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Geology of the Featherbed Cauldron Complex, North Queensland: Part 1 - Eruptive rocks and Post-Volcanic Sediments by D E Mackenzie

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AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Geology of the Featherbed Cauldron Complex, North Queensland: Part 1—Eruptive Rocks and Post–Volcanic Sediments

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D E Mackenzie

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ABSTRACT

The Featherbed Cauldron Complex comprises nine nested volcano-tectonic collapse structures: the Boonmoo Sag, the Eight Mile, Boxwood, Doolan Creek and Wolfram Cauldrons, and the Mount Mulligan, Featherbed, Djungan, and Wakara Calderas. The Tennyson, Featherbed, Djungan and Wakara Calderas are "classic" ring fault and ring dyke-bounded cauldron collapse structures, as may also be the Mount Mulligan, Wolfram, Doolan Creek and Boxwood structures. The Boonmoo Sag, in contrast, is a basin-like sag structure, without peripheral ring fault(s) or ring dykes.

Each cauldron and caldera contains or is spatially associated with a unique sequence of eruptive rocks that together make up the Featherbed Volcanic Group. This consists of: (1) the Boonmoo and Tennyson Volcanic Subgroups, which, along with the Jamtin Rhyolite, Beapeo Rhyolite, Wallaroo rhyolite, Redcap Dacite, Doolan Creek Rhyolite, and Nightflower Dacite, are Late Carboniferous in age; (2) the Timber Top Volcanic Subgroup, of Late Carboniferous(?) to Early Permian age; and (3) the Yongala (Featherbed Caldera), Djungan, and Wakara Volcanic Subgroups, all of Early Permian age. Thicknesses of the various eruptive sequences range from a few tens of metres (Wallaroo rhyolite, Doolan Creek Rhyolite) to at least a kilometre (Yongala Volcanic Subgroup, Featherbed Caldera). Total preserved volume of eruptive rocks in and around the cauldron complex is about 3000 km^3, and it is estimated that between 500 m (Featherbed Caldera) and at least 1 km (Boonmoo Cauldron) of material has been removed by erosion.

About 95 percent by volume of the Featherbed Volcanic Group is welded ignimbrite. The remaining 5% comprises: dacitic to andesitic lavas in the Boonmoo Volcanic Subgroup; rhyolitic lava flows and domes which crop out sporadically around the margins of the Featherbed Caldera, Djungan Caldera, and, especially, the Wakara Caldera; rare unwelded pyroclastic rocks, including tuffs; and very rare reworked (sedimentary) volcaniclastic rocks.

The eruptive rocks overall range in composition from andesitic-basaltic to rhyolitic, but there are several marked contrasts between rocks the Early Permian Featherbed-Djungan-Wakara-Mount Mulligan nest of calderas and the flanking Late Carboniferous Rocks. The Late Carboniferous rocks are of I-type chemistry, and span the entire compositional range, while those of Early Permian and probable Early Permian age are of A-type character and almost entirely of rhyolitic composition.

Apart from this remarkable compositional dichotomy, there are several other noteworthy features of the Featherbed Cauldron complex. Rheomorphically deformed ignimbrites, the result of plastic flow of hot, thick, ignimbrite piles, are common in the lowermost parts of the Featherbed/Yongala and Djungan sequences, and reach several hundred metres in thickness in the western Featherbed Caldera. Vitrophyres (glassy, variably welded ignimbrites formed by rapid chilling of melt-rich material at the base of an ash-flow) are extensively developed, and reach many tens of metres, possibly up to 200 m, in places. A massive, lithic-rich volcanic breccia or ignimbrite, containing clasts up to 40 m long and 15 m wide, is exposed over an area of several tens of square kilometres in the western Wakara Caldera; it is probably a vent or near-vent deposit.

Volcanism in the Featherbed Cauldron complex began at about 313 Ma in the far southeast, with eruption of the lowermost units of the Boonmoo Volcanic Subgroup, probably in a sag structure. This was followed by the eastern Boonmoo (Boonmoo Sag) succession and the Nightflower Dacite (in the far north) at about 306-308 Ma. A major volcanic-intrusive episode occurred at about 300 Ma, with development of the Eight Mile, Wolfram, Boxwood and Dooloan Creek Cauldrons and the Tennyson Caldera. The Jamtin Rhyolite and the Redcap Dacite were also emplaced during this episode, both probably being outflow equivalents of units in the Eight Mile sequence. The Mount Mulligan Caldera (Timber Top Volcanic Subgroup) appears to have formed slightly later than the Boonmoo and Wolfram structures, but was overprinted by the next major volcanotectonic episode. This episode was reponsible for the formation of the Featherbed Caldera, at about 290 Ma, and was followed by formation of the adjacent Djungan and Wakara Calderas at about 280 Ma.

The Nychum Volcanics, abutting the northern margin of the Wakara Caldera, were not examined in detail during this study. They appear to be approximately contemporaneous with the Wakara sequence, but differ markedly in many respects, including being composed mostly of lavas rather than ignimbrites.

ACKNOWLEDGEMENTS

The task of mapping and sampling the Featherbed volcanics and associated rocks would have been exceedingly difficult without the contributions and assistance of many people. Mr R.J. Bultitude of the Geological Survey of Queensland (now a section of the Department of Minerals and Energy), in particular, contributed a considerable amount to the work on the northwestern part of the complex (Wakara Cauldron) and to the helicopter-supported work on the central Featherbed Caldera. Mr I.P. Rienks, Mr L.J. Hutton, Mr. S.R. Law, and Mr P.T. Donchak, all of the (then) Geological Survey of Queensland, contributed to the geological mapping and sampling of the central and northern parts of the complex during helicopter-supported operations in 1983 and 1986. I also received valuable assistance from Rosemary Hegarty, Len Cranfield, and Mark Hayward, of the same organisation, with granite sampling during the 1984 field season.

I am very grateful for the generous support and encouragement of PNC Exploration (Australia) Ltd., and to Mr Stewart Williams and Mr Greg. McKay, who provided vital helicopter support during the 1983 field season as well as much useful information.

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I am also grateful to Drs D. Wyborn and D.H. Blake for constructive comments which materially improved this report.

INTRODUCTION

Felsic volcanic terrains have been an important focus of the attention of academic and exploration geologists for many years, but especially since the enormous mineral potential of terrains in the southwestern USA was recognised. It was there that many of the classic concepts and models of felsic volcanism and mineralisation, notably those relating to cauldron collapse and caldera evolution, were developed (*e.g.* Smith & Bailey, 1968; Steven & others, 1974; Lipman & others, 1976; Lipman, 1984).

The extent of felsic volcanic-intrusive terrains, mostly of Carboniferous to Permian age, in northeastern Queensland was demonstrated by regional geological studies including those of de Keyser & Wolff (1964), White (1965), de Keyser & Lucas (1968), and, in particular, Branch (1966). Branch recognised cauldron-collapse and ring-complex features in many of these terrains, and developed models for their evolution based on the early work in the southwestern USA (*e.g.* Smith, 1960a & b; Smith & others, 1960, 1961). However, Oversby & others (1980), Mackenzie & Oversby (1983), and Mackenzie (1987b) showed that the "classic" models of caldera evolution do not necessarily apply in northeastern Queensland. In particular, the Late Carboniferous volcanic sequences are mostly related to basin-like "sag" structures rather than circular or elliptical, fault-bounded, collapse structures. These authors also argued that differences in relative proportions of rock types and in structural style between the Late Carboniferous and Early Permian sequences may be related to differences in regional tectonic setting.

Interest in these felsic volcanic terrains by the mineral exploration industry was sparked by discoveries of uranium in the early 1970's (*e.g.* O'Rourke, 1975) and, more recently, by recognition of exploitable concentrations of gold at Kidston (Butler, 1984), Red Dome (Karjalainen & others, 1987), and several other localities.

The Featherbed Volcanics (Branch, 1966; here renamed Featherbed Volcanic Group) form the largest and best-exposed contiguous accumulations of mainly felsic volcanic and associated intrusive rocks in northeastern Queensland (Fig. 1). Both the sag and the cauldron-collapse structural style are represented, and there are corresponding contrasts in age, the ratio of mafic to felsic compositions, and in other chemical characteristics (Mackenzie, 1987b; 1988). There is also evidence to suggest that there is a genetic link between these structural and chemical contrasts and corresponding differences in type and style of mineralisation in and around the volcanics (Mackenzie, 1987b). Thus the Featherbed Volcanic Group represents an opportunity to integrate in a single volcanic-intrusive complex studies of (1) the structural and magmatic evolution of subsidence-related volcanic sequences, (2) the role in these processes of chemical differences in "parental" magmas and, ultimately, of source composition, and (3) the relationships between mineralisation and magma composition, magma evolution, and structural evolution.

The principal aims of this report are, as an accompaniment to the 1:100 000-scale geological map (Mackenzie & others, 1993), to document the geological characteristics and relationships of the extrusive rocks that comprise the Featherbed Cauldron complex, and to outline the structure and volcano-tectonic evolution of the complex. Subsequent reports, in preparation or planned, will (1) set out details of the intrusive rocks; (2) document the geochemistry and discuss the petrogenesis of both the extrusive and intrusive rocks; and (3) document mineralisation types and styles in the region and assess relationships with types and distribution of alteration, and with the magmatic and volcano-tectonic evolution of the complex.

OUTLINE OF GEOLOGY

The Featherbed volcanic-intrusive complex consists of a central, essentially contiguous, mass of extrusive and minor, high-level, intrusive rocks surrounded by a broad zone containing numerous, deeper-level intrusive bodies which cut sedimentary rocks of the Hodgkinson Basin (Mackenzie & others, 1993). The extrusive rocks may be divided into two groups: Late Carboniferous rhyolitic to andesitic ignimbrites and lavas of I-type character; and Early Permian, dominantly rhyolitic, ignimbrites and lavas of A-type character.

LATE CARBONIFEROUS

Extrusive rocks

The Late Carboniferous rocks crop out in five areas. In the southeast, the Boonmoo Volcanic Subgroup occupies a composite, basin-like depression - the Boonmoo Cauldron, comprising the Boonmoo Sag and the Eight Mile Cauldron - which is about 25 km in diameter and shows little unequivocal evidence of peripheral ring faulting (Figs 1, 2). The Boonmoo Volcanic Subgroup is intruded by several bodies of high-level porphyritic microgranite. Isotopic ages of these rocks range from about 313 Ma to about 300 Ma (Black, 1978; Black, pers. comm., 1990; AGSO, 1993).

In the central-east, between Wolfram Camp and Branch Creek, outliers of dacitic to rhyolitic ignimbrite are associated with major dykes and an arcuate granitic intrusion, suggestive of independent caldera-collapse structures. However, their petrological character also suggests that the eruptive rocks may be correlatives of ignimbrite sheets in the Boonmoo sequence.

To the west of the Boonmoo Cauldron, a thin remnant of a sequence of dacitic to rhyolitic ignimbrites, rhyolitic tuffs, and volcanogenic sediments (Tennyson Volcanic Subgroup) is contained within a semicircular depression bounded by the Tennyson Ring Dyke to the south and the southern margin of the Featherbed Caldera to the north. The Boxwood Volcanics to the south, a thin outlier of mainly dacitic ignimbrite, lava, and pyroclastic rocks, are associated with a ring structure about 10 km in diameter, but it is possible that they are correlatives of the lowermost part of the Tennyson Volcanic Subgroup.

Late Carboniferous rhyolitic to dacitic ignimbrites (Jamtin Rhyolite) crop out in the western half of a north-northwesterly trending syncline adjacent to the western margin of the Featherbed Caldera, and in a steeply-dipping outlier, on strike with the western limb of the fold, at Chillagoe. These rocks have been dated at about 302 Ma (L.P. Black, pers. comm., 1990; AGSO, 1993), and are likely correlatives of the younger, western part of the Boonmoo Volcanic Subgroup in the Eight Mile Cauldron. Ten kilometres to the northwest of Chillagoe, a block of steeply-dipping rhyolitic to andesitic ignimbrites (Redcap Dacite) is partly faulted into the Hodgkinson Formation basement, and partly engulfed by a large granodiorite pluton. These rocks may be correlatives of the Jamtin Rhyolite and upper Boonmoo Volcanic Subgroup.

The Doolan Creek Rhyolite crops out a few kilometres further to the north, occupying part of an approximately circular area which may be a cauldron subsidence structure. The volcanic rocks overlie Hodgkinson Formation, and are intruded by a variety of granitoids. The Nightflower Dacite, the most northerly of the Late Carboniferous rocks in the Featherbed Volcanic Group, crops out a few kilometres southeast of "Nychum" homestead, and about 35 km north of Chillagoe. Both the Nightflower Dacite (308 $\pm$ 4 Ma) and the Doolan Creek Rhyolite are possible correlatives of ignimbrites in the lower part of the Boonmoo Volcanic Subgroup (Boonmoo Sag); local eruptive source(s), although not identifiable with present data, are also possible.

Intrusive rocks

Granitic rocks of demonstrated or probable Late Carboniferous age crop out extensively both in and around the Featherbed cauldron complex. In the southeast, plutons ranging in composition from monzodiorite and gabbro to granite, but dominated by granite, intrude Hodgkinson Formation rocks. The most important of these intrusive rocks are the James Creek ("Wolfram"), Atlanta, Lass O'Gowrie, Hales Siding, and Petford Granites; the James Creek Granite also intrudes Upper Carboniferous extrusive rocks (Beapeo Rhyolite).

On the western side of the Featherbed complex, extensive bodies of granodiorite (Almaden and Ruddygore Granodiorites), along with several smaller intrusive bodies of granodioritic to granitic composition, intrude Upper Carboniferous Jamtin Rhyolite, Redcap Dacite, and Doolan Creek Rhyolite, as well as the Hodgkinson and Chillagoe Formations. South of Almaden, the predominantly granodioritic intrusives give way to a variety of granitic intrusions including the Ootan, Lucy, and Billycan Granites.

The Boonmoo Volcanic Subgroup is intruded by a variety of granitic bodies, including high- level porphyritic (micro)granites (*e.g.*, the Halpin Granite, which crops out over a large part of the eastern Boonmoo Sag, and the Gibbs Granite), leucogranites (Bamford Granite), and porphyritic granite/granodiorite (*e.g.*, Borneo Granite). The Tennyson Volcanic Subgroup is intruded by the Cottell Rhyolite ("Tennyson Ring Dyke"). In the north of the Featherbed complex, the Nightflower Dacite is intruded by small bodies of granodiorite and granite.

Bodies of granite and granodiorite intruding Hodgkinson Formation adjacent to the northern end of the Featherbed complex (Djungan Caldera), including the Pandora and Big Watson Granites, are tentatively assigned a Late Carboniferous age, based on their mineralogical and geochemical similarity to isotopically dated Late Carboniferous intrusives.

Rhyolite dykes of uncertain age, but regarded as probably Late Carboniferous on the basis of their geological relationships, cut most of the Late Carboniferous extrusive and many of the intrusive units. A dyke of basaltic andesite composition which cuts across the Boonmoo Sag along a major structural feature may also be of Late Carboniferous age.

Isotopic (mainly Rb-Sr whole-rock ± mineral) ages of the granitic rocks range from *ca.* 313 Ma (Hales Siding), or possibly 318 Ma (Lass O'Gowrie) to *ca.* 300 Ma (Black, 1978; Black & Mackenzie, in prep.).

