at 32.8 ± 1.5 my (Wellman and McDougall, 1974a). Basalt 12 km northwest of Armidale has been dated at 25.1 ± 0.1 my (Appendix A). These ages span a period from the middle Oligocene to the early Miocene (Appendix B). Three dates do not precisely define the period of Tertiary basalt extrusion in the Armidale area, and there may be both younger and older Tertiary basalts in the Armidale area than those so far dated.

The three sites at which basalt has been dated lie on an approximate northwest-southeast line through the Armidale-Uralla region (Figure 2). At

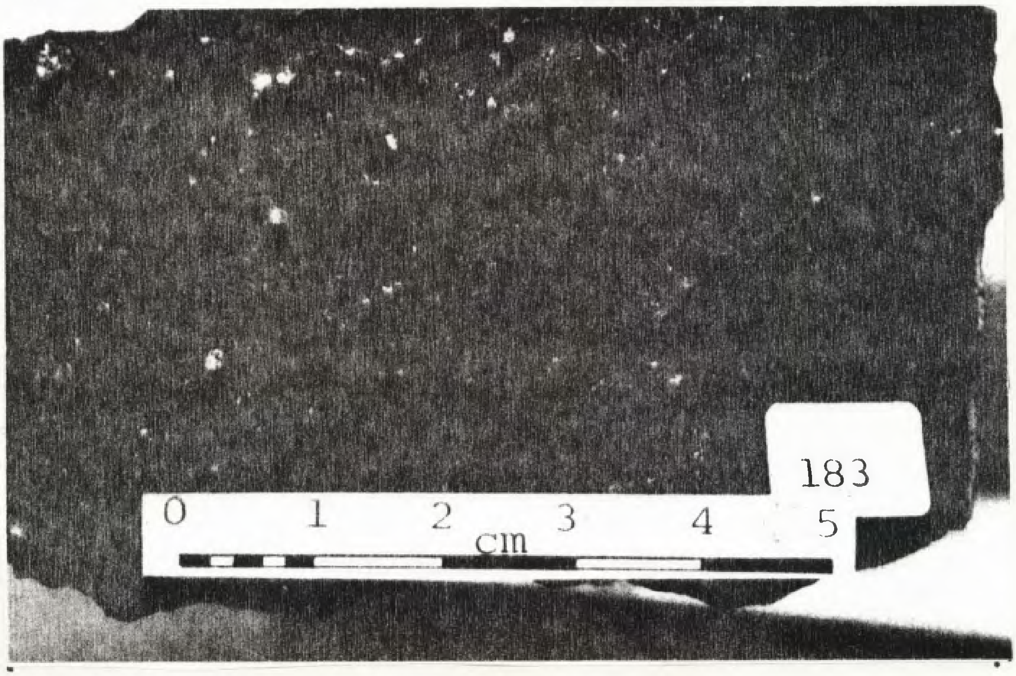

Plate 1. Holocrystalline alkali olivine basalt. Olivine is variably weathered (Dumaresq sheet GR 593280).

Plate 2. Photomicrograph, alkali olivine basalt (Sample 227, crossed nicols). Actual width of field is 2.5 mm. Olivine phenocrysts, labradorite laths and augite. Opaque mineral is magnetite. (Dumaresq sheet GR 656285).

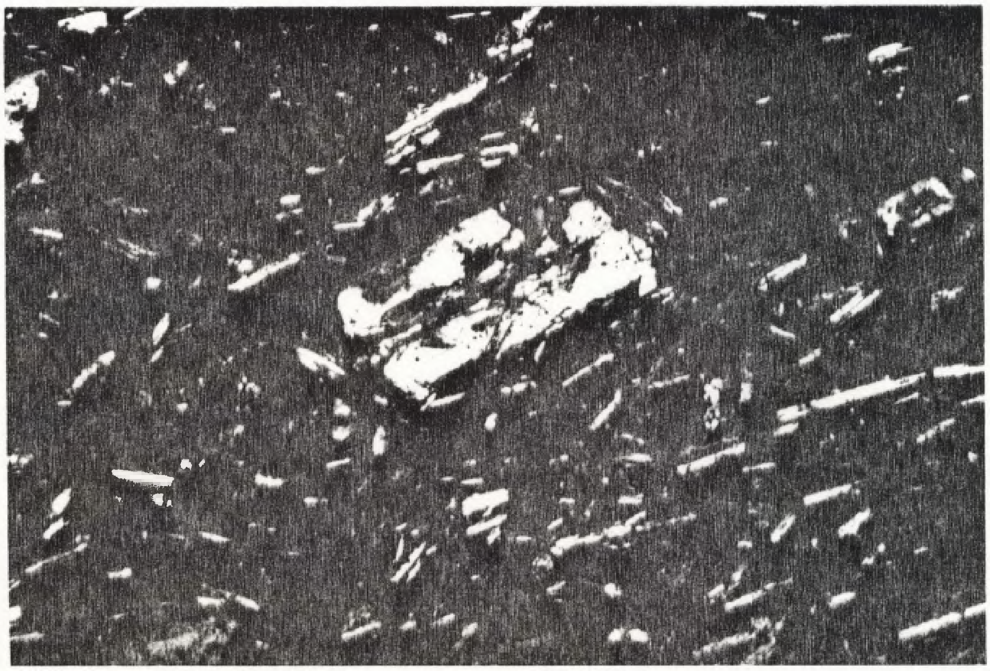

Plate 3. Photomicrograph, alkali olivine basalt (Sample 185, crossed nicols). Actual width of field is 2.5 mm. Moderately weathered olivine phenocrysts containing serpentine veins, labradorite laths. Opaque minerals are magnetite. The sample is from a columnar jointed, highly fractured outcrop (Dumaresq sheet GR637273).