EARLY PERMIAN

Extrusive rocks

Main Featherbed-Djungan-Wakara composite caldera

Almost the entire preserved volume of the Early Permian volcanic rocks, and probably about 70-80% of that of the Featherbed Volcanic Group as a whole is contained within the Featherbed-Djungan-Wakara composite caldera (referred to hereafter as the Featherbed Cauldron). Rhyolitic ignimbrites dominate the eruptive sequences, making up over 90% by volume, the remainder made up of rhyolitic volcanic breccia (some of which is intrusive), rhyolite flows and domes, and rare tuff. The Featherbed Cauldron cuts across all other volcano-tectonic structures that make up the Featherbed Volcanic Group, and is bound by a continuous ring-fault system intruded over much of its length by porphyritic microgranite ring dykes.

The southernmost and largest caldera of the Featherbed Cauldron is the Featherbed Caldera: it has an elliptical main, southern portion with a parallel-sided, graben-like feature extending to the northwest where it is truncated by the Djungan and Wakara Calderas. Crossing the "graben" from west-southwest to east-northeast is the Combella Creek Hinge Zone (Fig. 2), which is marked by a large dyke of Lags Microgranite in the west, a dyke and small stocks of Lags Microgranite at the east-northeastern end, and a broad zone of structural disturbance. Structural disturbance - faulting and tilting - is particularly evident in the area around the junction of Hot Springs Creek with the Walsh River. The hinge zone appears to be a result of differential collapse of the Featherbed Caldera whereby the south-southeastern end of the caldera has rotated considerably downward, in trapdoor fashion, relative to the north-northwestern end.

The Featherbed Caldera is approximately 770 km^2 in area, and the eruptive sequence (Yongala Volcanic Subgroup) is at least 1 km, possibly as much as 2 km, thick in the thickest (eastern) part. The Yongala Volcanic Subgroup has been dated isotopically at about 290 Ma.

The Featherbed Caldera sequence is faulted in the north against the Djungan Caldera sequence (Djungan Volcanic Subgroup), an eruptive pile covering about 300 km^2 and about 1300m thick. The main part of the Djungan Caldera is roughly circular or elliptical, and, like the Featherbed Caldera, it has a graben-like extension to the west-northwest. There is also a suggestion here of a trapdoor-like collapse, with the southeastern side of the caldera appearing to have collapsed to a greater degree than the northwestern side. The uppermost ignimbrite unit in this sequence has been isotopically dated at 281 ± 4 Ma (L.P. Black, pers. comm., 1991).

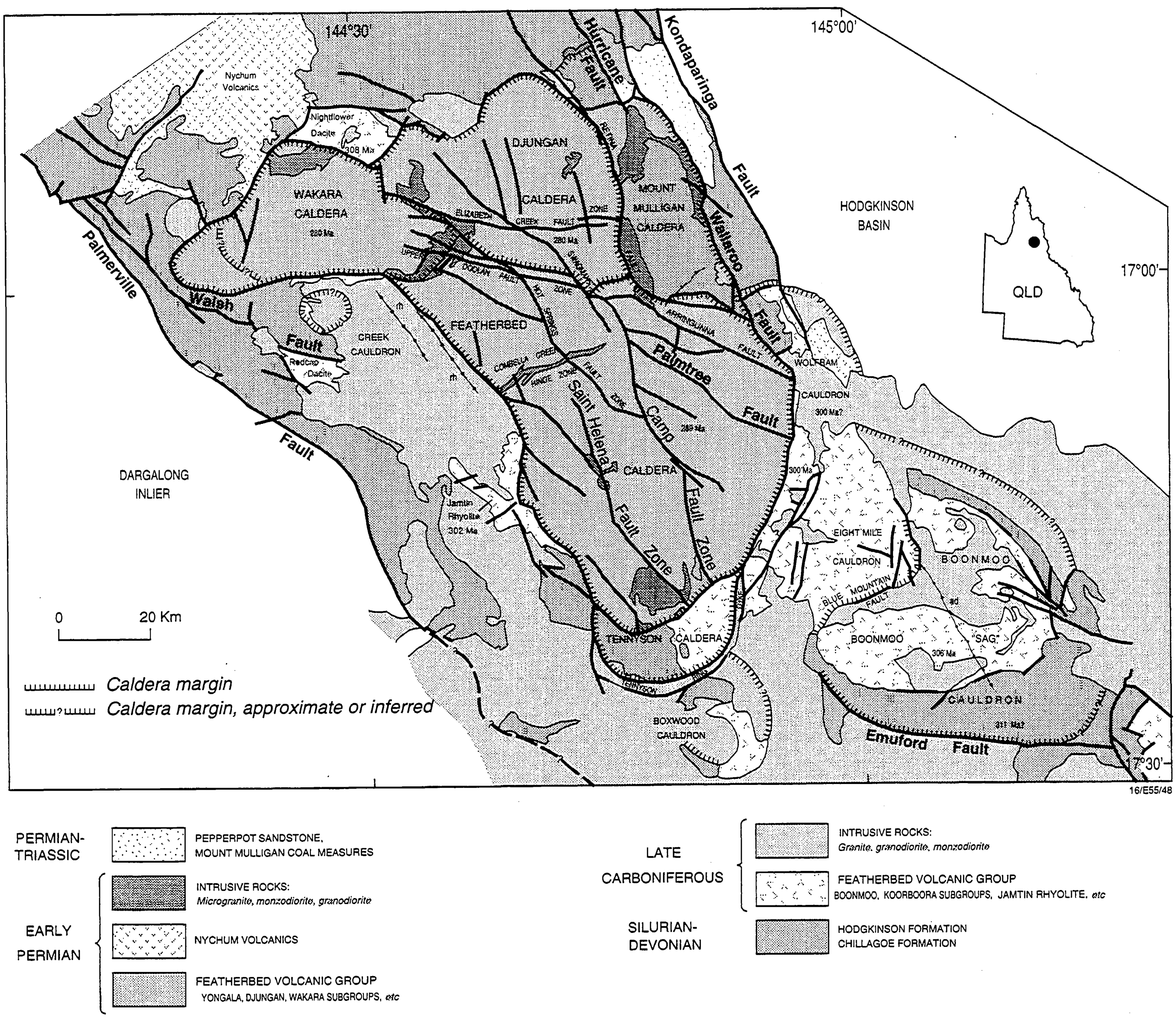

Figure 2. Generalised geology and structure of the Featherbed cauldron complex, showing constituent calderas and cauldrons.

Extrusive rocks outside the Featherbed Cauldron

Isolated outliers of ignimbrite and lava (Timber Top Volcanic Subgroup) extensively intruded by granodiorite stocks and rhyolite dykes to the west and southwest of Mount Mulligan are regarded as probably Early Permian on the basis of their mineralogical and geochemical similarity to isotopically dated rocks of the main Featherbed, Wakara and Djungan Calderas further to the southwest and west.

Finally, the Nychum Volcanics (Bultitude & Domagala, 1988), which consist of an extensive but thin and discontinuous sheet of basaltic to rhyolitic lavas, ignimbrites and tuffs, are cut by the marginal ring fault-dyke system of the Featherbed cauldron which forms the southern boundary.

Intrusive rocks

The Featherbed Cauldron sequences are intruded by a peripheral, discontinuous porphyritic microgranite ring dyke complex (including Lags Microgranite), and by several, very shallowly-emplaced bodies of porphyritic granite to granodiorite (St Helena Monzogranite, Bustlem Granite, Yokas Granite, and part of the Lags Microgranite). Lags Microgranite also forms a 300 to 600 m-wide cross-cutting dyke in the western Featherbed Caldera. Isotopic ages from the Lags and Bustlem Microgranites are ~280 Ma (L.P. Black, pers. com., 1991); the Yokas Microgranite may be slightly younger.

Some of the dyke-like bodies of andesite and dacite adjacent to the margins of the Featherbed Cauldron may be intrusive and of Early Permian age, and a swarm of rhyolitic to andesitic dykes parallel to the northwestern margin of the Featherbed Caldera, and cutting Late Carboniferous Ruddygore Granodiorite and other rocks, is most likely also of Early Permian age.

Intrusive rocks, of both Early Permian and Late Carboniferous age, associated with the Featherbed Cauldron complex are the subject of a separate detailed report (Mackenzie, in prep.); named intrusive bodies to the southwest and west of the Featherbed Caldera and those in and around the Wakara Caldera are described by Bultitude & others (in press).

LOCALITY, PHYSIOGRAPHY, AND ACCESS

The Featherbed volcanic complex is located about 100km west of Cairns, to the west of the Atherton Tableland, in northeastern Queensland. The southeastern part of the area, from Stannary Hills to lower Emu Creek, is dominated by low to moderate, rounded hills which are generally higher and steeper towards the south and east. Relief ranges from a few metres in parts of the drainage of Eccles Creek to about 350 m in the south and in the Stannary Hills area (Fig. 1). A prominent range of rugged peaks, including Mount Pinnacle (865 m), between Eccles and Eureka Creeks, about 10 km SE of Dimbulah (Figs 1, 3), is the result of the relative resistance to chemical weathering of intensely sericitised rhyolitic to dacitic ignimbrites. The main part of the Featherbed complex, westward and northwestward from Emu Creek, is essentially a deeply dissected plateau (the Featherbed Range), bounded by steep, rocky, escarpments averaging about 120-140 m and ranging up to 200 m high. Relief within the "plateau" area is generally about 200-300 m, but ranges up to 600m in the northeast of the Featherbed Caldera. Slope steepness and relief show a general decrease form southeast to northwest, with the most subdued terrain in the Elizabeth Creek-Nightflower mine area (corresponding with the Nightflower Dacite).

The Featherbed Range is bisected by the Walsh River (Figs 1, 3), a perennial stream since diversion into it of irrigation waters *via* the Mareeba and Dimbulah horticultural areas from Tinaroo Dam on the upper Barron River. The gorge cut by this river through the volcanics averages about 250-300 m deep, ranging up to almost 500 m deep, and provides some excellent exposures and sections.

Vegetation comprises moderately sparse to moderate cover of mainly eucalypts and acacias, and moderately dense grass (dominantly "speargrass"). Tree cover is slightly denser on the east-facing, higher, slopes on the eastern side of the complex; "grass trees" and cycads are common in these areas. Tree cover within the Featherbed complex is generally denser than on the surrounding, generally lower and less rugged terrain, which is generally more densely grassed.

Dimbulah, a town of about 200 people at the centre of a tobacco-growing area, is about 10 km from the eastern margin of the complex and is accessible by all-weather bitumen road from Mareeba and Cairns. The Burke Developmental Road, which links Dimbulah with Chillagoe, Wrotham Park station, and, ultimately, the Gulf of Carpentaria, traverses the southeasternmost (Boonmoo Cauldron) and southernmost (Tennyson Caldera) lobes of the Featherbed complex, and passes close to the northwesternmost margin, at the Walsh Crossing (Fig. 3). Several tracks, mostly associated with "Boonmoo" station, traverse parts of the Boonmoo Sag, one linking "Boonmoo" with Orient Camp and the Emuford-Herberton road, but, apart from a small number of minor tracks which give access to very limited areas of its margins, most of the Featherbed complex is accessible only by horseback, helicopter, or, most effectively, foot.

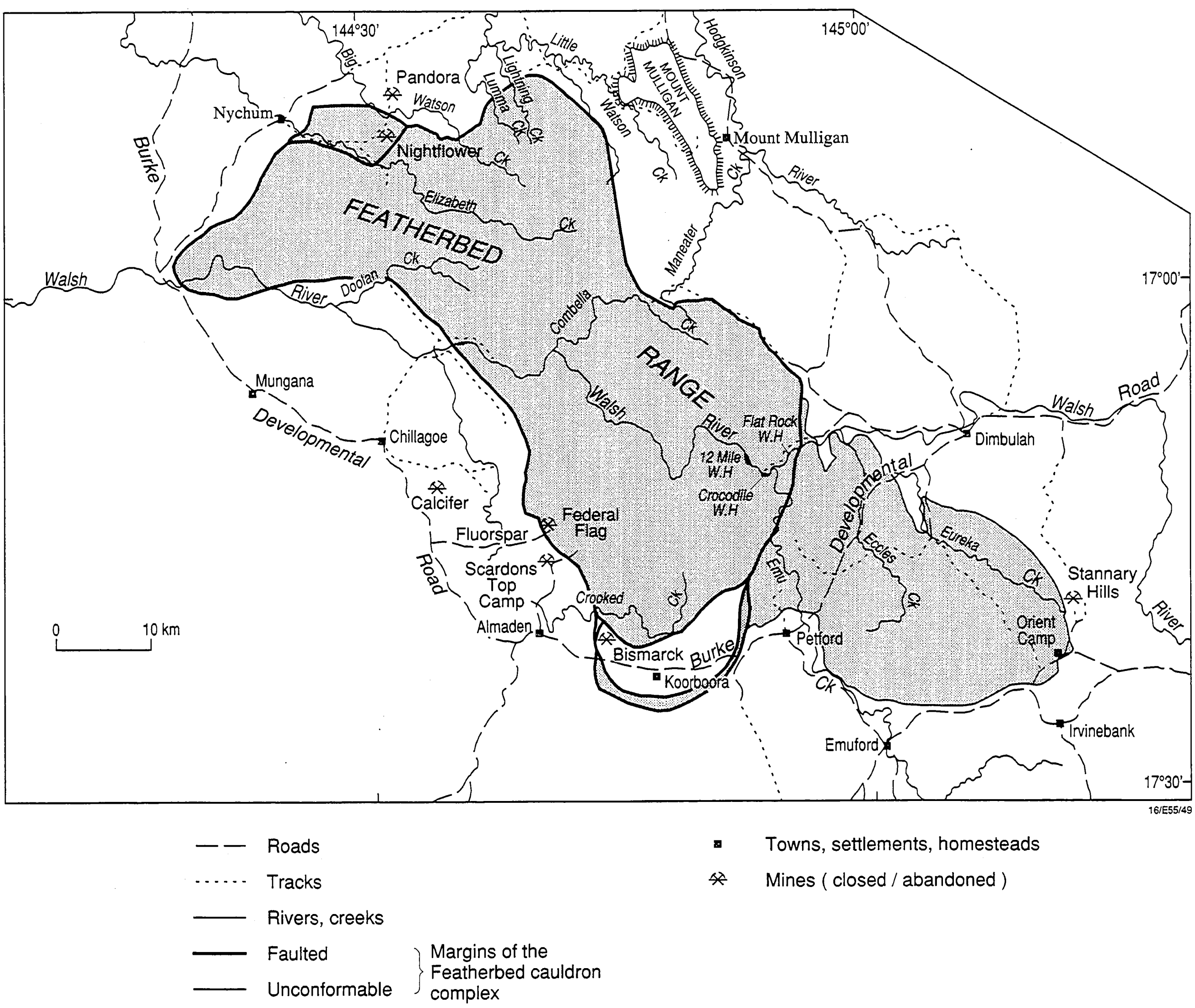

Figure 3. Principal geographic features and road access, Featherbed cauldron complex.

To the west of Dimbulah, a track extends down the north side of the Walsh River to Flat Rock, Crocodile, and 12 Mile Waterholes, about 10 km into the complex. Northwest of Dimbulah, a track westward from the Wolfram Camp mine area gives access to the margin of the complex in the upper Maneater Creek-Combella Creek area. Tracks in the area west of Mount Mulligan give limited access to the Timber Top Volcanic Subgroup and to the northeastern margin of the main cauldron complex; these tracks are linked to that linking "Nychum" with the Mitchell River near its junction with the Hodgkinson River. Rough tracks from "Nychum" give some access to the northern part of the complex in the Elizabeth Creek, Nightflower mine, and Big Watson Creek areas; "Nychum" is linked to the Burke Developmental Road by a good gravel road. A station track from Chillagoe airstrip provides access to Fisherman Waterhole on the Walsh River, at the western margin of the Featherbed complex, and possibly, depending on the amount of recent erosion, to the Pinchgut Pinnacle area, a few km to the south, and to Doolan Creek where it cuts through the margin of the complex. Other tracks from the Chillagoe area, from Almaden, and from the highway between these towns provide access to the Calcifer, Fluorspar, Federal Flag Mine, and Scardons Top Camp mine areas on the western margin. There is also very limited access to the southern margin of the main cauldron complex *via* tracks to the Bismarck mine area, and into the upper reaches of Crooked Creek from the Koorboora area.

REGIONAL GEOLOGICAL AND STRUCTURAL SETTING

The Featherbed Cauldron Complex overlies and intrudes sedimentary and minor igneous rocks near the western margin of the Siluro-Devonian Hodgkinson Basin (Figs 1, 2). The Hodgkinson Basin is bounded on its western side by the Palmerville Fault, along which Proterozoic metamorphic rocks (Dargalong and McDevitt Metamorphics) and granites have been overthrust towards the east (Shaw & others, 1987; Withnall & others, 1987). To the east of the Palmerville Fault are several subparallel, anastomosing thrust faults (Shaw & others, 1987), some of which cut and displace parts of the older units of Featherbed Volcanic Group. For example, the Timber Top Volcanic Subgroup and Beapeo Rhyolite are cut by the Hurricane and Wallaroo Faults. The Redcap Dacite and Jamtin Rhyolite have been faulted and tilted (in the case of the Jamtin Rhyolite, folded) by folding and thrusting(?) movements near the western margin of the Hodgkinson Basin; these movements produced a series of mostly west-younging fault slices (Shaw & others, 1987; Bultitude & others, 1990).

Some of the major faults subparallel to the Palmerville Fault merge with cauldron-margin faults (*e.g.*, Retina Fault; Fig. 2). The Hurricane Fault appears to extend to the Wolfram Camp area where it is obscured (or overprinted) by the James Creek and Atlanta Granites. However, the fault is aligned with a straight and probably faulted (concealed) boundary on the northeastern side of the Eight Mile Cauldron, and with an andesite dyke that cuts across the entire Boonmoo Cauldron complex (Fig. 2): it is likely that these structures are extensions of, or directly related to, the Hurricane Fault.

Although there is evidence of movement on the Palmerville Fault itself as late as Tertiary, principal movements on the Palmerville fault system were pre-300 Ma (Shaw & others, 1987), and none of the faults significantly displaces the main mass of the Featherbed Volcanic Group. There is, however, evidence to suggest that the tectonic development of the western part of the Hodgkinson Basin, in particular development of the system of faults subparallel to the Palmerville Fault, has had a significant effect on the structural evolution of the Featherbed complex. This is discussed in EVOLUTION OF THE FEATHERBED CAULDRON, below.

Adjacent to the northeastern margin of the volcanics and separated from them by one of the fault zones subparallel to the Palmerville Fault (Hurricane Fault: Halfpenny & others, 1987) is an isolated mesa of Late Permian to Triassic(?) terrestrial sediments - the Mount Mulligan Coal Measures and Pepper Pot Sandstone (Amos & de Keyser, 1964; Oversby, 1987). The lowermost parts of this sequence contain variably reworked detritus derived from the Featherbed Volcanic Group.

GEOLOGY

The Featherbed Cauldron Complex is a composite of three or more Late Carboniferous subsidence structures, associated remnants of probable outflow sheets, and a Late Carboniferous-Early Permian subsidence structure, overprinted by a fault- and ring dyke-bounded composite of three calderas of Early Permian age (Fig. 2). Ring(?) dykes and other high-level intrusions, and remnants of ignimbrite sheets and lava flows in the northeast, between the Mount Mulligan massif and the Featherbed Range, may also be of Early Permian age (based chiefly on their composition), but are also overprinted by the main composite caldera.

Because there are several important differences between them, it is appropriate to describe the Late Carboniferous volcanics (and associated intrusive rocks) separately from those of Early Permian age.

NOMENCLATURE

Igneous rock nomenclature in this report generally follows that of the IUGS, as summarised by Le Maitre (1986). However, it was found that the term "rhyodacite" was very useful in distinguishing in the field between the highly felsic (or silicic), generally mafic-poor "true" rhyolites and less felsic, lower-silica, more mafic-rich rocks. Consequently, "rhyodacite" is retained as a descriptive term, although not used in formal nomenclature.

IGNIMBRITE NOMENCLATURE

In order that nomenclature of pyroclastic rocks of ash-flow origin are more informatively named, I have adopted the approach used for several years by BMR/AGSO geologists (*e.g.*, Oversby, 1978) of using the term "ignimbrite" rather than "ash-flow tuff", as used in North America. I also use compositional terms for naming ignimbrite units (*e.g.*, Arringunna Rhyolite) rather than genetic terms such as "Arringunna Tuff", as such a unit would be called in the USA. This of course means that ignimbrites (or ash-flow tuffs) are not distinguished from lava flows in name alone, but the alternative (*e.g.*, "Arringunna Rhyolitic Ignimbrite") seems cumbersome and makes nomenclature very repetitive.

Crystal Content

Ignimbrites are subdivided into the following classes based on content of crystals and crystal fragments:

Very crystal-poor - <5%

Crystal-poor - 5-10%

Moderately crystal-poor - 10-15%

Moderately crystal-rich - 15-25%

Crystal-rich - 25-35%

Very crystal-rich - 35-45%

Extremely crystal-rich - >45%

Lithic Clast Content

Ignimbrites are subdivided into the following classes based on content of lithic clasts:

Very lithic-poor/Lithic-bearing - <1%

Lithic-poor - 1-5%

Moderately lithic-poor - 5-15%

Moderately lithic-rich - 15-25%

Lithic-rich - 25-35%

Very lithic-rich - >35%

FEATHERBED VOLCANIC GROUP

LATE CARBONIFEROUS

Volcanic rocks of the Featherbed Volcanic Group, together with associated intrusive rocks, dated as Late Carboniferous (313Ma to 301Ma) by Richards & others (1966), Black & Richards (1972), Black (1978) and L.P. Black (pers. comm., 1990, 1991) are preserved in a basin-like subsidence (sag) structure about 25km in diameter in the southeast of the complex (Fig. 2; Boonmoo Volcanic Subgroup, Table 1). The Jamtin Rhyolite, on the western side of the Featherbed Caldera, has been dated at 301 ± 11 Ma (Black, pers. commm., 1990; a minimum age), and the Nightflower Dacite, on the northern margin of the Wakara Caldera, has been dated at 308 ± 4 Ma (L.P. Black, pers. comm., 1991). The Tennyson Ring Dyke (or Tennyson Volcanic Fissure: Branch, 1966) in the south is also regarded as of Late Carboniferous age (301 ± 9Ma) by Black (1978). Volcanic rocks that are probably of Late Carboniferous age on the grounds of either their geological relationships, or their mineralogical and chemical similarities, to the dated rocks are:

(1) in the south, between the Tennyson Ring Dyke and the faulted margin of the Early Permian composite cauldron (Tennyson Volcanic Subgroup);

(2) in the west, where remnants of possible ignimbrite outflow sheets are preserved as flat-lying outliers and variably tilted fault slices (Doolan Creek Dacite, Redcap Dacite);

NYCHUM VOLCANICS)				
WAKARA VOLCANIC SUBGROUP		DJUNGAN VOLCANIC SUBGROUP		
Rackarock Rhyolite	- Pwm	Lumma Rhyolite		
	- Pwk	Lightning Creek Rhyolite		
	- Pwj	Pdd		
Ticklehim Rhyolite	- (Pwi)	Pdc		
Pwg	- Pwh	Aroonbeta Rhyolite		
Pwf		Scrufflem Rhyolite		
Gavin Rhyolite	- Pwe$_3$	Pd		
	- Pwe$_2$			
	- Pwe$_1$			
Pwx Ple	Pwd			
Stuarts Rhyolite	- Pwc			
	- Pwb$_2$			
	- Pwb$_1$			
Wollenden Rhyolite	- Pwa$_3$			
	- Pwa$_2$			
	- Pwa$_1$			
Pla, Plb, Plc, Pld, Ple,				
Plx, Plg, Pli, Plt, Plv,				
Plw, Plk, Plm, Pln, Plo,				
Plr				
	(Fisherman Rhyolite)			

YONGALA VOLCANIC SUBGROUP				
Arringunna Rhyolite	- Pfa$_1$			
	- Pfa	TIMBER TOP VOLCANIC SUBGROUP		
Combella Rhyolite	- Pfc - Pfc$_2$	Breccia Creek Rhyolite		
	- Pfc$_1$	Pfv, CPb		
Fisherman Rhyolite	- Pff/Pff$_i$	CPt		
	- Pfl	Controversy Hill Rhyolite		
———————————?		CPu, CPu$_1$		
		CPa		
		?———————————		
TENNYSON VOLCANIC SUBGROUP		BOXWOOD VOLCANICS		
Lappa Rhyolite				
Allsorts Rhyolite	- Ckai			
	- Cka			
	- Ckat			
Dalnotter Dacite				

BOONMOO VOLCANIC SUBGROUP				
Eight Mile sequence				
Rock Hole Rhyolite		Jamtin Rhyolite (Cjr$_{1-4}$, Cjd),		
Theodolite Rhyolite	- Cbt$_2$	Wallaroo rhyolite - (Crw$_{1,2}$)		
	- Cbt$_1$			
Verdure Andesite	Redcap Dacite	- Crv$_3$		
Adder Dacite		- Crv$_2$	Beapeo Rhyolite	- Crb
Hopscotch Rhyolite		- Crv$_1$		- Cab
Muirson Rhyolite				

Boonmoo sequence				
Eureka Rhyolite				
Bluewater Rhyolite		Nightflower Dacite, Doolan		
Cummings Rhyolite		Creek Rhyolite(?)		
Orient Rhyolite				
Bedlog Rhyolite				

Table 1. Summary of stratigraphy, Featherbed Volcanic

(3) in the northeast: small outliers of ignimbrite between Wolfram Camp and Maneater Creek, and at least some of the volcanic rocks between the main (Early Permian) composite caldera and the Mount Mulligan block are probably of Late Carboniferous age.

Boonmoo Volcanic Subgroup - Boonmoo Cauldron

The Boonmoo Cauldron is a composite cauldron of roughly elliptical overall shape, truncated along its western side by the Featherbed Caldera; its total area is about 650 km. The Cauldron is divided into two parts - the Boonmoo "Sag" in the east and the Eight Mile Cauldron in the west - by the Blue Mountain Fault. This fault is a curved, dip-slip fault with significant west-side down movement, judging from the juxtaposition of the high-level Halpin Granite on the eastern side of the fault with a thick volcanic pile to the west.

Around most of the periphery of the Boonmoo Sag, contacts between the extrusive sequence and Hodgkinson Formation basement are gently to moderately (15^{o} to 40^{o}) inward dipping. However, arcuate faults are apparent along segments of the margin in the south (Montalbion area), southeast (Orient Camp), and east (northwest of Stannary Hills), and it is possible that more extensive ring faulting is buried beneath the outermost parts of the Sag. The Emuford Fault, an arcuate dip-slip (north side down) fault that extends about 30 km from near Mount Black in the west (GR7863-850760) east-southeast to the Mount Misery area (GR7963-120660), strongly resembles a partial ring fault. However, no continuation could be traced around the eastern end of the Boonmoo Cauldron, there is no evidence of extrusive rocks in or near the fault, and it is filled by high-level intrusive rocks only at its extreme western end. Similarly, an arcuate contact between the Atlanta Granite and the Hodgkinson Formation, and/or an arcuate fracture-lineament system within the Atlanta Granite and parallel to this contact, may represent part of a ring-faulted caldera margin. However, the arcuate form of these features is the sole evidence of such an origin.

The Eight Mile Cauldron is bounded on the east by the Blue Mountain Fault and associated faults, and is faulted against the Featherbed Caldera in the west. Its northern and south(west)ern extremities are obscure, and overprinted by granitoid intrusions.

Lawrence (1973) divided the volcanic sequence in the Boonmoo Cauldron into three, each postulated to represent a different eruptive "centre". The isotopic age data summarised above and remapping by the author support only a twofold subdivision: an eastern sequence about 313 Ma old and a western sequence about 301 Ma old. The volcanic stratigraphy is summarised in Table 1.

Boonmoo Cauldron ("Sag")

The lowermost, oldest, part of the Boonmoo sequence consists of several sheets of dacitic to rhyolitic ignimbrite, with minor intercalated rhyolite lava, airfall tuff, and reworked pyroclastic deposits.

Bedlog Rhyolite (Cbl)

Derivation of name. Bedlog Rhyolite is named from Bedlog Creek, on Atherton 1:100 000 Sheet, which transects the unit and joins Gibbs Creek at GR7963-056757, 5 km northwest of Irvinebank.

Distribution. Bedlog Rhyolite is the lowermost unit of the Boonmoo Sag sequence. It is exposed in two main areas: in the Gibbs Creek-Chinaman Creek valley east of Montalbion, and in the Elizabeth Bluffs area, 5km NE of Emuford. Tuff(?) and poorly welded ignimbrite tentatively correlated with these rocks crops out in the Stannary Hills area, near the Ivanhoe mine. An outlier of moderately welded ignimbrite about 2km east of the Gladstone mine, also in the Stannary Hills area, is also correlated with Bedlog Rhyolite.

Type section. A complete section of the Bedlog Rhyolite is not exposed; however, representative lithologies are well exposed at GR7963-063755 (pebbly arenite and conglomerate, at/near the base), at GR7963-063756 (rhyolite lava, near the base?), and in a quarry at GR7963-943726 (ignimbrite).

Lithology. At the base of the unit is a discontinuous basal layer, up to about 3m thick, of volcanigenic pebbly quartzofeldspathic arenite, volcanigenic rudite and lutite together with minor, very fine-grained, sparsely porphyritic, flow-laminated rhyolite. These rocks are overlain by about 15-20m of medium-grey, poorly to moderately welded, lithics-poor, crystal-rich, hornblende(?)-biotite rhyolitic ignimbrite with a very fine eutaxitic texture. The ignimbrite thickens, and is more intensely welded and better exposed, towards the west. It is weakly to moderately altered (biotite and possible hornblende are completely altered; accessory allanite is unaltered) to calcite, sericite, and chlorite. The lithic clasts, which constitute less than 1% of the rock and range up to only a few mm across, include porphyritic rhyolite and low-grade metasiltstone.

Thickness. Bedlog Rhyolite ranges in thickness from 35-60 m in the Bedlog Creek area to about 120 m in the Long Waterhole area.

Eruptive source(s). Westward increases in thickness and in abundance and size of crystals suggest that this part of the outcropping unit is closest to the/an eruptive source, but the unit as a whole has a distal aspect.

Structure and relationships. Bedlog Rhyolite dips at about 15-30° northward into the Boonmoo "Sag". It overlies Hodgkinson Formation unconformably, and is overlain, either paraconformably or disconformably, by Orient Rhyolite.

Topography. Most of the unit is characterised by very subdued topography, with brown tones on airphotographs slightly darker than those of the overlying Orient Rhyolite. The ignimbrite component of the unit forms prominent small hills with, in the west (Long Waterhole area), well-developed dip slopes.

Age. Isotopic dating of units overlying the Bedlog Rhyolite produced ages of about 310-313 Ma (Black, 1978): this is a minimum age for the unit.