Plate 4. Basalt hand specimen with blocky fracture and mottled weathering. Sample from summit of Mitchells Knob (Dumaresq sheet GR 651280)

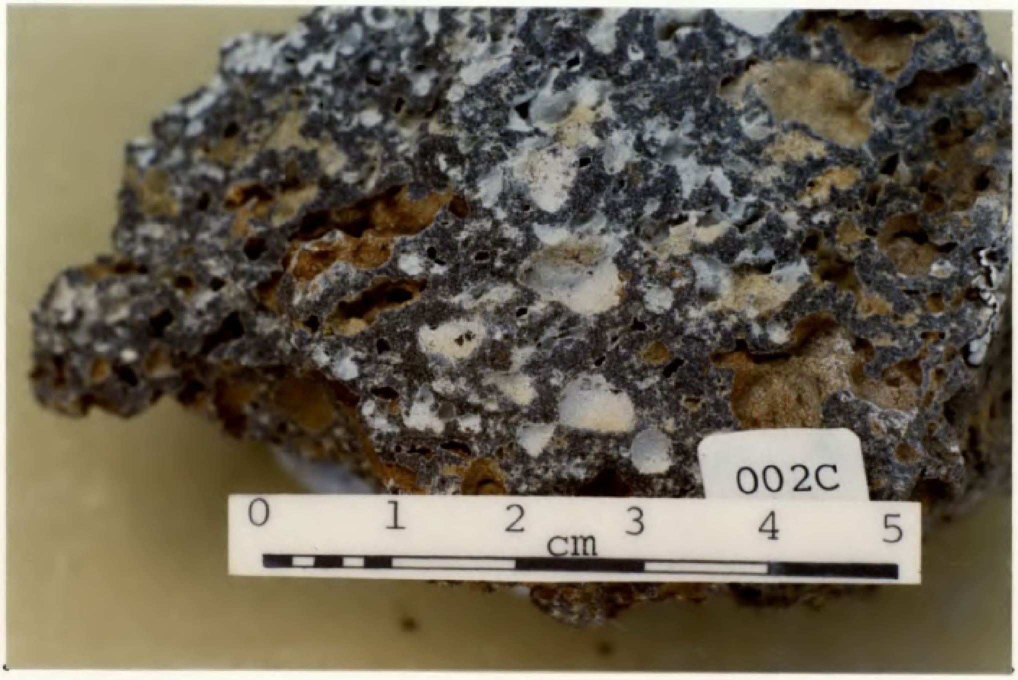

Plate 5. Vesicular basalt with calcite in some amygdales. Sample was from weathered surface remnants, and no conclusion could be drawn about vesicle orientation and possible flow direction (Armidale sheet GR 545107).

Plate 6. Tertiary basalt exposed to a depth of 14 m at 'Wyndella', 13 km northwest of Armidale (Dumaresq sheet GR 631352). Photograph taken looking north. Vesicle orientation in basalt suggests flow from the north. This site is discussed in Section 2.2.

Plate 7. Columnar basalt in a quarry at Bald Knobs, 7 km south of Armidale, and 4 km east of the eastern boundary of Map 1 (Armidale sheet GR 709145). Columns are 20-30 cm in diameter, and dip about 80° to the east. Similar columnar basalt outcrops at the summit of Arthurs Seat, 800 m to the north. Basalt from the Bald Knobs quarry has been used as construction material.

each site the basalts form topographic highs in the modern landscape. As there do not appear to be valley fill basalts on the floors of modern valleys in the Armidale-Uralla region, the dated basalts are probably parts of the most recent flows at each of the three sites.

Ages obtained for other basalts in the Central Province are:

1. 33.8 my 11 km west of Glen Innes (Wellman and McDougall, 1974a)
2. 34.3 my south of Glen Innes (McDougall and Wilkinson, 1967)
3. 22.6 my 11 km southwest of Inverell (Wellman and McDougall, 1974a)
4. 21.5 my at Inverell (McDougall and Wilkinson, 1967)
5. 19.0 my at Inverell (McDougall and Wilkinson, 1967).

Wellman and McDougall (1974a, 1974b) split the Cainozoic volcanics in the Central Province into two age groups, corresponding to two phases of extrusion. The age groups were 35-34 my, and 22.5-19.5 my. The 25 my age obtained for a basalt 12 km northwest of Armidale suggests either that the age difference between the two phases may not be as great at originally thought, or that there were actually at least three phases of extrusion, rather than two, in the Armidale-Uralla region. This latter interpretation appears reasonable.

A basalt sample from 6 km northeast of Ebor in the Ebor-Dorrigo Volcanic Province was dated at 18.2 my (Wellman and McDougall, 1974a). Samples from the Doughboy Range 50 km east of Armidale were dated at 44 and 38 my, but as the samples were collected only 1 km apart the age difference was thought by Wellman and McDougall (1974a) to be probably due to argon loss, and the actual age is probably 44 my or older (Wellman and McDougall, 1974a).

CHAPTER 3

PETROGRAPHY AND CLASSIFICATION OF FERRICRETE

3.1 DEFINITIONS

3.1.1 FERRICRETE MATERIAL

The term 'ferricrete' is used in this thesis to refer to a wide variety of materials in which iron weathering products have been concentrated. In the Armidale area this iron-rich material is variable in appearance and is found in a variety of slope and soil profile contexts. As one of the aims of this chapter is to examine the petrology of this material, it seemed unwise to refer to it as 'laterite', a term that has been frequently broadened in meaning to include assumptions about genesis, distributon and related soil horizons.

The problems associated with the use of the term laterite were dealt with at some length by Paton and Williams (1972). They concluded that as the term has been applied to materials 'as diverse and genetically distinct as iron-cemented colluvial rubble, weathered basalt, mottled clays, and kaolinised igneous rocks', it no longer has value as a precise description.

Much of the ferricrete in the Armidale-Uralla region appears petrographically synonomous with laterite described elsewhere by other workers. For this reason laterite descriptions and two laterite classification schemes are referred to in discussing ferricrete in the Armidale-Uralla region. Two examples from the literature on laterite illustrate the difficulties involved in producing a concise and useful definition of such a diverse family of materials. Du Preez (1949) described Nigerian laterite as

> a mass that may be vesicular, or concretionary, or vermicular, or more or less massive, consisting essentially of iron oxide with or without clastic quartz, and containing small amounts of aluminium and manganese. Although its hardness varies it can usually be broken and shaped readily with a hammer

This definition is so broad as to be of very limited use. Yet other definitions are very specific. For example, Sivarajasingham _et al._ (1962) described laterite in Nigeria as

> highly weathered material (1) rich in secondary forms of iron, aluminium or both; (2) poor in humus; (3) depleted of bases and combined silica; (4) with or without non-diagnostic substances such as quartz, limited amounts of weatherable primary minerals or silicate clays; and (5) either hard or subject to hardening upon exposure to alternate wetting and drying.

In this thesis I use the term ferricrete to refer to cohesive material, rich in weathered iron minerals.

3.1.2 THE FERRICRETE PROFILE

Although ferricrete in the Armidale-Uralla region commonly occurs as surface concretions, it also forms horizons in the soil. McFarlane (1976) referred to this as 'the most essential part of its environment', and gave examples of ferricrete horizons in Uganda up to 61 m thick. Ferricrete horizons in Sierra Leone are 2-12 m thick, and in some regions form 'a hard, almost continuous sheet over wide areas' (Thomas, 1978). Despite the presence of thick ferricrete profiles, many African ferricrete deposits are only 1-2 m thick (Ollier, _pers.comm._). In the Sydney area of New South Wales, ferricrete formed on the Hawkesbury Sandstone is up to 4 m thick, and has been interpreted as 'iron-rich sandstone units' (Hunt _et al._, 1977). The thickest ferricrete horizons in the Armidale-Uralla region are less than 2 m thick. This is a common thickness for ferricrete in other regions.