Synonymy. Bedlog Rhyolite was included as part of the Featherbed Volcanics (undivided) by Branch (1966). The part of the unit northeast of Montalbion was recognised as a separate unit by Lawrence (1973), but not named.

Orient Rhyolite (Cbo_{1-4})

Derivation of name. The name Orient is derived from Orient Creek, which joins Cummings Creek at GR7963-087794, and Orient Camp, an abandoned mining settlement on the bank of Orient Creek.

Constituent units. Orient Rhyolite comprises four unnamed members: Cbo_1, Cbo_2, Cbo_3, and Cbo_4.

Distribution. Orient Rhyolite crops out around the southeastern margin of the Boonmoo sag between the Stannary Hills area in the east and the Le Roys Camp area (145°E) in the west. It also crops out in an outlier east of Stannary Hills, near the Gladstone mine. The lowermost subunit (Cbo_1) crops out along the southern margin of the sag, between Cummings Creek and Long Waterhole on Gibbs Creek, and in the outlier near the Gladstone mine. The main outcrop area of the second subunit (Cbo_2) is in the Orient Camp area, extending 6km to the southwest and 5km to the north. It also crops out in the outlier near the Gladstone mine. The third subunit (Cbo_3) crops out as a belt 100 to 300m-wide extending 6km northeastward and northward from Orient Camp. The fourth subunit, Cbo_4, crops out as a lenticular body, about 2.7 km long, 2 km north of Orient Camp.

Type section. The type section of Orient Rhyolite is composite: Cbo_1, Cbo_2, and Cbo_3 are exposed along the Emuford-Stannary Hills road between Chinaman Creek (GR7963- 062757) and the junction with the Weinert/Boonmoo track (-083787), and along that track to GR7963-078795; Cbo_3 and Cbo_4 are exposed along a disused track between GR7963- 085819 and -078825.

Lithology. The Orient Rhyolite consists of four mappable subunits, each representing either a group of similar ignimbrite flow sheets, or a single flow sheet.

The lowermost subunit (Cbo_1) consists of dark greenish-grey, densely welded, crystal-rich to very crystal-rich, hornblende-biotite-rhyolitic ignimbrite containing accessory Fe-Ti oxide(s), zircon, apatite, and rare allanite. Near the top of the unit, on the Emuford- Stannary Hills road, it contains abundant quartz and feldspar crystals up to 8 mm long. It is moderately to intensely altered in places (e.g. 3km west of Montalbion), mainly to calcite, sericite, and chlorite. Eutaxitic texture, marked by pumice clasts up to 2 cm long and containing phenocrysts up to 8mm across, is discernible in places. The unit contains minor lenses of volcanogenic sedimentary rocks, including a massive, polymictic rudite made up of pebbles and cobbles of ignimbrite (Cbo_1, Cbl) and Hodgkinson Formation arenite and lutite.

The second subunit (Cbo_2) consists of medium to dark green-grey to brown, fine to medium-grained, intensely welded, moderately crystal-rich to crystal-rich, hornblende(?)- biotite rhyolitic to rhyodacitic ignimbrite characterised by subhedral to euhedral quartz crystals 4-6mm across. Identification of hornblende in some samples is uncertain because of the degree of alteration to calcite, chlorite, and sericite. Allanite is a conspicuous and common accessory mineral, along with Fe-Ti oxide(s), zircon, and trace apatite. The very fine eutaxitic texture is generally visible only in thin section.

The third subunit (Cbo_3) consists of dark grey to green-grey or dark greenish-brown (where weathered), intensely welded, fine-grained, moderately crystal-poor, augite(?)-hornblende-biotite-rhyodacitic ignimbrite with a poorly-developed, very fine, eutaxitic texture variably overprinted by recrystallisation. Accessory minerals are magnetite, zircon, and apatite; a trace of possible allanite is present in one specimen. The ignimbrite is variably altered to calcite, chlorite, and sericite, or to sericite and Fe oxides. One kilometre north of Orient Camp, this ignimbrite is overlain by a lens about 3.5km long and 100-150m thick of dark- grey, very fine-grained, crystal-poor, rhyolitic ignimbrite which is variably sericitised. In the Orient Camp area, a lens up to 25m thick and about 350m long of tuff and moderately reworked, volcanic-derived, sandstone crops out at the base of the main ignimbrite sheet (Lawrence, 1973).

The fourth subunit, Cbo_4, consists of pale brown to cream, fine, crystal-poor, rhyolitic ignimbrite and very dark-grey, sparsely porphyritic rhyolite. The rocks are extensively and intensely sericitised.

Thickness. Total thickness ranges from about 350m in the Gibbs Creek area to about 150m in the Stannary Hills area. Thickness of Cbo_1 ranges from about 200m in the Gibbs Creek area to about 80-100m in the Gladstone mine area. The second subunit (Cbo_2) is about 200-250 m thick in the Orient Camp area, thinning to the southwest and north to 100m or less; it is about 100 m thick in the outlier near the Gladstone mine. The third subunit (Cbo_3) is about 70-150m thick; the fourth subunit, Cbo_4, is lenticular, and ranges up to 120-190 m thick.

Eruptive source(s). Variations in thickness and in the size and abundance of crystals suggest that the part of the unit most proximal to source is in the Montalbion area.

Relationships. Where Orient Rhyolite overlies Bedlog Rhyolite, the relationship is disconformable or possibly unconformable; where it rests directly on Hodgkinson Formation, the contact is either unconformable, or, as in the Montalbion and Orient Camp areas, faulted. Cbo_2 partly overlaps Cbo_1 to rest unconformably on Hodgkinson Formation, or disconformably (possibly unconformably) on Bedlog Rhyolite. Relationships between Cbo_2, Cbo_3, and Cbo_4 are paraconformable or disconformable. Cummings Rhyolite overlies Cbo_2 disconformably or unconformably, as does the Bluewater Rhyolite, which overlaps Cbo_3 and Cbo_4 to rest for the most part directly on Cbo_2. Orient Rhyolite is intruded by Gibbs Microgranite and by an andesite dyke of uncertain (Early Permian?) age.

Structure. Orient Rhyolite dips at about 15^{o} to 30^{o} to the north in the Orient Camp area and to the west, but may dip more steeply to the northwest and west in the Deadman Gully area. It is faulted against Hodgkinson Formation basement to the southeast of Orient Camp and in the Montalbion area: it is possible that these faults are small step-faults within a main ring-fault system represented by the Emuford fault (see discussion below).

Topography. Most of the Orient Rhyolite is characterised by low relief, medium-brown soil tones on airphotos, and scattered, low, bouldery outcrop. The finer-grained ignimbrites and lava(s) within Cbo_3 and Cbo_4 form terrain with slightly darker tones, more relief (up to 100 m), and steeper slopes.

Age. Biotite from the Orient Rhyolite has been dated by means of Rb-Sr isotopes at about 313 Ma (Black, 1978).

Synonymy. Orient Rhyolite was included in the Featherbed Volcanics (undivided) by Branch, 1966. The main part of the unit, between Deadman Gully in the northeast and Long Waterhole in the west, was recognised by Lawrence as a separate, but unnamed, unit.

Cummings Rhyolite (Cbc) *(new name)*

Derivation of name. The name Cummings is derived from Cummings Creek, which joins Gibbs Creek at GR7963-052766 and traverses the eastern end of the unit.

Distribution. Cummings Rhyolite (Cbc) forms a belt 200-300m wide and 5km long in the Montalbion area, and a belt 300-400m-wide and 3.5km long 2km west-southwest of Montalbion.

Lithology. The unit consists of medium-to-dark-grey, intensely welded, fine-grained, moderately crystal-poor to moderately crystal-rich, augite-hornblende-biotite rhyodacitic ignimbrite containing accessory magnetite, zircon, and apatite. Its very fine-grained groundmass is recrystallised, obliterating any eutaxitic texture. The ignimbrite is slightly to moderately altered to sericite, chlorite, and calcite; secondary biotite is present in places, close to the Gibbs Microgranite (see below).

Thickness ranges from about 25m in the east to about 100m in the west.

Eruptive source(s). Cummings Rhyolite appears to be entirely a distal facies, and location of its eruptive source(s) is unknown.

Structure and relationships. Cummings Rhyolite dips at a moderate to shallow angle (15- 30^{o}) to the north. It disconformably or unconformably overlies Orient Rhyolite, and is disconformably or unconformably overlain by Bluewater Rhyolite. It is intruded by Gibbs Granite, and by an andesitic dyke of uncertain (Early Permian?) age.

Topography. Cummings Rhyolite is distinguished topographically (on airphotographs) from Orient Rhyolite by paler regolith/outcrop tones and slightly increased relief, and from Bluewater Rhyolite by paler tones and lower relief.

Age. The Cummings Rhyolite is probably about the same age as Orient Rhyolite, *i.e.,* about 313 Ma.

Synonymy. Cummings Rhyolite was included in undivided Featherbed Volcanics by Branch (1966). It was recognised in part as a mappable entity by Lawrence (1973), but not named.

Bluewater Rhyolite (Cbb)

Derivation of name. The name Bluewater is from Bluewater Creek, which joins Emu Creek at GR7963-830794, and traverses the western part of the unit.

Distribution. Bluewater Rhyolite crops out over much of the southern third of the Boonmoo Cauldron, extending from near the Bluewater Creek-Emu Creek junction in the west to the Stannary Hills area in the east, and also crops out in a narrow belt around the northeastern and northern margins of the cauldron as far as Carbonate Creek.

Type section. The type section of the Bluewater Rhyolite is along a track between Orient Camp and "Boonmoo" homestead, between GR7963-078796 (base) and -052812 (top). Scattered outcrop of typical Bluewater Rhyolite may be seen along most of this section, although it is interrupted by an intrusion of porphyritic microgranite (Halpin Granite) around -065800.

Lithology. The Bluewater Rhyodacite consists of dark-grey to dark bluish- or greenish-grey, densely welded, medium-grained, crystal-rich, augite-hornblende-biotite rhyodacitic to rhyolitic ignimbrite with a generally finely recrystallised groundmass. Orthopyroxene is present in one specimen from the Stannary Hills area; it is abundant in one specimen, a biotite-2-pyroxene rhyodacitic ignimbrite from 7km southeast of Petford. Accessory minerals are magnetite, zircon, and apatite; allanite is extremely rare. Small (generally less than 1 cm) lithic clasts, mainly of ignimbrite similar to the third subunit of the Orient Rhyolite, are also very rare. The ignimbrite is in most part slightly to moderately altered to chlorite + sericite ± epidote.

Thickness. In the south, the Bluewater Rhyodacite is possibly up to 2000m thick (if the approximately 15° northerly dip observed in the south is consistent), and certainly at least 900-1000m thick, decreasing northeastward to about 700m west of Stannary Hills. In these areas, the unit appears to consist of several flows, which range from a few tens of metres to 100 m or more thick. In the arc northwestward from Stannary Hills, where it rests directly on basement, the ignimbrite is 100-200m thick and appears to comprise a single cooling, and possibly flow, unit.

Eruptive source(s). There is no clear systematic variation in lithic clast or pumice clast sizes to indicate possible direction(s) to eruptive source, but thickness variation suggests that an/the eruptive source area was in the southwest of the present outcrop area.

Relationships. Bluewater Rhyolite overlies Orient Rhyodacite and Cummings Rhyodacite in the south and southeast of the Boonmoo "lobe", or sag structure, in a disconformable or possibly unconformable relationship. In the east and north, it rests unconformably on Bedlog Rhyolite, or directly on Hodgkinson Formation basement. It is intruded by Halpin Granite, Gibbs Granite, granites interpreted as equivalent to Petford Granite (Bailey, 1984), and by an andesite dyke of possible Early Permian age.

Structure. Bluewater Rhyolite dips at about 10-15° to the north in the south of the cauldron; dips decrease northward toward the cauldron centre, but steepen (to about 20- 30?) around the eastern and northern margins of the cauldron.

Topography. Most of the outcrop area of Bluewater Rhyolite is characterised by moderate to steep, rounded hills with a "mottled", irregular texture (due to patchy tree growth and patches of bouldery outcrop) and relief typically between 100 and 200 m. Soil/regolith tones on airphotographs are medium brown (during the dry season), and significantly darker than the adjacent rock units (both extrusive and intrusive).

Age. Black (1978) obtained biotite Rb-Sr ages for the Bluewater Rhyodacite (then not distinguished from the other units of the southeastern part of the Featherbed Cauldron) of 309 to 311 Ma; he also derived an age of 311± 16 Ma from an isochron based mainly on samples from the Bluewater Rhyodacite. Recent Rb-Sr dating (L.P. Black, pers. comm., 1990) of a sample from about 190 m above the base of the unit in the southwest gave an age of 306 ± 3 Ma (initial $^{87}Sr/^{86}Sr = 0.710 \pm$ 0002)..

Synonymy. Bluewater Rhyolite was included in undivided Featherbed Volcanics by Branch (1966). It was recognised as a mappable, but unnamed, unit by Lawrence (1973), whose boundaries for this unit differ only slightly from those now recognised.

Eureka Rhyolite (Cbu) *(new name)*

Derivation of name. Eureka Rhyolite is named from Eureka Creek, a major tributary of the Walsh River; Eureka Creek traverses the northeastern portion of the Boonmoo Cauldron, including the main outcrop area of Eureka Rhyolite.

Distribution. The unit crops out in three main areas in the northeast of the Boonmoo Cauldron: an approximately equidimensional area of about 20 km^2 east of "Boonmoo" homestead connected to a ~1 km-wide, ~15-km long belt parallel to the northeastern cauldron margin, an ~11 km^2 area between Eureka and Murphy Creeks, and a ~4 km^2 area a few km farther south.

Type section. Typical Eureka Rhyolite is exposed along a track which follows the old "Boonmoo"-Stannary Hills railway track, along the northern side of Eureka Creek.

Lithology. Eureka Rhyolite consists of massive, pale- to dark-grey or pinkish-grey, intensely-welded, moderately crystal-rich to crystal-rich, hornblende-biotite rhyolitic ignimbrite, commonly containing small amounts of clinopyroxene, orthopyroxene, or both. Accessory minerals are magnetite, zircon, apatite, and, commonly, allanite. The groundmass is generally recrystallised, and eutaxitic texture is evident in few specimens. Most specimens are slightly to moderately altered, generally to sericite and chlorite, with or without calcite, silica, or clay mineral(s).

Thickness. The unit is at least 400-500 m thick as presently exposed, but its original thickness is unknown because the top is not preserved.

Eruptive source(s). The only possible indication of direction to source observed in the Eureka Rhyolite is a northwestward increase in **preserved** thickness, which may not necessarily reflect original thickness variation.

Structure and relationships. Attitude of layering in the Eureka Rhyolite is uncertain because eutaxitic foliation is rarely evident in outcrop. However, it is probably subhorizontal to gently dipping (towards the centre of the Boonmoo "Sag") over most of the area. Eureka Rhyolite overlies Bluewater Rhyodacite, apparently conformably, in the northeastern part of the Boonmoo Sag between the upper reaches of Murphys Creek and its junction with Eureka Creek. It is intruded by Halpin Granite, Deadman Granite, Bock Granodiorite, and a small rhyolite plug of uncertain (probably Early Permian) age.

Topography. Eureka Rhyolite is characterised by moderately steep, rounded hills with relief of up to 250 m, a moderate tree cover, and pale soil and dry-season grass tones. Outcrop is moderately abundant, and in the form of bouldery patches and rises, and solitary boulders.

Age. Eureka Rhyolite is (slightly) younger than Bluewater Rhyolite (306 ±3 Ma), and older than Borneo Granite (304 ±4 Ma) which intrudes rocks equivalent to, or younger than, Eureka Rhyolite.

Synonymy. Branch (1966) included Eureka Rhyolite in undivided Featherbed Volcanics; Lawrence (1973) recorded it as a mappable, but unnamed, unit.

Eight Mile Cauldron sequence

Rocks of the Boonmoo Sag sequence described above are separated from those to the west by the Blue Mountain Fault, across which both extrusive and intrusive (discussed separately below) lithologies change notably in character. The Eight Mile sequence occupies a modified semi-circular structure, truncated in the west by a complex set of north-northeasterly trending faults, and comprises Muirson Rhyolite, Hopscotch Rhyodacite, Adder Dacite, Verdure Andesite, and Theodolite Rhyolite. The relationship between the Rock Hole Rhyolite, in the west, and the other units is uncertain: it is mostly separated from them by either faults or intrusive bodies. It also has some petrographic and geochemical affinities with the Tennyson sequence to the southwest and the Jamtin Rhyolite to the west.

Muirson Rhyolite (Cbm) *(new name)*

Derivation of name. Muirson Rhyolite is named from Muirson Creek, which drains the northernmost parts of the unit, and joins the Walsh River at GR7863-838018.

Distribution. Muirson Rhyolite is the lowermost exposed and most extensive unit in the Eight Mile Cauldron sequence. The two main areas of outcrop are in the north, and around the southern margin of the Eight Mile Cauldron. In the north, it extends in a 3.5 km-wide belt from lower Eureka Creek 10 km south-southwest to Eight Mile Mountain, and in a 2 km-wide strip 7 km southeastward toward Mount Pinnacle. In the south, it extends from near Murphys Creek in the east to Emu Creek in the south, and up to 5 km northward into the interior of the cauldron. Smaller areas of outcrop, most of which are fault blocks or slices, occur in the Bamford Hill and Dover Castle mine areas.

Type section. The type section of Muirson Rhyolite is between GR7863-843001 (at or near base) and 7863-878983 (top), mostly along a track between the Eureka Creek-Pinnacle Creek junction and the Walsh River near its junction with Muirson Creek.

Lithology. The unit consists of dark to very dark grey to bluish-grey or green-grey, intensely welded, medium-coarse-grained, moderately to very crystal-rich, hornblende- biotite rhyolitic ignimbrite, some specimens of which contain very minor possible pyroxene (completely altered to chlorite, etc.). It is characterised by prominent quartz crystals 4-7mm across, and by a variably developed eutaxitic texture, generally marked by very dark-grey, strongly porphyritic pumice clasts up to several cm long and 1-2cm thick. Lithic clasts, including porphyritic andesite up to 2cm long, are very rare. In some areas, particularly in upper Oaky Creek, southwest of the Dover Castle mine, the rock contains abundant, spherulitic, devitrified glass; some of this glass is also palagonatised, suggesting that part(s) of the unit may have flowed into water.

Accessory minerals in the Muirson Rhyolite are magnetite, apatite, zircon and, commonly, allanite; titanite is present in some of the more mafic parts of the unit. The ignimbrite is moderately to intensely altered, mostly to combinations of chlorite, sericite, calcite, opaque oxide(s), epidote, and leucoxene; relatively coarse-grained white mica (muscovite?) is present in a few specimens. In the Muirson Pinnacle area, the rock is intensely sericitised, and in the area south and southeast of the Dover Castle mine, it is altered, recrystallised (biotite is also finely recrystallised), and contains disseminated pyrite.

Thickness is difficult to estimate because of the lack of consistent dip indicators and because the base and the top are rarely exposed in the same section. It is at least 350m, and possibly up to 750m, in the south, increasing to 1km or more in the northwest, between Eight Mile Mountain and Muirson Pinnacle.

Eruptive source(s). Indicators such as size and abundance of lithic and pumice clasts suggest that the part of the Muirson Rhyolite between Eight Mile Mountain and Muirson Pinnacle is the most proximal to eruptive source(s).

Relationships. Muirson Rhyolite is faulted against Rock Hole Rhyolite (base is not exposed), and overlain conformably or paraconformably by Hopscotch Rhyolite. It is intruded by Borneo Granite, Petford Granite and rocks interpreted as equivalent to Lags Microgranite; it may also be intruded by Halpin Granite, but the contact between them is a smooth curve, and may be entirely faulted.

Structure. In the southeast (upper Eccles Creek-Hopscotch Creek), Muirson Rhyolite appears to dip gently to moderately (10-30^{o}) towards the north and is faulted against (or, possibly, intruded by) Halpin Granite. In the Muirson Pinnacle-Eight Mile area, the unit is fault-bounded on the west, and appears to dip at moderate angles (*ca* 30^{o}) to the east. Dips turn more southerly towards Eureka Creek, then southwesterly in the area between Eureka Creek and Mount Pinnacle. Dips in the Bamford Hill area are 20-30^{o} to the east- southeast, but may be steeper in the Dover Castle mine area, particularly near the Tennyson Ring Dyke. In both these areas, the unit is affected by extensive, mainly normal(?), faulting associated with the Tennyson Caldera.

Topography. Most of the terrain on the Muirson Rhyolite is low, rounded hills (relief up to ~80-100 m), with a medium cover of trees and medium to medium-dark (brownish) tones on airphotos. Areas of intense alteration, such as Muirson Pinnacle and two smaller hills immediately to the north, are steeper, have more relief (up to 150 m), and a denser tree cover.

Age. The age of the Muirson Rhyolite is constrained by the 306$\pm$3 Ma age of the Bluewater Rhyolite which it overlies, and the 304$\pm$4 Ma age of the Borneo Granite which intrudes it. An isochron from which Black (1978) calculated a 301$\pm$9 Ma age included data from samples of Muirson Rhyolite, but it also included data from samples of Adder Dacite, Rock Hole Rhyolite, and Cottell Rhyolite.

Synonymy. Muirson Rhyolite was included by Branch (1966) in undivided Featherbed Volcanics. It was mapped as an unnamed, discrete unit by Lawrence (1973), although its distribution differed in detail from that recognised here.

Hopscotch Rhyolite (Cbh) *(new name)*

Derivation of name. The name is from Hopscotch Creek, which joins Eccles Creek at GR7963-879914 and transects the unit near the Cairns-Mungana railway line, in the Verdure siding area.

Distribution. Hopscotch Rhyolite crops out, generally rather poorly, over a large proportion of the central area of the Eight Mile cauldron. The main outcrop area extends from near the Eureka Creek-Pinnacle Creek junction southward along the western side of Pinnacle Creek, southward and southeastward along the valley of Eccles and Snake Creeks to Murphys Creek, and southwestward and westward through the valleys of Theodolite, Three Mile and Adder Creeks to Emu Creek. It also extends in a narrow strip (up to ~1 km wide) southeastward from near the Eureka Creek-Pinnacle Creek junction to Mount Pinnacle. Small outliers also crop out in the area between Bamford Hill and Dover Castle.

Type section. The most accessible complete section through the Hopscotch Rhyolite is from GR7863-845866 (base) 1200 m southward along the Burke Developmental (Dimbulah- Petford) Road to a sharp left-hand bend, then 120 m south-southwestward to GR7863- 841854 (top). This section includes at the top a coarse, crystal-rich variant of the ignimbrite (Cbh_1.

Lithology. The Hopscotch Rhyolite is typically a dark to medium grey or green-grey, moderately to densely welded, lithic clast-poor to -absent, crystal-rich, augite(??)- hornblende(?)-biotite rhyodacitic ignimbrite. Very dark grey-green to green pumice *fiamme* up to 10 cm long and 2 cm thick are a common and characteristic feature, as are the generally large (up to 8 mm), rounded, quartz crystals. Sizes of both pumice clasts and crystals tend to increase from southeast to northwest, but lithic clasts (mostly fine-grained andesite) appear to be most abundant in the southwest. Devitrified, originally very glassy rocks are evident mainly in the southeast. The numbers of flow sheets and cooling units in the Hopscotch Rhyolite are not known, mainly because of the poor outcrop. Dips of the ignimbrite sheet(s), as indicated by aligned pumice clasts, are generally in the range 10° to 30° over most of the outcrop area, but range up to 75° in the Burke Highway-upper Three Mile Creek area (where the rocks are folded in to a moderately tight syncline), and in tilted fault blocks in the Emu Creek and Dover Castle mine areas.

A wedge of very coarse, crystal-rich, augite?-hornblende-biotite ignimbrite (Cbh_1) about 2 km long and possibly up to about 100 m thick crops out across the Burke Developmental (Dimbulah-Petford) Road about 1 km south of the Three Mile Creek crossing, at the top of the Hopscotch Rhyolite. It contains subequant crystals of quartz up to 1.5 cm and feldspar up to 1 cm across.

Crystal content of the Hopscotch Rhyolite typically comprises 10-15% quartz (up to 7 mm), 10-15% feldspar (up to 4 mm; K-feldspar and plagioclase subequal), and 1-2% hornblende (mostly chloritised) and biotite. Most samples also contain a minor amount of augite, or, more commonly, an altered ferromagnesian mineral with the morphology of (clino?)pyroxene. Accessory minerals include magnetite, apatite, zircon, monazite(?) and titanite (trace); allanite is very rare.

The Hopscotch Rhyolite is altered throughout, generally to assemblages consisting of various proportions of chlorite, sericite, calcite, and secondary opaque $Fe \pm Ti$ minerals; epidote is commonly also present - the alteration is mainly propylitic - and some rocks contain up to 1-2% pyrite.

Distinguishing characteristics. Hopscotch Rhyolite may be distinguished (with difficulty) from the underlying Muirson Rhyolite by its poorer outcrop, its slightly more mafic (*e.g.*, pyroxene more common) composition, and the consequently slightly darker soil tones detectable in some areas on airphotos.

Thickness is about 300-350 m in the south, decreasing to about 150-200 m in the north.

Eruptive source(s). Outcrops in the Three Mile Creek/Cairns-Mungana railway area, south of Eight Mile Mountain, are the parts of the unit most proximal to source, based on abundance and size (up to 15 x 5 cm) of pumice clasts.

Relationships. Hopscotch Rhyolite overlies the Muirson Rhyolite in an apparently conformable relationship, and is overlain, also apparently conformably, by Adder Dacite and Verdure Andesite. In the northeast, it is unconformably overlain by small outliers of Theodolite Rhyolite. It is intruded by Borneo Granite, Bamford Granite, and Cottell Rhyolite.

Structure. In the east of the Eight Mile Cauldron, Hopscotch Rhyolite forms a series of open folds: the most northerly, in the Pinnacle Creek area, has a doubly-plunging, northwest-southeast axis; the others are irregularly, but generally west-northwestward, plunging. Dips are probably in the range 10° to 30°, although dip indicators are scarce and inconsistent. The folds are cut and/or truncated by faults in the west. On the eastern side of Bamford Hill, and probably in the fault blocks on the eastern side of Emu Creek and to the west of Bamford Hill, dips are probably moderate and eastward.

Topography. The Hopscotch Rhyolite underlies generally low-relief terrain characterised by very low, rounded hills, open to moderately sparse eucalypt savannah woodland, and very sparse outcrop. Tones on airphotographs are medium to medium-pale brown (in the dry season), and very even, or "smooth".

Age. Like that of the Muirson Rhyolite, the age of the Hopscotch Rhyolite is tightly constrained between 306 ±3 Ma and 304 ±4 Ma.

Synonymy. Branch (1966) included Hopscotch Rhyolite in undivided Featherbed Volcanics. Lawrence (1973) recognised most of the rocks now included in Hopscotch Rhyolite as an unnamed mappable unit, but his boundaries differ in detail in many areas from those recognised by Mackenzie & others (1993).

Adder Dacite (Cba) *(new name)*

Derivation of name. The name Adder is taken from Adder Creek, a tributary of Three Mile Creek, 5.5 km northeast of Petford.

Distribution. The largest outcrop area of Adder Dacite extends from around Eight Mile Mountain (except in the north) southward to Adder Creek and southwestward to Bamford Hill. Several outliers are located in the in the area between Eccles Creek and the Cairns-Mungana railway line, and a small outlier is located immediately west of the Pinnacle Creek crossing on the Burke Developmental Road. It also crops out in a small area to the between Bamford Hill and the Dover Castle mine. Total outcrop area is about 15 km^2.

Distinguishing characteristics. Adder Dacite is readily distinguished in the field from the underlying Hopscotch Rhyolite by its darker colour and general lack of obvious quartz; it differs from underlying units on airphotographs mainly by its darker soil (and outcrop) tones. However, it is difficult to distinguish in the field or on airphotographs from the overlying Verdure Andesite.

Type section. A complete section of the Adder Dacite is not exposed: however, an almost complete section is reasonably well exposed along the track from the Burke Developmental Road to the Eight Mile mine area, between GR7863-828888 (base) and -816896.

Lithology. The unit consists predominantly of dacitic to rhyodacitic ignimbrite, with dacitic to andesitic lavas at the base and near the top. Dips of the ignimbrite sheets, as indicated by highly flattened pumice clasts (generally only visible on slightly to moderately weathered surfaces), is gentle to moderate (10-30°), except near the Eight Mile Fault in the Eight Mile and Dover Castle mine areas, where they are steep to near-vertical.

The ignimbrites are typically dark grey to greenish or purplish grey, medium to fine grained, lithics-poor to moderately lithics-rich, moderately to very crystal-rich, and commonly contain abundant, dark, strongly porphyritic (plagioclase phenocrysts up to 1 cm; quartz phenocrysts up to 8 mm) pumice clasts up to 15 cm long. The crystal component is dominated by feldspar (mostly plagioclase; ~1-2 mm), with up to about 10% hornblende and/or biotite and up to 2% quartz, which range up to 5 mm in the more mafic rocks and up to 8 mm in the more felsic rocks. Lithic clasts tend to decrease in abundance from about 5% in the southwest to 1-2% in the east, and are mostly in the size range 1-5 cm; clast lithologies include variably porphyritic dacite, some with 1-cm plagioclase, 8- mm quartz phenocrysts, sparsely porphyritic andesite, and rare biotite-rich schist. The lavas are moderately to strongly plagioclase-phyric, with rare quartz pheno/xenocrysts. Accessory minerals in both ignimbrites and lavas include magnetite, apatite, zircon, rare monazite(?), and very rare titanite. Moderate to strong alteration to propylitic assemblages - various proportions of chlorite + epidote + calcite ± sericite - is ubiquitous, and some rocks, notably in the Eight Mile and Dover Castle mine areas, also contain up to several percent pyrite.

Thickness is about 250-300 m in the Eight Mile Mountain area, decreasing to about 100 m or less in the Eccles Creek area.

Eruptive sources. Relative abundance and size of lithic clasts are greatest in the area on the southwestern side of Eight Mile Mountain, implying that this is the most proximal to source(s) of the preserved parts of the Adder Dacite.

Relationships. Over most of its outcrop area, Adder Dacite overlies, apparently conformably, Hopscotch Rhyolite, and is overlain, also with apparent conformity, by Verdure Andesite. However, Adder Dacite directly overlies Muirson Rhyolite in places (*e.g.*, 5 km NE and 3 km SE of the Eight Mile mine), and does not appear to be present beneath much of the main outcrop area of Verdure Andesite in the Mount Pinnacle-Eccles Creek area in the northeast. In places there appears to be a gradational, almost imperceptible, contact between Adder Dacite and Verdure Andesite. Adder Dacite is intruded by Borneo Granite and Bamford Granite.

Structure. The structure of the Adder Dacite parallels that of the Hopscotch Rhyolite: a series of open folds in the east of the Eight Mile Cauldron, and east-dipping(?) fault blocks in the southwest.