In McFarlane's (1976) experience the ferricrete horizon is commonly overlain by red soil, though dark soil or pale, leached soils are sometimes present. McFarlane (1976) suggested that where the overlying soils are pale and leached the ferricrete may have formed by the accumulation of iron leached from the overlying horizons. McFarlane (1976) has explained the presence of large accumulations of ferricrete where there is only a thin overlying horizon of soil, by suggesting that the iron-rich horizon is migrating vertically downwards, incorporating saprolite. While this is taking place, progressive erosion of the ground surface ensures there is only a thin layer of soil over the ferricrete at any time.

Underlying the ferricrete horizon in the supposedly typical ferricrete profile is a mottled zone in turn underlain by a pallid zone. The mottled horizon may merge into the ferricrete horizon or abut it sharply. There does not appear to be any clear relationship between the extent and development of the mottled zone and the characteristics of the ferricrete profile. McFarlane (1976) frequently found the mottled zone absent. In the Armidale-Uralla region ferricrete horizons sometimes contain a mottled zone, but pallid zones are absent. Most of the ferricrete in the Armidale area occurs as lag deposits. The ferricrete comprising these surface deposits varies in size from pisoliths to boulders. Surface deposits are found throughout the Armidale-Uralla region from valley floor to interfluve.

3.2 PETROGRAPHY

3.2.1 NOMENCLATURE

Ferricrete nomenclature in the following discussion generally follows that of Brewer (1964). The basic 3-dimensional ferricrete unit is the glaebule. Glaebules with undifferentiated or structureless internal fabric are termed nodules (after Brewer, 1964). Glaebules consisting of a series of concentric layers about a centre are termed concretions (after Brewer, 1964), and usually indicate formation by accretion (Brewer, 1964; Coventry et al., 1983).

Both nodules and concretions sometimes have outer skins that are different in 'concentration, texture , structure or fabric' (Brewer, 1964) to the rest of the glaebule. These outer skins are termed cutans (after Brewer, 1964), and can form by deposition, diffusion or _in situ_ modification of the soil material around the glaebule.

Cutans in ferricrete in the Armidale-Uralla region are almost without exception grain cutans (after Brewer, 1964), having formed on skeleton grains such as nodules and concretions. Most cutans are also compound (after Brewer, 1964), consisting of several layers of of minerals or chemically different materials. There are a few occurrences of simple cutans (after Brewer, 1964), composed of a single mineral or chemical substance, and having only one visible layer.

Ferricrete in the Armidale-Uralla region contains cutans of four main mineralogies. Sesquans and mangans (after Brewer, 1964) are the most common. Sesquans are composed mainly of sesquioxides or hydroxides, and mangans consist mainly of manganese oxides and hydroxides. Less common are argillans and silans (after Brewer, 1964). Argillans are mainly composed of clay minerals, and silans are composed of silica, especially microcrystalline quartz grains or chaldedony.

Glaebules can be formed elsewhere and transported to their present location, or they can be formed _in situ_. All transported glaebules are inherited, and some glaebules formed _in situ_ are also inherited. These include glaebules that are _in situ_ relicts of parent rock or other parent material (Brewer, 1964). The following glaebule and cutan features indicate probable inherited (transported) origin.

1. Different sand and silt particle size distributions inside and outside glaebules (Coventry _et al._, 1983).
2. Adjacent glaebules with different sand and silt particle size distributions (Coventry _et al._, 1983), or different sorting.
3. Adjacent glaebules with different lithologies (Coventry _et al._, 1983).
4. Broken cutans on glaebules (Coventry, _et al_., 1983).
5. Cutans abraded through parts of their concentric laminations, and quartz

grains protruding from corroded or corraded glaebule surfaces.

6. Features indicating physical or chemical activity within glaebules (such as the quartz laminae noted by Coventry et al., 1983), that do not extend outside the glaebule.

3.2.2 FERRICRETE GLAEBULES

Ferricrete in the Armidale-Uralla region is commonly glaebular, with a wide glaebule size range within samples. The glalebule size range is about 1-13 mm, with the usual size range being about 1-7 mm. The glaebules are usually ferruginous, often rich in quartz, and are commonly orange to red-brown in colour. Glaebules are usually nodular rather than concretionary.

Ferricrete frequently contains cavities, which can be vesicular (tube-like), cellular (spheroidal) or intermediate between the two. Some cavities are simply spaces between glaebules. Other larger cavities appear to be structures within the ferricrete (Plates 8-14).

Concretions when present are usually of similar size to nodules in the same sample. There are rare exceptions to this, and the manganiferous concretion visible in Plate 15 measures 1.5 mm by 0.5 mm, though the exposure in the polished section may not show its maximum dimensions. The concretion consists of colloform laminations. It encloses ferruginous cement at parts of its margin, and has almost certainly formed *in situ*, in a pre-existing cavity.

3.2.3 CLASTIC GRAINS

Quartz grains are common components of both glaebules and the ferricrete matrix. The quartz component is variably rounded, with a size range of 0.01-1.0 mm (Plates 8- 21). Besides quartz, ferricrete often contains fragments of basalt, silcrete, chert, jasper and feldspar. Silcrete fragments are distinguishable from chert even in these small inclusions, by the presence of silica-cemented sand grains. These fragments are sometimes angular. Ferricrete in the Armidale-Uralla region appears richer in clastic sediments (particularly quartz) than ferricrete described by McFarlane (1976), Ollier (1976) and Young (1976). These workers made few references to the presence (or absence) of quartz and other clastic grains. The quartz grains in ferricrete in the Armidale-Uralla region were probably carried and deposited by streams. The presence of fragments of silcrete, chert and jasper in ferricrete in the Armidale-Uralla region is another indication of probable fluvial or colluvial transport of these materials into the area of ferricrete formation (Plate 16). As these fragments are often angular the distance of transport may have been short, although the angularity of small quartz grains is thought to be persistent during fluvial transport (Folk, 1968).

The quartz grains in both the ferricrete matrix and in glaebules characteristically have simple extinction and few fluid inclusions (Appendix F). For example, examination of thin sections of Samples 135 and 286 (Plates 8,9), using an empirical quartz grain classification scheme (Folk, 1968), gave the following results.

<u>Sample</u> <u>135</u> (vesicular nodular ferricrete)

Matrix quartz (n=103): 90% of grains have simple extinction with few fluid inclusions.