Topography. Adder Dacite forms low, rounded hills and rolling plains with generally lower relief (up to 40 m) than the Hopscotch Rhyolite. Where it is intensely altered, such as east of Emu Creek, it is more resistant to weathering, and relief is up to 100 m. Vegetation is slightly denser (and trees taller) than that on the Hopscotch Rhyolite, and soil and grass tones (in the dry season) slightly darker.

Age. The age of the Adder Dacite is constrained by the same isotopic ages that limit the age range of the Muirson and Hopscotch Rhyolites. An isochron age of 301±9 Ma obtained by Black (1978) included data from a sample of Adder Dacite, but it also included data from samples of Muirson Rhyolite, Rock Hole Rhyolite, and Cottell Rhyolite.

Synonymy. Adder Dacite was included by Branch (1966) in undivided Featherbed Volcanics. Lawrence (1973) recognised most of the unit as now mapped, though with much more generalised boundaries, as a separate but unnamed map entity.

Verdure Andesite (Cbe) *(new name)*

Derivation of name. The name Verdure is taken from Verdure siding on the Cairns-Mungana railway, Atherton 1:100 000 sheet area (7963).

Distribution. Verdure Andesite crops out in four areas: between Pinnacle Creek and Mount Pinnacle in the northeast - the largest area; near the junction of Eccles and Horse Creeks in the east; in the Eight Mile mine area in the west; and in a small, fault-bounded wedge near the Dover Castle mine in the southwest. Total outcrop area is about 32 km^2.

Type section. A complete section of the Verdure Andesite is not preserved: the best- exposed, most complete section is between GR7963-920901 (near base) and -926910, near a station track on the northern side of the Cairns-Mungana railway line.

Lithology. Verdure Andesite consists mostly of very dark grey, medium-fine-grained, crystal-rich, andesitic ignimbrite, with minor andesite lava. Lava occurs at the base of the unit 4 km east of Eight Mile Mountain. Thin (1-10 m) lenses of andesitic lava and fine lithic-lapilli tuff 2.5 km southwest of Mount Pinnacle are about 200 m above the base of the unit - which in this area is marked by a massive volcanic rudite - and crop out over a strike length of about 3 km. This indicates that at least two major cooling units are present in this area; in other areas, outcrop is insufficient to enable flow or cooling units to be distinguished. Lithic clasts range up to 40 cm across, and pumice *fiamme* up to 1x10 cm; both extremes were observed in the northeast, indicating that these rocks are the most proximal to eruptive source(s).

The ignimbrites are poor to very poor in lithic clasts (mostly fine-grained to moderately porphyritic andesite to dacite), and rich to very rich (30-45%) in crystals and crystal fragments of plagioclase, augite, and greenish-brown basaltic hornblende; some rocks also contain possible orthopyroxene (chloritised). The lavas are moderately to strongly porphyritic (commonly glomeroporphyritic), with phenocrysts of plagioclase, generally augite, and hornblende in a fine to very fine-grained matrix of the same minerals (dominated by plagioclase) and minor magnetite. Accessory minerals in both lithologies are apatite, monazite(?), and, commonly, rare titanite.

The unit is almost universally altered, to various degrees, to propylitic assemblages of chlorite + calcite ± sericite + epidote + Fe, Ti oxides and/or titanite. Rocks in the Eight Mile mine area have been hornfelsed by the Borneo Granodiorite and Bamford Granite, and ferromagnesian minerals have recrystallised to hornblende and biotite. Similarly, in the Dover Castle mine area, hornfelsing by the Bamford Granite(?) and Tennison Ring Dyke has caused much of the pyroxene and hornblende to recrystallise to biotite + hornblende or tremolite-actinolite + biotite; these rocks also generally contain up to 5% by volume pyrite.

Thickness. Preserved thickness of the Verdure Andesite is at least 80-90 m and possibly up to 350-400 m in the east, but unknown (at least 60 m) in the west.

Eruptive source(s). The coarse-lithic and -pumice clast-rich rocks in the area 2-3 km southwest of Mount Pinnacle are indicative of proximity to an eruptive source.

Relationships. Over much of the northeastern and eastern outcrop areas, Verdure Andesite apparently overlaps Adder Dacite to rest directly on Hopscotch Rhyolite, suggesting that it unconformably overlies these units. It is unconformably overlain by Theodolite Rhyolite, and intruded in the west by Borneo Granite and Bamford Granite, and in the east by an andesite dyke of probable Early Permian age.

Structure. The structure of the Verdure andesite consists essentially of two boat-like synclines in the east of the Eight Mile Cauldron, and east(?)-dipping fault blocks/slices to the southwest of Eight Mile Mountain and west of Bamford Hill.

Topography. Terrain underlain by Verdure Andesite is characterised by low, rounded hills and rises with relief typically 40 m, medium-sparse to medium tree cover, and medium to dark brown to red-brown soil (and, in the dry season, grass) tones.

Age. Verdure Andesite, like the units beneath it, is between 306±3 (the age of the Bluewater Rhyolite) and 304 ±4 Ma (the age of the Borneo Granite) in age.

Theodolite Rhyolite (Cbt) *(new name)*

Derivation of name. This unit is named from Theodolite Creek, a tributary of Hopscotch Creek, 10 km northeast of Petford (Chillagoe 1:100 000 sheet 7863).

Distribution. Theodolite Rhyolite is the uppermost unit in the Eight Mile sequence proper. It crops out on Eight Mile Mountain and adjacent peaks (the type area), and on Mount Pinnacle and the area immediately to the west; total outcrop area is about 8 km^2.

Type section. The type section of the unit is on the western slope of Eight Mile Mountain. between GR7863-82158990 (base) and -82509005 (top), where thin-bedded tuff and minor rhyolitic ignimbrite (Cbt_1) are overlain by massive, crystal-rich rhyolitic ignimbrite (Cbt_2).

Lithology. The basal part of the unit (Cbt_1) consists of rhyolitic fine-ash (crystal-)vitric tuff and medium to coarse-ash crystal tuff, generally with fine graded bedding, thin-bedded siltstone and sandy quartz siltstone, some with small lithic pebbles, and fine pebble conglomerate. This horizon ranges from a few metres thick in the east to about 50-70 m thick in the Eight Mile Mountain area. These rocks are overlain by a massive, medium to dark-grey, lithics-poor to -rich, crystal-rich to very crystal-rich (30-45%), hornblende-biotite rhyolitic ignimbrite (Cbt_2). Lithic clasts include rhyolite (dominant), porphyritic dacite, quartzose siltstone, and andesite(?). In most areas, the ignimbrite is slightly to strongly altered to propylitic assemblages (various proportions of sericite, chlorite, calcite, and epidote); metamorphic biotite is evident near the Borneo Granite in the Eight Mile Mountain area. Alteration is most intense near the Pinnacle Creek-Eureka Creek junction, where rocks are intensely ferruginised or silicified, and commonly brecciated. Only a few metres of unwelded ignimbrite are preserved in the north and northeast; thickness increases to about 150 m, most of which is intensely welded, in the Eight Mile Mountain area.

Thickness. Preserved thickness ranges from a few metres to about 20 m in the east, and from about 120 m to 200 m in the Eight Mile Mountain area.

Structure and relationships. In each outcrop area Theodolite Rhyolite is subhorizontal and clearly unconformable on the underlying units, Verdure Andesite, Adder Dacite, and Hopscotch Rhyolite; the top of the unit is not preserved. It is intruded by a felsic phase of the Borneo Granite in the Eight Mile Mountain area.

Topography. The upper subunit of Theodolite Rhyolite (Cbt_2) forms mostly elevated terrain, with relief of up to 100 m, and medium tree cover. Where Cbt_1 is exposed over an appreciable area, such as 3.5 km northwest of Mount Pinnacle, it forms mesa-like landforms with up to 80 m and medium-dense, relatively tall, tree cover.

Age. Theodolite Rhyolite is intruded by Borneo Granite (304 ±4 Ma), and is stratigraphically higher than Bluewater Rhyolite (306 ±3 Ma).

Synonymy. Branch (1966) include Theodolite Rhyolite in undivided Featherbed Volcanics. Lawrence (1973) mapped an unnamed unit with distribution similar in general terms to that of the Theodolite Rhyolite.

Rock Hole Rhyolite (Cbr) *(new name)*

Derivation of name. The name Rock Hole is derived from "The Rock Hole", a rock pool on a small creek 2.3 km west of Muirson Pinnacle (Chillagoe 1:100 000 sheet - GR822990).

Distribution. Rock Hole Rhyolite is the westernmost exposed unit assigned to the Boonmoo Volcanic Subgroup. It crops out southward from the Walsh River to the Eight Mile mine area in a continuous belt that narrows from about 4 km in the north to 2 km wide in the south. Small, partly fault-bounded areas of outcrop of an ignimbrite tentatively equated with Rock Hole Rhyolite occur in the area immediately west, northwest, and southwest of the Dover Castle mine. Total outcrop area of the unit is about 30 km^2.

Type section. Neither the top nor the base of the Rock Hole Rhyolite is exposed (if either is preserved), and the unit is relatively homogeneous and monotonous. Rocks typical of the unit are well exposed at several localities along a track that links the Eight Mile mine area with the Walsh River to the north (*e.g.*, around GR7863-794922, around -805945, between -803961 and -80459700, and around -808955).

Lithology. Rock Hole Rhyolite consists of a massive, characteristically pale pinkish-grey, pink, purplish-pink, or orange-pink, moderately to very crystal-rich, leucocratic, biotite- bearing, rhyolitic ignimbrite. Eutaxitic fabric was observed at only one locality, the remainder being devoid of any indicators of "bedding" attitudes or structure. The rocks are slightly to very altered, generally to sericite, chlorite, and calcite; clay(s) is(are) present in some rocks north of the Walsh River.

Rocks to the west of Dover Castle mine correlated with Rock Hole Rhyolite are greenish- cream to green-grey or brownish to, reddish grey, very crystal-rich rhyolitic ignimbrites, and broadly similar to those described above except for their colour. The colour difference is probably due principally to a different style of generally more intense alteration (propylitic assemblages of sericite, chlorite, calcite, and epidote ± clay(s)). Some of the rocks contain lithic clasts (up to 10-15%), and in one area, directly west of the mine, some are associated with lava and lava breccia.

Thickness of the unit is difficult to estimate because of the general lack of a discernible fabric that would allow dip determinations; it must be at least 200 m, and possibly as much as 1000 m.

Eruptive source(s). There are no clear indications of direction to, or proximity of, eruptive source(s). However, the apparent thickness of the unit suggests that it is not a distal or outflow facies, and it is possible that it has buried its eruptive source.

Structure and relationships. The relationship of the Rock Hole Rhyolite to the remainder of the Boonmoo Volcanic Subgroup is not clear. It is faulted along its western margin against rocks of the Early Permian Featherbed Cauldron, and largely fault bounded along its eastern margin against Muirson Rhyolite, Adder Dacite, and Verdure Andesite. In one locality, the "Captain Morgan" W-Mo deposit, 3.3 km NNE of the Eight Mile mine, Rock Hole Rhyolite appears to dip gently beneath Muirson Rhyolite; however, it is probable that an east-dipping fault separates the two units. In the north, the Rock Hole Rhyolite is either faulted against or overlain by Early Permian Fisherman Rhyolite (*q.v.*), and intruded by 280 Ma-old Lags Microgranite (*q.v.*). In the south, it appears to overlie Lappa Rhyolite, but these two units are very difficult to distinguish from one another in the field, and the identification of Rock Hole Rhyolite in this area is tentative at best. The ignimbrite is extensively intruded by Borneo Granite.

Age. Rock Hole Rhyolite predates the Borneo Granite, which has been dated at 304 ± 4 Ma (L.P. Black, pers. comm., 1990), and is younger than Bluewater Rhyolite (306 ± 3 Ma). It has not been dated separately, but data from a sample were included in an isochron, which also includes data from samples of Muirson Rhyolite, Adder Dacite, and Tennyson Ring Dyke, from which Black (1978) calculated a 301 ± 9 Ma age.

Tennyson Volcanic Subgroup - Tennyson Caldera

The Tennyson Caldera is the most southerly component of the Featherbed Cauldron, and is located 35 km southwest of Dimbulah, centred on the tin-mining hamlet of Koorboora; Lappa Junction railway siding is on the northeastern margin, and the Bismarck tin mine on the northwestern extremity. The Caldera comprises the Tennyson Ring Dyke (Branch, 1966), which is described below, and a thin sequence of ignimbrites: Dalnotter Dacite, Allsorts Rhyolite, and Lappa Rhyolite. The ignimbrites are preserved only in the eastern half of the remnant caldera, the northern third of which has been obliterated by the Featherbed Caldera. The western half of the caldera is occupied by Hodgkinson Formation arenites, siltites and minor lutites, which form a highly irregular basement to the Tennyson sequence. The Tennyson sequence is probably of Late Carboniferous age: the Tennyson ring dyke plots on a 301±9 Ma Rb-Sr whole-rock isochron, along with Muirson Rhyolite and Rock Hole Rhyolite (Black, 1978), which, on geological grounds, appear to be time-equivalents of Dalnotter Dacite and Lappa Rhyolite.

Dalnotter Dacite (Ckd) *(new name)*

Derivation of name. The name Dalnotter is derived from the "Dalnotter" tin mine, at GR7863-688779 (Chillagoe 1:100 000 sheet).

Distribution. Dalnotter Dacite is the basal unit of the Tennyson sequence, and is exposed in two areas, covering a total of about 18 km^2: in the upper Two Mile Creek area, southwest of Lappa Junction, and in the headwaters of Crooked Creek, in the northeast of the Tennyson Caldera.

Type section. A complete section through the Dalnotter Dacite is exposed along a tributary of Two Mile Creek from GR7863-714766 (base) to -710772 (junction with Two Mile Creek) then to -720782 (junction with a south-flowing tributary) and north along this tributary to -718786 (top). Good, reasonably accessible, exposure of typical Dalnotter Dacite is located in Two Mile Creek at GR7863-687766.

Lithology. Dalnotter Dacite consists entirely of dark-grey to greenish-grey, crystal-rich to very crystal-rich, hornblende-biotite dacitic ignimbrite. In places, the ignimbrite contains conspicuous pumice clasts up to 2 cm thick and 10 cm long. Small quantities of lithic clasts - mostly very small ($\leq$1 cm), subangular fragments of fine-grained dacitic to andesitic rocks and rhyolitic ignimbrite - are present in rocks 1 km northwest of Mount Cottell. Small, dark, fine-grained sedimentary clasts are abundant but sporadically distributed in rocks at the base of the unit where it overlies an inlier of basement on Allsorts Creek. The ignimbrite is moderately to strongly altered to propylitic assemblages of chlorite, sericite, calcite, and epidote.

Thickness is highly variable, ranging up to about 100 m in the northwest.

Eruptive source(s). The outcrops with the most abundant and largest crystal, lithic, and pumice clasts, and therefore the most proximal to eruptive source(s), are in the extreme east, near Lappa Junction.

Relationships. Dalnotter Dacite overlies arenites of the Hodgkinson Formation on an angular unconformity, and is overlain, apparently conformably, by Allsorts Rhyolite. In the east, it overlies, or interfingers with, dacitic ignimbrite mapped as Muirson Rhyolite; it is possible that the two are equivalent. In the south, Dalnotter Dacite is intruded by and/or faulted against the Tennyson Ring Dyke, and in the north it is faulted against Lags Microgranite and Arringunna Rhyolite of the Featherbed Caldera.