Glaebule quartz (n=82): 87% of grains have simple to slightly undulose extinction with few fluid inclusions.

<u>Sample</u> <u>286</u> (massive nodular ferricrete)

Matrix quartz (n=106): 94% of grains have simple extinction with few fluid inclusions.

Glaebule quartz (n=105): 99% of grains have simple extinction with few fluid inclusions.

Other ferricretes contain a greater variety of extinction types and/or fluid inclusion abundance, as shown by Sample 145 (Plate 15).

Sample 145 (vesicular nodular ferricrete)

Matrix quartz (n=105): 65% of grains have straight to slightly undulose extinction with few fluid inclusions, 24% have straight to slightly undulose extinction with abundant fluid inclusions.

Glaebule quartz (n=110): 75% of grains have straight to slightly undulose extinction with few fluid inclusions; 24% have straight to slightly undulose extinction with abundant fluid inclusions.

The extinction/inclusion characteristics of quartz grains in ferricrete enable some tentative conclusions to be drawn regarding possible quartz sources. These conclusions, and the significance of extinction/inclusion variations, are discussed in Section 7.3.

There are also uncommon ferruginously cemented breccias in the Armidale area. These breccias contain variable proportions of ferruginously cemented fine sediments as well as clasts of silcrete, quartz, chert and jasper in a ferruginous matrix (Plate 17). Some samples consist of angular clasts of ferruginous cemented sand bound together in a ferruginous cement. The angular clasts are 3-20 mm in maximum dimension. Other samples contain angular 0.2-1.0 cm clasts of chert, jasper and occasionally silcrete, in a ferruginous cement.

At several sites in the Armidale area there are uncemented nodules. These are sometimes accumulated as ant mounds, and are often accompanied by fragments of quartz, chert and jasper (Plate 18). There are also examples of part-cemented nodular ferricrete in the Armidale area. Usually these samples are only minimally cemented, and the surface nodules of the ferricrete are left almost free-standing (Plate 19). Most ferricrete is well cemented. Reworked ferricrete is also found in the Armidale-Uralla region. This ferricrete contains angular to sub-angular ferricrete inclusions (Plates 20,21).

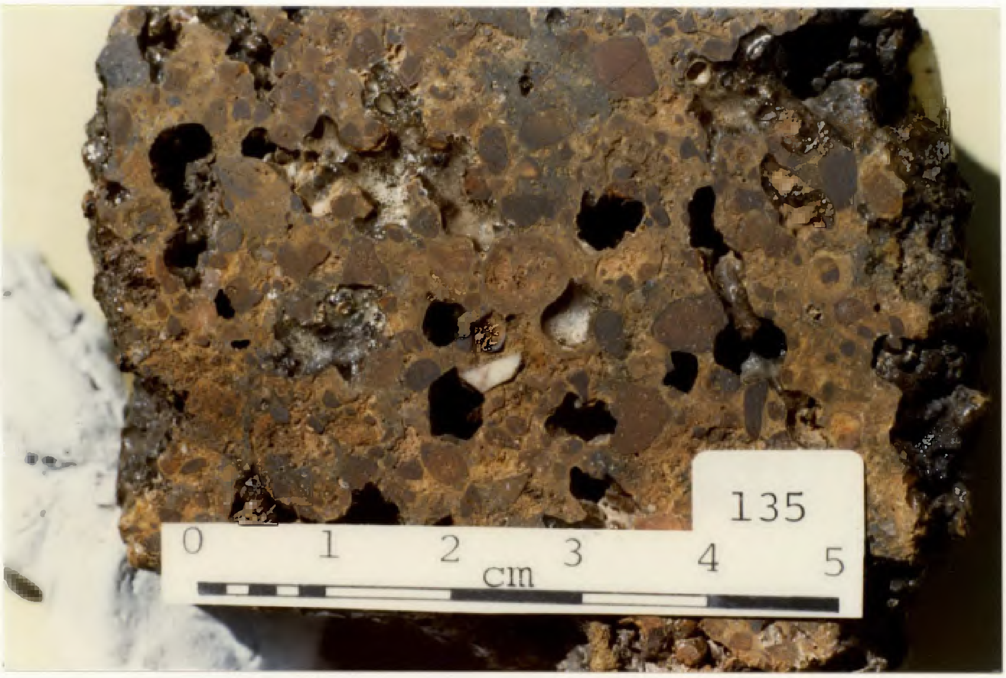

Plate 8. *Nodular vesicular ferricrete, with 1-10 mm nodules, angular quartz sand 0.1-0.5 mm, and minor chert and mudstone fragments (Armidale sheet GR 600190).*

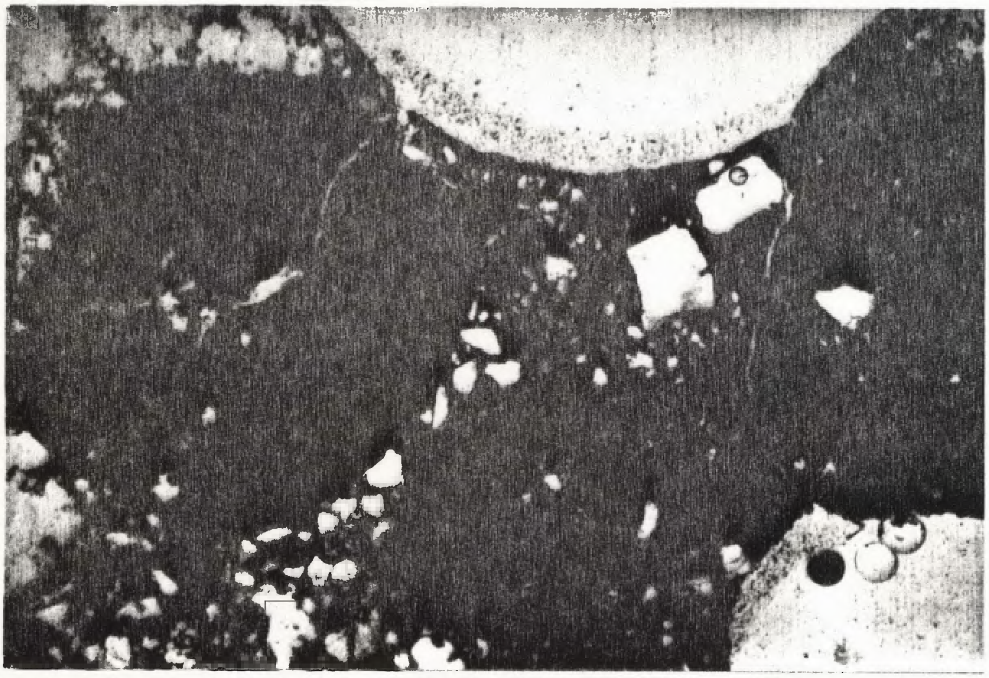

Plate 9. *Photomicrograph of Sample 135 shown in Plate 8 (ordinary light). Actual width of field is 3.5 mm. Minor solutional embayment of quartz grains. Vacuoles visible at bottom centre and top left of Plate. Quartz grains in matrix are generally much larger than those in nodules, and there is great variation in abundance of quartz grains. Both features indicate likely inherited (transported) origin for nodules. Occasional feldspars in nodules and matrix. Compound grain cutans, probably sesquans, on some nodules. Cutan banding extends into matrix, indicating in situ cutan development after deposition of nodules.*

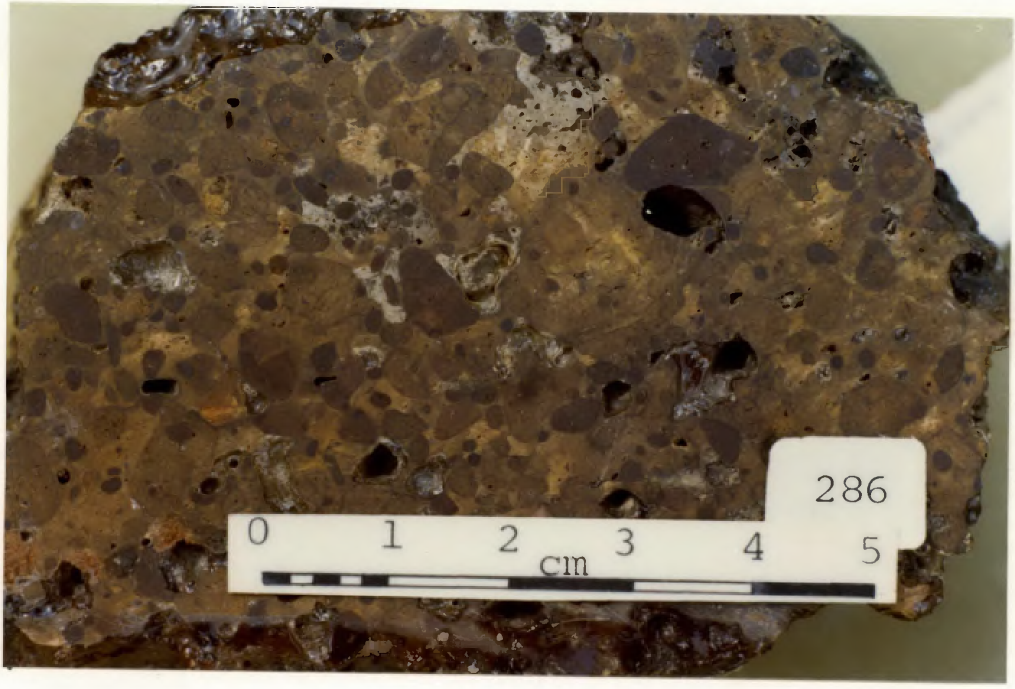

Plate 10. *Massive nodular ferricrete, with 1-10 mm nodules and well sorted, rounded to sub-angular quartz sand (Armidale sheet GR 577230).*

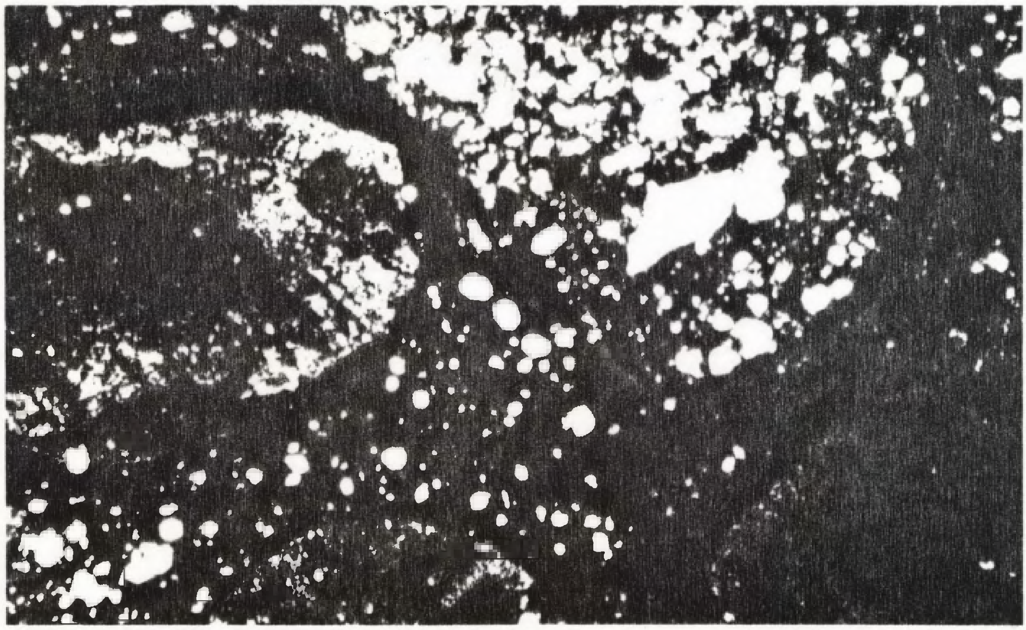

Plate 11. *Photomicrograph of Sample 286 shown in Plate 10 (ordinary light). Actual width of field is 2.5 mm. Quartz and occasional feldspar grains in both matrix and nodules. Nodule quartz grains generally smaller than those in matrix (matrix quartz up to 0.5 mm, nodule quartz as small as 0.01 mm). Quartz grains in nodules are poorly sorted, with large variations in grain size between nodules. Some nodules have abraded margins. These features indicate nodules are probably inherited (transported), rather than formed in situ. Most nodules are manganiferous and spheroidal. Compound grain cutans, probably sesquans, are present on some nodules, such as the two nodules at top right and top left. Cutan bands continue into matrix, indicating cutan development in situ, after nodule deposition.*

Plate 12. *Massive nodular ferricrete, with nodules 1-6 mm and sub-angular quartz sand 0.2-1.0 mm. This Sample is more highly weathered than Sample 286 (Plate 10), and vesicles are forming in the ferruginous cement where weathering is most advanced (Dumaresq sheet GR 663365).*