Structure. In the south of the caldera, Dalnotter Dacite is flat-lying to gently northward dipping. In the northern area, it probably varies from flat lying in the south to southeastward dipping (away from the Featherbed Caldera ring fault).

Topography. Landforms on the Dalnotter Dacite are typically very subdued, with only gentle, smooth rises in the southern area and low, rounded hills in the north. Outcrop is very poor in the south, and sparse and patchy in the north. Tree cover is medium-sparse to sparse, and dominated by silver-leafed ironbark, forming a conspicuous vegetation anomaly. Soil and dry-season grass tones are medium to medium-dark brown on airphotographs.

Age. The Dalnotter Dacite is probably younger than 306±3 Ma-old Bluewater Rhyolite, and older than the 301±9 Ma Rb-Sr age (Black, 1978) from an isochron that includes data from the Cottell Rhyolite, which intrudes Dalnotter Dacite. It is certainly older than the 289±7 Ma average age for the Arringunna Rhyolite. The 301±9 Ma isochron is of dubious validity because it includes data from samples of several different units - Muirson Rhyolite, Adder Dacite, Rock Hole Rhyolite, and only one from the Cottell Rhyolite.

Synonymy. Dalnotter Dacite was included by Branch (1966) in undivided "Featherbed Volcanics". Most of the northern outcrop area was included by Lawrence (1973) with rocks now assigned to the Muirson Rhyolite; he did not map the Two Mile Creek area.

Allsorts Rhyolite (Cka) *(new name)*

Derivation of name. The name is derived from Allsorts Creek, which joins Two Mile Creek 2 km east of Koorboora siding on the Cairns-Mungana railway line.

Distribution. Allsorts Rhyolite is the most voluminous unit of the Tennison sequence: it crops out over an area of about 20 km^2 in the headwaters of Allsorts, Two Mile, and Oak Creeks, northeast of Koorboora.

Type section. A complete section through a representative part of the unit is exposed along a tributary of Two Mile Creek, between GR7863-718786 (base) and -71658015 (above eastern side of creek - top).

Lithology. Allsorts Rhyolite consists of three subunits. The lower part of the formation consists of a subunit made up of thin ignimbrite sheets, tuff, and volcaniclastic sediments (**Cka_t**), and a subunit dominated by rhyolitic lava and crystal-poor ignimbrite (Cka). The upper part of the unit is a more homogeneous rhyolitic ignimbrite sequence (Cka_i).

In the northeast, the lower sequence contains a basal lens, about 3 km long and up to 80- 100 m thick, of andesite which rests on 1-2 m of rhyolitic fine-ash vitric tuff. The andesite is overlain by up to 100 m of medium-fine, moderately crystal-poor rhyolitic ignimbrite, and/or by up to 130 m of flow-laminated, sparsely porphyritic rhyolite lava. The rhyolite lava horizon extends several kilometres to the south, pinches out 1.3 km WNW of Mt Cottell, and reappears farther west where the lava sequence again is 80-100 m thick. The rhyolite, the underlying tuff-ignimbrite sequence, and the overlying ignimbrite horizon vary considerably in thickness in the eastern wedge, and the tuff-ignimbrite sequence is absent in places. The tuff-ignimbrite and ignimbrite sequences merge westward with a complex sequence (**Cka_t**) of thinly interbedded rhyolitic fine-ash vitric tuff, silty to coarse sandy volcaniclastic sediments of rhyolitic composition, and sheets up to a few metres thick of unwelded, variably lithic-rich, ignimbrite (Fig. 4A). Thin-bedded to laminated material resembling volcaniclastic arenite and siltite at the top of this interval in places (*e.g.*, Allsorts Creek) may be base-surge deposits associated with the overlying ignimbrite sequence. The western basal sequence ranges up to 80-90 m thick in and to the east of Allsorts Creek, but thins and is finally overlapped in the west by the rhyolite lava sequence (Cka).

The andesite in the northeast is fine-grained, aphyric to very sparsely porphyritic, and contains clinopyroxene and hornblende; it is strongly altered to chlorite, sericite, and epidote. The tuffs are pale brown, cream, or white, commonly thin-bedded to laminated, fine-ash vitric tuffs containing a small proportion of crystal clasts, and are of rhyolitic composition. The ignimbrites are pale grey to buff or white, moderately crystal-poor to crystal-poor, and range from lithics-free to containing up to 30% subangular clasts up to between 5 and 10 cm across of sparsely porphyritic rhyolite.

The upper ignimbrite subunit (**Cka_i**) consists of numerous sheets of rhyolitic ignimbrite, ranging from moderately lithic-rich or lithic-rich and crystal-poor (the majority) to lithics-poor and moderately crystal-rich. A well-exposed section in Allsorts Creek shows rhythmic repetition of coarse-lithics-rich ignimbrite grading upward into finer-lithics-poor ignimbrite near the base of the subunit. Nearer the top, this section also contains a thin horizon of base-surge material (or unwelded, fine, crystal-poor ignimbrite), a 0.7 m-thick layer of fine-ash vitric tuff overlain by a bed at least 1.5 m thick of thin-bedded to laminated volcaniclastic arenite or possible coarse-ash crystal tuff, several metres of fine, crystal-poor rhyolitic ignimbrite, and a massive, lithics-rich ignimbrite.

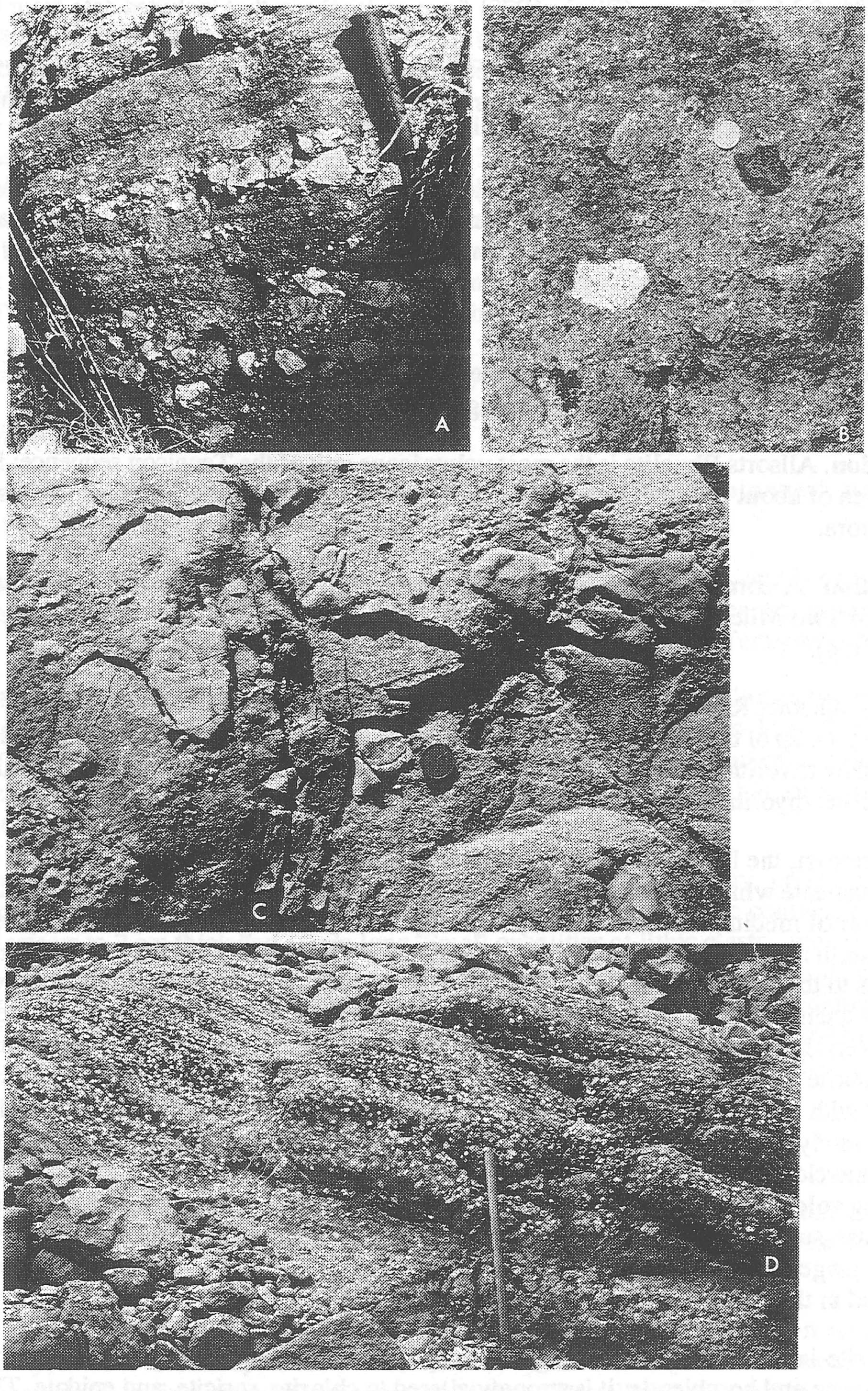

Figure 4.

A. Poorly welded, poorly sorted, lithic-rich rhyolitic ignimbrite, Allsorts Rhyolite, Tennyson Volcanic Subgroup, Allsorts Cree, GR7862-717786.

B. Nightflower Dacite, subunit Cnc, showing clasts of andesite, quartz, meta-arenite, and rhyolite. Elizabeth Creek, GR7764-320348.

C. Nightflower Dacite: volcanogenic rudite/breccia at base of subunit Cna. GR7764-363367.

D. Fisherman Rhyolite(?): well-layered, spherulite-rich ignimbrite, Lightning Creek (east branch), northern margin of Djungan Caldera, GR7864-506410.

The ignimbrites are pale-grey to buff, cream-brown or (off-)white, and contain biotite. Clasts are angular to subangular, between 1 and 10 cm, rarely 20-30 cm, across, and dominantly of sparsely porphyritic rhyolite similar to that in subunit Cka. One ignimbrite sheet, at the base of the subunit in the north, contains small clasts (up to 5 cm of) a variety of lithologies, including granite, fine-grained andesite or dacite, and porphyritic dacite.

All lithologies in the Allsorts Rhyolite are moderately to intensely altered, typically to combinations of sericite, clay minerals (dominantly kaolinite, but also vermiculite), hematite, and, less commonly, chlorite. Propylitic alteration was noted in only one sample of Cka subunit in the north.

Thickness. The unit is about 100-135 m thick in the west, thinning to about 50 m in the east.

Eruptive source(s). Abundance and size of lithic clasts in the ignimbrites are greatest in the more westerly parts of the outcrop area, suggesting that pyroclastic flow was from the west.

Relationships and structure. Over most of its outcrop area, the unit appears to conformably overlie Dalnotter Dacite, but in the west, it overlaps the Dacite to rest directly on Hodgkinson Formation basement. In the east, it unconformably(?) overlies Muirson Rhyolite and Rock Hole Rhyolite. Allsorts Rhyolite is disconformably overlain by, or possibly grades upward into, Lappa Rhyolite (*q.v.*) and is faulted against rocks of the Early Permian Featherbed Caldera. Dips are 10-20° to the north, northwest, or west, tending to steepen slightly in the northeast, and to decrease to subhorizontal in the north and northwest. The unit is intruded by dykes of rhyolite and andesite of probable Early Permian age, and by a plug of probably Tertiary olivine basalt.

Topography. Allsorts Rhyolite is characterised by generally subdued terrain, although relief of up to 50 m occurs on slopes, and on two small, mesa-like hills, where welded ignimbrite overlies easily-eroded pyroclastic/volcaniclastic deposits. Tree cover is short and sparse, and tones on airphotographs are very pale due to the almost white colour of the rocks and overlying soils.

Age. Allsorts Rhyolite, like the Dalnotter Dacite, is younger than 306±3 Ma and older than 289±7 Ma.

Synonymy. Branch (1966) included Allsorts Rhyolite in undivided "Featherbed Volcanics".

Lappa Rhyolite (Ctl) *(new name)*

Derivation of name. The unit is named from Lappa Creek which traverses part of the Lappa Rhyolite 8.5 km northwest of Petford and is a tributary of Emu Creek.

Distribution. Lappa Rhyolite is the uppermost unit of the Tennyson Caldera sequence, and is preserved only in the most elevated, northeasterly parts of the Caldera. It forms a watershed separating the headwaters of Lappa, Oak, Two Mile, and Allsorts Creeks from one another and from the heads of Swagmans Camp Creek and tributaries of upper Crooked Creek. Total outcrop area is about 12 km^2.

Type section. A complete section of the Lappa Rhyolite is not preserved; however, the lower part of the unit is well exposed along upper Oak Creek, between GR7863-72658320 and -721832. More accessible outcrops of typical (basal) Lappa Rhyolite are at -71658015 and 726797, and a section through altered Lappa Rhyolite overlying Dalnotter Dacite is well exposed between -70858395 and -71008385.

Lithology. Lappa Rhyolite consists entirely of dark-grey to greenish- or brownish-grey, welded, moderately to very crystal-rich (20 to 40%) rhyolitic ignimbrite. The crystal and crystal fragment component is made up of subequal proportions of K-feldspar, plagioclase, and quartz, and about 1% biotite (chloritised). Outcrops at and near the base of the unit in the upper reaches of the northern branch of Oak Creek contain up to 2% small (1-2 cm, rarely 5 cm), subangular to subrounded clasts of sparsely porphyritic rhyolite. Outcrops near the headwaters of Allsorts Creek are devitrified, originally very glassy rocks, and show extremely well-developed, fluidal, eutaxitic texture. The rocks are slightly to moderately altered, generally to sericite + chlorite ± epidote and calcite; the lithics-poor ignimbrite at the base of the unit in Oak Creek and some of the rocks in the headwaters of Allsorts Creek are altered to sericite + chlorite + kaolinite + hematite ± calcite, indicating early propylitic and later clay-hematite alteration, and/or weathering.

The Lappa Rhyolite is geochemically a highly fractionated I-type (or "calc-alkaline") rock, with about 77% SiO_2, very low Fe, Mg, and Ca, 2.6-3.0% Na_2O, and about 5% K_2O. Trace-element characteristics include low Ba (26-44 ppm), Sr (13-15 ppm), La (22-32 ppm) and Ce (56-69 ppm), and high Pb (38-39 ppm), Th (51-53 ppm), and U (10-12 ppm).

Thickness. The top of the unit is not preserved: remaining thickness ranges from about 60 m in the west to at least 100 m in the north.

Eruptive source(s). Preserved thickness and degree of welding in the Lappa Rhyolite increase towards the northeast, and lithic clasts are most abundant in upper Oak Creek and near the head of Swagmans Camp Creek. These observations suggest that the eruptive source(s) was(were) in the east or northeast, and possibly outside the Tennyson Caldera.

Relationships and structure. Lappa Rhyolite overlies Allsorts Rhyolite disconformably, and offlaps it to rest directly on Dalnotter Dacite in the northeast; it is essentially flat lying. In the north, it is faulted against rocks of the Featherbed Caldera, and intruded by a small plug of Tertiary(?) olivine basalt.

Age. Lappa Rhyolite, like Allsorts Rhyolite and Dalnotter Dacite, is younger than 306$\pm$3 Ma and older than 289$\pm$7 Ma.

Synonymy. Branch (1966) included Lappa Rhyolite in undivided "Featherbed Volcanics".

Units not assigned to Calderas/Cauldrons or Subgroups

Nightflower Dacite (Cna, Cnb, Cnc) (new name)

Derivation of name. The name Nightflower is taken from the Nightflower group of mines 12 km east of "Nychum" homestead, at GR7864-367363.