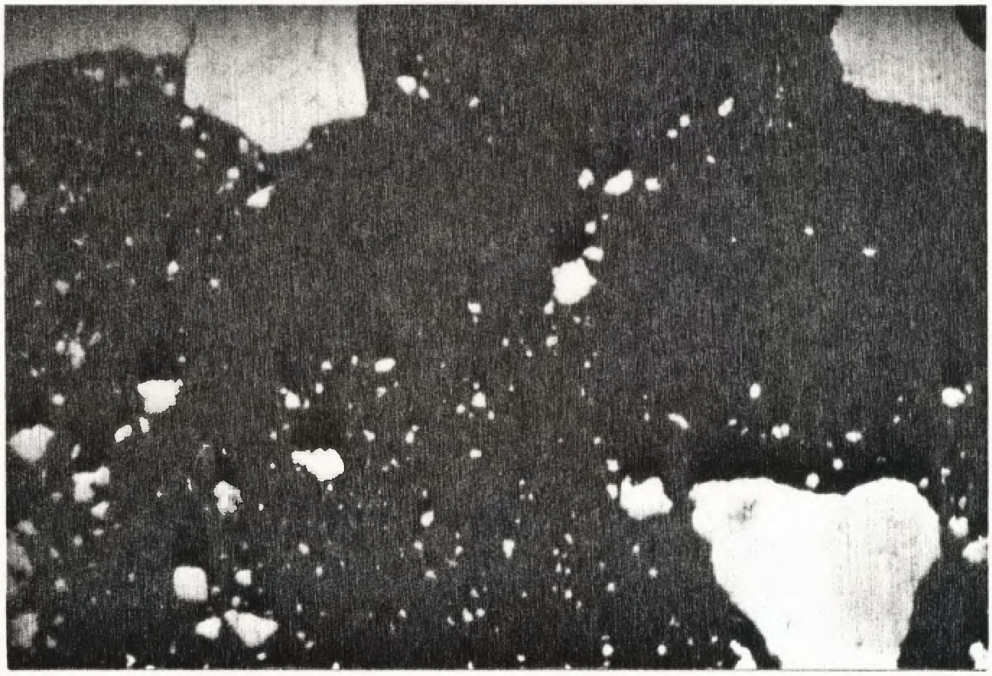

Plate 13. *Photomicrograph of Sample 077 shown in Plate 12 (ordinary light). Actual width of field is 3.5 mm. Ferruginous cement contains abundant angular to sub-angular quartz grains. Most nodules contain very few quartz grains, as can be seen above, though several nodules elsewhere in thin section contain abundant, unsorted angular quartz. This suggests the nodules are inherited (transported). Most nodules are manganiferous and spheroidal. Some have compound grain cutans, probably sesquans, though these are not visible in this Plate.*

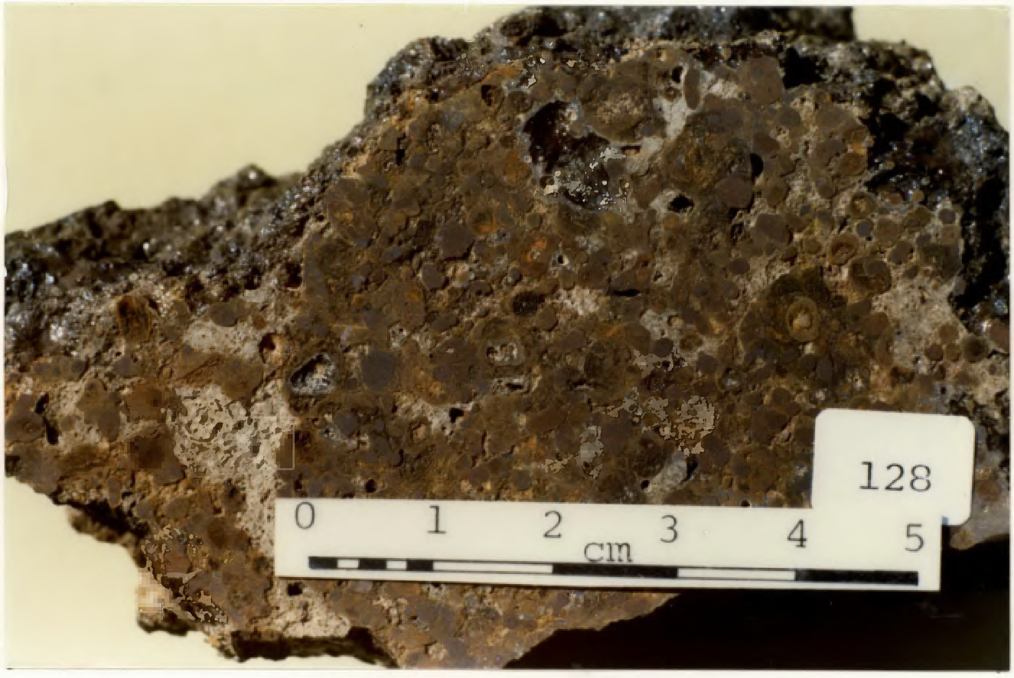

Plate 14. Massive nodular and concretionary ferricrete; nodules and concretions 0.1-0.5 mm, and abundant angular quartz grains (0.2-1.0 mm) in ferruginous matrix. No feldspar evident in matrix or glaebules. Most concretions consist of two or three layers. They are manganifeous and spheroidal, and contain 0.05 mm angular quartz grains. Nodules are mainly manganiferous, spheroidal normal nodules, with 0.05-0.2 mm angular quartz grains. Differences in quartz abundance and glaebule type indicate likely inherited (transported) origin for glaebules. Some nodules have simple grain cutans, probably sesquans or argillans. In places the cutans fill out abrasion irregularities on the surfaces of nodules and concretions, indicating in situ development of cutans after glaebule deposition (Armidale sheet GR 626177)

Plate 15. Vesicular nodular ferricrete, with 1-6 mm nodules and 0.5-6.0 mm angular chert clasts. Sample contains large manganiferous colloform concretion. Thin section shows no abrasion of concentric growth rings of this concretion. Likely therefore that it formed in situ, within a large vesicle. No features comparable to this concretion have ben found in other samples. Other glaebules are nodular, with varying quantities of unsorted quartz, and occasional feldspar. This suggests nodules are inherited (transported). Occasional simple grain cutans, probably silans, consisting of chalcedonic chert (Dumaresq sheet GR 602281).

<u>Plate 16.</u> Massive nodular ferricrete, nodules 0.1-10 mm, some with compound grain cutans, probably sesquans. Angular 2.5 cm basalt clast. Structure of sample is massive, but there are occasional cavities, some containing calcite fills. Other cavities (such as the one above '4' on the scale) are partly filled with 0.05-0.2 mm quartz grains in weathered ferruginous cement. This indicates a probable phase of iron mobilisation after the main phase of ferricrete development. Matrix contains occasional rounded quartz grains, such as the 0.4 mm ovoid example at centre left. This suggests some included sediments were transported significant distances before cementation (Dumaresq sheet GR 592257).

<u>Plate 17.</u> Ferruginously cemented chert breccia. Sample from an indurated horizon in a minor gully just above floodplain level. The chert is probably derived from rocks of the Sandon Beds on which the breccia has formed, and it is possible the ferricrete is near-contemporary. the angularity of the chert clasts suggests minimal transport before cementation. The sample contains occasional 1.3 mm rounded quartz grains, indicating probable contributions of clasts from different source areas. Sample contains several 1-3 mm nodules. One 2 mm nodule (visible near top right of Plate) has a whitish-coloured simple grain cutan, possibly a silan. Sharp cutan boundary and lack of quartz in nodule indicate probable inherited (transported) origin. (Dumaresq sheet GR 619273).

Plate 18. *Uncemented 2-6 mm nodules and 1-3 mm angular chert clasts from an ant mound. None of the glaebules examined are concretionary. Some nodules contain 0.05 mm angular quartz grains. Many nodules are abraded and/or broken, indicating inherited (transported) origin (Dumaresq sheet GR 617265).*

Plate 19. *Part cemented nodular ferricrete, nodules 0.1-10 mm. Exposed in the bank of Dumaresq Creek, at 'Saumarez'. This sample appears to represent an intermediate stage between the uncemented nodule stage of Sample 216 (Plate 18), and the completely ferruginised examples in Plates 8-16 (Armidale sheet GR 611179).*

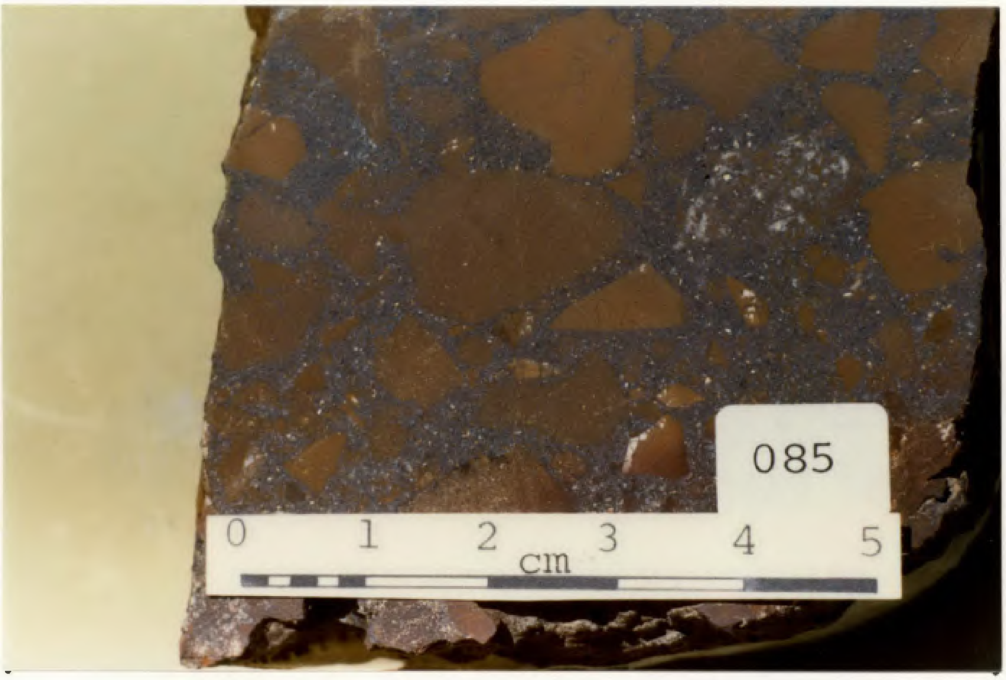

Plate 20. *Massive ferricrete with angular clasts of reworked fine-grained ferricrete, in ferruginous cement rich in quartz sand. Clast at top centre right contains microcrystalline quartz filling. Angular clast to left of sample-number label, is partly quartz. Variation between clasts indicates probably inherited (transported) origin; angularity suggests clasts have not moved far from their source (Armidale sheet GR 625202).*

Plate 21. *Photomicrograph of Sample 085 shown in Plate 20 (ordinary light). Actual width of field is 2.5 mm. Angular to sub-rounded quartz (0.05-1.0 mm) is abundant in ferruginous cement, with solutional embayment visible in quartz grains. Quantity of quartz in angular ferricrete clasts varies from sparse to abundant. Ferruginous cement is much harder than is usual for ferricrete, and probably contains cryptocrystalline silica.*

3.3 EXISTING CLASSIFICATION SCHEMES

Although there have been many studies of ferricrete, there have been few attempts at producing a classification scheme for the material. The schemes of Young (1976) and McFarlane (1976) for African materials are among the best known and are presented as being applicable elsewhere.

3.3.1 YOUNG (1976)

This morphologic classification can be summarised as follows.

1. Massive laterite. This is a hard mass usually containing some cavities. It is either cellular with rounded cavities that may or may not be connected, or vesicular with mainly tubular cavities.
2. Nodular laterite. This material consists of individual sub-rounded concretions. Nodular laterite is further divided into cemented, partly cemented and non-cemented laterite, as well as iron concretions. Iron concretions or spaced nodular laterite differs from non-cemented or packed nodular laterite by comprising less than 60% by weight of the total soil horizon. These subdivisions of nodular laterite are not always easy to apply in the field, as often there is considerable mophologic variation within one ferricrete outcrop.
3. Recemented laterite. This material is composed of reworked particles and fragments of ferricrete that have been deposited and recemented.
4. Ferruginised rock. This is rock in which the minerals have been progressively replaced by iron.
5. Soft laterite. This is a 'mottled iron-rich clay which hardens irreversibly on exposure to air or to repeated wetting and drying' (Young, 1976).

3.3.2 McFARLANE (1976)

McFarlane's ferricrete classification scheme was based on ferricrete in Uganda, but was intended to have general application. McFarlane's initial distinction was between 'discrete concretion laterite' (the nodular type of Young, 1976), and 'the continuous phase variety, in which the indurated elements forms a continuous coherent skeleton'.

In this scheme McFarlane (1976) used the terms pisolith and oolith to distinguish between nodules of different sizes. As defined by McFarlane (1976), pisoliths are larger than 2 mm in maximum dimension, ooliths are smaller than 2 mm. The terms pisolitic and oolitic were reserved for cemented concretions of pisoliths or ooliths, while the more general terms pisolithic and oolithic referred to either cemented or uncemented laterite. Pisolithic laterite is composed mainly of pisoliths, oolithic laterite contains mainly ooliths.

McFarlane (1976) divided continuous phase (non-nodular) laterite into vermiform and cellular types. Vermiform laterite contains tube-like structures while the cavities in cellular laterite are 'irregularly shaped cells rather than tubes' (McFarlane, 1976). Although McFarlane (1976) thought that vermiform and cellular laterite may be more mature forms than pisolithic ferricrete, she offered no explanation of what happens to the prominent nodules in pisolithic ferricrete when it matures into vermiform or cellular ferricrete.

3.3.3 LIMITATIONS OF EXISTING CLASSIFICATION SCHEMES

The classifications of Young and McFarlane were devised in landscapes unlike that of eastern Australia where there have been widespread Cainozoic basalt extrusions. The weathering of these east Australian Cainozoic basalts has supplied large amounts of iron and aluminium weathering products to the environment. Soils formed on these basalts have provided a host profile for ferricrete development.

There are also other problems with the application of the classification schemes to ferricrete in the Armidale region. For example, using Young's scheme some specimens of ferricrete from the Armidale area, in which concretions are visible but the overall appearance is of a hard mass, usually containing cavities, can be classified validly as either massive laterite or cemented nodular laterite.

Young's (1976) distinction between cellular and vesicular laterite is difficult to apply in cases where cavities are intermediate between cellular and vesicular, or in samples containing both cellular and vesicular cavities. Such samples are common in the Armidale-Uralla region (Plate 8).

At a number of sites in the Armidale-Uralla region, ferricrete contains varying amounts of quartz sand and/or Palaeozoic rock fragments. Young's (1976) classification scheme does not allow recognition of this variable sediment content. In the Armidale area where sand and Palaeozoic clasts often comprise highly visible proportions of the total ferricrete, it is important that any classification scheme recognises these variations and enables them to be recorded.

Similar problems arise in relation to the highly variable amounts of included clastic quartz in ferricrete, and the size and degree of weathering of the grains. The cement of ferricrete samples in the Armidale-Uralla region contains up to 50% quartz sand by volume, varying from fine to very coarse, and from angular to well rounded. Because of the importance of these variations in the interpretation of depositional and fluvial environments during ferricrete genesis, such major differences should be recognised in a classification scheme. Young's (1976) classes of partly and non-cemented laterite do not appear to be present in the Armidale-Uralla region, so these classes are redundant.

In summary there are at least two main problems in applying Young's (1976) ferricrete classification scheme in the Armidale-Uralla region. First, the scheme does not enable accurate description of samples intermediate between massive and nodular ferricrete. Secondly, the scheme fails to recognise the wide variations in the shape, size and lithology of the included clasts.

In McFarlane's (1976) classification scheme the distinction between pisolithic and oolithic laterite is not relevant to ferricrete in the Armidale-Uralla region, since all the nodular ferricrete examined had nodules with a size range spanning this arbitrary distinction. In addition to this problem, McFarlane's (1976) definition of pisolith and oolith sizes is not universally accepted. Pisoliths are more usually defined as being 1-10 mm in diameter; and ooliths, 0.25-2.0 mm in diameter (American Geological Institute, 1976). This difference in definition is not crucial, but because the terms pisolith and oolith do refer to particles of specific size, neither one alone can describe a single ferricrete sample that contains nodules ranging in size from a fraction of a millimetre to as much as 10 mm.

McFarlane (1976) made vermiform laterite (the vesicular laterite of Young, 1976) and cellular laterite mutually exclusive of pisolithic and oolithic ferricrete. Pisolithic (nodular) ferricrete in the Armidale-Uralla region nearly always contains cellular, vesicular or mixed cavities, indicating incomplete replacement of nodules by cavities, but not invalidating McFarlane's (1976) conclusion that vermiform and cellular laterite may represent more mature stages of ferricrete development than pisolithic laterite. The result of McFarlane's (1976) classification is that unless ferricrete samples are very strongly vermiform or cellular they are classified either as pisolithic or oolithic. The nodule size range in ferricrete in the Armidale-Uralla region usually runs from oolith to pisolith. McFarlane (1976) classified profiles containing both pisoliths and ooliths, as pisolithic.

For these reasons neither Young's (1976) nor McFarlane's (1976) classification schemes are entirely satisfactory for describing and classifying ferricrete in the Armidale-Uralla region. Despite the shortcomings of these classification schemes, some of the distinctions made in them are useful, and can help in building a workable scheme for the classification of ferricrete in the Armidale-Uralla region.

3.4 CLASSIFICATION OF FERRICRETE

A system of classification that overcomes the incompleteness of existing classification schemes, and the difficulties encountered in applying them in the Armidale-Uralla region, needs to embody the following.

1. A distinction between ferricrete with cavities and ferricrete without cavities. The sub-distinction between vesicular and cellular cavities is sometimes difficult to apply, but marks a real distinction in ferricrete petrography in the Armidale area.
2. A distinction between nodular and concretionary ferricrete.
3. A description of the proportion and characteristics of quartz and other clasts in the ferricrete.

The following classification scheme recognises ferricrete in the Armidale-Uralla region according to four criteria.

1. Massive, vesicular or cellular. Massive ferricrete contains no cavities, vesicular ferricrete contains mainly tubular cavities, and cellular ferricrete contains mainly rounded cavities. The terms cellular and vesicular follow the usage of Young (1976).
2. Nodular or concretionary. Nodular ferricrete consists mainly of ferruginous nodules in ferruginous cement. Concretionary ferricrete consists mainly of ferruginous concretions in ferruginous cement. Some ferricrete contains both nodules and concretions.
3. Glaebule size range and origin. The glaebule size range is the size in millimetres of any glaebules in the sample. A distinction should be made between inherited (transported) glaebules and those formed *in situ*.
4. Other components. Where ferricrete contains non-ferricrete components

(such as quartz, chert or basalt), these should be described. The description should list rock type, apparent grain size, degree of weathering if apparent, and degree of rounding of the clasts.

Using this scheme, a ferricrete sample containing tubular cavities, nodules 1-5 mm in diameter, and angular chert clasts up to 8 mm long, is described as: vesicular nodular ferricrete, with 1-5 mm nodules and angular chert clasts to 8 mm. A highly weathered ferricrete sample with no cavities, no glaebules and no inclusions, but containing relict structures apparently inherited from the parent rock, would be described as: massive, highly weathered non-nodular ferricrete, with relict parent rock structures. Some of the highly weathered profiles at the base of Arthurs Seat (Armidale sheet GR 551199) and Bald Knobs (Armidale sheet GR 710145) are examples of this ferricrete type. The ferricrete samples shown in Plates 8-20 are described using this classification scheme.