Distribution. Nightflower Dacite crops out over a crudely rectangular area of about 27 km^2 along Elizabeth Creek, 1-12 km southeast of "Nychum" homestead. The name is taken from the "Nightflower" group of mines, which are located near the southeastern end of the outcrop area.

Type section. The type section is from GR7864-310381 (contact between basal subunit and ring dyke) to -307377 (outlier of middle subunit) then to -309370 (faulted contact between basal and middle subunits) then to -310368 (contact between middle and upper subunits), and finally to -321348 (track, within upper subunit, which is subhorizontal here). numerous outcrops of typical Cnc (upper subunit) may be seen along the track from "Nychum" to the Big Watson River.

Lithology. Nightflower Dacite consists of three main subunits, Cna, Cnb, and Cnc, and a discontinuous basal epiclastic-pyroclastic rudite subunit (Cnx) which crops out in only two small areas, between 10 and 13 km east-southeast of "Nychum". At the more westerly locality, the basal rudite, or breccia, is about 2 m thick, and consists of angular clasts up to 1 m across of quartzose arenite, and smaller (a few cm) clasts of dark mudstone and siltstone (Fig. 4C). The lower contact, with Hodgkinson Formation, the source of the clasts, is highly irregular, while the upper contact is sharp and gently undulating. At the more easterly locality, the basal rudite is up to ~20 m thick, but the clasts, while of similar lithologies, are smaller ($\leq$15 cm), better rounded, and better sorted than to the west.

Cna, the lowermost ignimbrite subunit of the Nightflower Dacite, crops out mainly on the northern margin of the unit; similar ignimbrite crops out in a small, probably fault- bounded area on the southwestern margin. The subunit consists of pale-grey, grey, or greenish-grey, moderately to poorly welded, mostly lithics-poor, very crystal-rich (45-60%), biotite-bearing rhyolitic ignimbrite. Its thickness may be as great as 200 m, but is probably closer to 150 m. It forms generally massive, bouldery, outcrops, with little indication of layering. Lithic clasts are more abundant (up to 10, and perhaps 20 vol.%) and larger near the base of the subunit than elsewhere: angular to subrounded clasts 10-15 cm long occur at the base; 20 m above it they are 3-5 cm long, and near the top, 1-2 cm. Clast lithologies are predominantly dark-grey quartzose arenite and mudstone from the Hodgkinson Formation, but near the base, clasts of biotite granite and porphyritic biotite microgranite are also present.

The ignimbrite is moderately to strongly, propylitically altered to chlorite + sericite + epidote + calcite + Ti, Fe oxides. Alteration is particularly intense in the small, fault- bounded(?) area on the southwestern margin.

Cnb overlies Cna with apparent conformity (paraconformably?) over most of its extent. However, Cnb is also preserved in four small, gently southward dipping outliers which rest on an apparently very uneven surface developed on Cna: this suggests an unconformable relationship. The subunit is about 20 to 35 m thick in the east, but appears to be very thin or absent at the western end of the main outcrop area of Cna. It consists of medium to dark, generally greenish-grey and fine-grained, lithics-poor to -rich, moderately crystal- poor to crystal-poor, biotite-hornblende dacitic ignimbrite and, in the largest of the outliers, a basal horizon of strongly porphyritic biotite-hornblende dacite lava(?) a few metres thick. The ignimbrite contains clasts of rhyolitic ignimbrite and quartzose sandstone and siltstone, and, in places, crystals or crystal fragments up to 1 cm across. It is intensely altered to propylitic assemblages of chlorite + epidote + calcite + sericite + Ti oxide(s).

Cnc, the uppermost and by far most voluminous component of the Nightflower Dacite, is a massive dacitic ignimbrite sheet at least 150 m thick, and may be as much as 350 m thick. There is no clear evidence of breaks between flow sheets, suggesting that the subunit is a single cooling unit. It consists of medium to dark grey, lithics-free to moderately lithics-rich, crystal-rich to very crystal-rich, hornblende-biotite dacitic (to rhyodacitic) ignimbrite which contains minor amounts of clinopyroxene (probably augite), notably in its lower portions, and a trace of garnet (largely reacted to biotite and feldspar).

The base of the subunit is marked in places by a thin (<1 m) layer of laminated, fine, crystal-poor volcanogenic arenite or ignimbrite, probably of base-surge origin. The base of the ignimbrite sequence proper is characterised in most exposures by a relative abundance of subangular lithic clasts up to 20 cm across; clast size is greatest in the northeast, possibly indicating direction to source(s). Lithic clast size and abundance both decrease gradually upwards, with most of the unit containing a few percent by volume of clasts up to 3-5 cm across (Fig. 4B). Clast lithologies include very fine, aphanitic rhyolite (predominant), medium-coarse porphyritic rhyolite, feldspathic-quartz arenite to siltite (Hodgkinson Formation), and abundantly porphyritic dacite. A coarse pumice (eutaxitic) foliation, with pale grey, strongly porphyritic pumice clasts up to 8 cm long, is apparent in some outcrops.

Most of the subunit is slightly to very altered to propylitic assemblages (chlorite + sericite $\pm$ calcite $\pm$ epidote), with secondary biotite present in some rocks. In one area, near the junction of Rackarock and Elizabeth Creeks, 3 km southeast of "Nychum", the ignimbrite is intensely fractured, quartz-veined, and altered to/replaced by quartz, tourmaline, and opaque oxide(s). Tourmaline is also evident in several places near the Bilch Creek Granodiorite (Cgdn: below). In the east, a north-northeasterly trending fault has juxtaposed a sliver of Hodgkinson Formation arenite against Cnc; ignimbrite adjacent to the fault is intensely sericitised, fractured, and quartz-veined, and contains gelena-sphalerite-pyrite mineralisation (Nightflower group of mines - see below).

Thickness. Total thickness of the sequence is about 300 m, but may be greater if dips in the uppermost subunit are steeper than estimated (*i.e.*, ~5^{o}).

Eruptive source(s). Variation in size and abundance of lithic clasts, particularly in the basal part of Cnc, indicate that eruptive source(s) may have been in (or close to) the northeastern margin of the outcrop area, close to Big Watson Creek. However, strong petrological and geochemical similarities between Cna and the more felsic components of Cnc suggest that a source in the Doolan Creek Cauldron for at least some of the Nightflower Dacite cannot be ruled out.

Relationships. In an area about 4 km east-northeast of "Nychum" homestead, the Nightflower Dacite may be seen to rest on a very irregular surface underlain by strongly folded sedimentary rocks of the Hodgkinson Formation; in the same general area, it is overlain disconformably or unconformably by the Early to Middle Permian (Bailey & others, 1982; Bultitude & Domagala, 1988) Nychum Volcanics. Nightflower Dacite also rests unconformably on Hodgkinson Formation along part of its northern margin, 10 km east of "Nychum" homestead, and on either side of Elizabeth Creek, 1-2 km southeast of "Nychum". Elsewhere, the Nightflower Dacite is in faulted contact with Hodgkinson Formation, and with Early Permian (*ca* 280 Ma) volcanic rocks of the Wakara and Djungan Calderas. It is also cut by granodiorite (Bilch Creek Granodiorite) and porphyritic microgranite (Wabaredory Granite) stocks, a small lens of granite, dykes of microgranite and rhyolite, and possibly by rhyolite domes or flows; none of the intrusive rocks has been dated.

Structure. The Nightflower Dacite dips at about 10° to the south along its northern margin, with dip probably decreasing to mainly subhorizontal (<5°) in the south. There is some evidence of steepened dips near the faulted southwestern margin of the ignimbrite sequence. The ignimbrites are cut by a small number of normal faults with WNW, ENE, NNE, and (probably) NNW trends and probably small movements. The Nightflower group of mines is located on a NNE-trending fault which has up-faulted a slice of Hodgkinson Formation into the volcanic sequence.

Topography. Nightflower Dacite is characterised by low to moderate relief, low ruggedness, and a medium to medium-sparse, medium-height tree cover with conspicuous rounded, dense clumps that are developed mainly on patches of boulder scree. Outcrop is patchy and bouldery, resembling that of an intrusive rock. Tones on airphotographs are mainly slightly darker than on the surrounding Djungan Volcanic Subgroup, Wakara Volcanic Subgroup, Nychum Volcanics, and Hodgkinson Formation (Dh), although Cna is generally a little paler than Dh.

Age. A sample from the uppermost subunit of Nightflower Dacite produced a biotite Rb- Sr age of 308 Ma and a whole rock-mineral Rb-Sr isochron age of 308±4 Ma (L.P. Black, pers. comm., 1990); this Late Carboniferous age is consistent with the observed geological relationships of the unit.

Doolan Creek Rhyolite (Cda, Cdb) (redefinition of unit)

Doolan Creek Rhyolite (Bultitude & Domagala, 1988) is the revised name for the "Doolan Creek Rhyodacite" of de Keyser & Wolff (1964), Branch (1966) and de Keyser & Lucas (1968). It consists of two, irregularly-shaped outcrop areas on the northeastern and southwestern sides of the "Doolan Creek Ring Complex" of Branch (1966). This "ring complex" is a roughly circular aggregation of intrusive and extrusive rocks in the area around the junction of the Walsh River and Doolan Creek (from which the unit derives its name), 15 km NNE of Chillagoe. Total outcrop area of the unit is about 15 km^2.

Lithology. Doolan Creek Rhyolite consists of a more felsic lower subunit, Cda, and a more mafic subunit, Cdb. The lower subunit, Cda, consists of medium to dark greenish-grey to grey, moderately crystal-rich to crystal-rich, mafic rhyolitic ignimbrite containing abundant biotite and much less abundant hornblende. The upper subunit, Cdb, consists of dark-grey to greenish-grey, strongly recrystallised, lithic clast-poor to moderately poor (up to 10%), crystal-rich to very crystal-rich (35-40%), hornblende-biotite dacitic to rhyolitic ignimbrite; ferromagnesian minerals are more abundant than in Cda, and K-feldspar is rare or absent. Lithic clasts, which range up to 10 cm long, are predominantly quartzose fine sandstone to siltstone derived from the Hodgkinson Formation.

Both subunits are slightly to moderately altered to propylitic assemblages of chlorite + muscovite and/or sericite ± calcite ± epidote. The petrography of the Doolan Creek Rhyolite is described in detail by Bultitude & Domagala (1988).

Thickness of the Doolan Creek Rhyolite is uncertain; it may be up to about 500 m thick, but is probably considerably less, and closer to 200 m.

Eruptive source(s). There is no unequivocal evidence pointing to a source for the Doolan Creek Rhyolite: however, the abundance and size of lithic clasts in Cdb are not consistent with distal emplacement, and a local source cannot be ruled out.

Relationships. Doolan Creek Rhyolite unconformably overlies and/or is faulted against, sedimentary rocks of the Hodgkinson Formation. It is intruded by Ruddygore Granodiorite, Bungabilly Granite and several dykes and small stocks of microgranite, and is cut in the north by the margin of the Wakara Caldera.

Structure. The crudely circular overall distribution of the Doolan Creek Rhyolite and associated intrusive rocks, the arcuate southwestern margin of the unit, and the arcuate form of faults and lineaments that circumscribe the southern and southeastern margins of the Doolan Creek extrusive-intrusive complex are all suggestive of a cauldron subsidence structure. Attitude of layering in the Doolan Creek Rhyolite is uncertain because of the generally poor, or massive, nature of the outcrop. Dips in the southwest are probably gentle eastward/northeastward (to subhorizontal?), while in the north and northeast, close to the margin of the Wakara Caldera, layering probably dips at moderate angles to the north.

Topography. Doolan Creek Rhyolite is characterised by low, rounded topography and moderately dark tones on airphotographs.

Age. Doolan Creek Rhyolite is petrologically and geochemically similar to (part of) the Nightflower Dacite (308 ± 4 Ma), and also similar to some components of the Redcap Dacite and Jamtin Rhyolite. Biotite from the Ruddygore Granodiorite (which intrudes Doolan Creek Rhyolite) gave Rb-Sr isotopic ages of between 301 and 302 Ma (Richards, 1981). These observations are consistent with a Late Carboniferous age, most likely close to that of the Nightflower Dacite.

Unnamed sedimentary rocks (Cs)

Cs is the map symbol applied to a subhorizontal sequence of medium-fine to very coarse, commonly pebbly, arkosic arenites, one of the rare examples of clastic sedimentary rocks preserved beneath rocks of the Featherbed Volcanic Group. The sediments are up to 40- 50 m thick, and crop out around the southwestern margin of the small outlier of "Wallaroo rhyolite" (Crw_1, Crw_2, Crw), about 13 km northwest of Wolfram Camp mine. They unconformably overlie Hodgkinson Formation arenites and siltites, and are overlain, probably unconformably, by a sheet-like body of fine-grained, sparsely porphyritic, 2- pyroxene-biotite-hornblende andesite (**Cad**), and by "Wallaroo rhyolite". The andesite contains variable amounts of xenocrystic quartz and feldspar, and is continuous with a vertical, northeast-trending dyke of mostly coarser-grained andesite (discussed below); it is not known with certainty whether the sheet of fine-grained andesite is a flow or a sill, but the former is more likely.

"Wallaroo rhyolite" (Crw_1, Crw_2, Crw) (informal name)

"Wallaroo rhyolite" is the informal name, derived from Wallaroo Creek (northern Chillagoe-southern Mount Mulligan 1:100 000 sheets, 16 km northwest of Wolfram Camp) applied to a small (3.5 km) outlier of rhyolitic lava and ignimbrite located about 14 km northwest of Wolfram Camp mine.

The base of the Wallaroo rhyolite on the western side of the outlier is marked by flows of pale brown, sparsely porphyritic rhyolite (**Crw**) which merge to the northwest with a 1 km-long, wedge-like dyke of intrusive rhyolite. The rhyolite is overlain by rhyolitic ignimbrite which has been subdivided into two subunits. The lower subunit (**Crw_1**), which ranges up to between 60 and 100 m thick, consists of pale buff, white, or brown-grey, variably weathered, unwelded to welded, devitrified, lithics-free to -poor, crystal-poor rhyolitic ignimbrite. The upper subunit (**Crw_2**) consists of a few metres of interbedded rhyolitic fine-ash vitric tuff and lithics-poor to -rich, crystal-rich rhyolitic ignimbrite overlain by a sequence up to 120 m thick made up of (1) pale buff or greenish-cream, weathering to white or pale grey, lithics-poor, crystal-rich to -poor, rhyolitic ignimbrite a few tens of metres thick; (2) pale buff, cream, or white, flow-laminated, very fine, sparsely porphyritic rhyolite which is brecciated in several areas; and (3) pale buff, welded, very fine-grained, crystal-poor rhyolitic ignimbrite..

Lithic clasts in the ignimbrites include silicified, devitrified ex-very glassy, sparsely porphyritic rhyolite, crystal-poor rhyolitic ignimbrite, and fine-grained andesite. "Wallaroo rhyolite" is moderately to intensely altered to sericite + hematite ± silica ± calcite.

Wallaroo rhyolite conformably, or, more likely, disconformably, overlies the fine-grained andesite (Cad) and epiclastic sedimentary rocks (Cs) described above, and unconformably overlies Hodgkinson Formation. The base of the Wallaroo rhyolite is intruded in the southeast by rhyolite dykes which are probably comagmatic with rhyolites higher in the sequence. The ignimbrite sheets are flat lying or gently dipping.

The outlier of Wallaroo rhyolite forms a prominent mesa-like hill with steep sides and an undulating upper surface. Vegetation cover is sparse, and dominated by bushy acacias and small eucalypts. There is abundant outcrop of pale-toned rocks, including extensive rock pavements, and the hill as a whole is very pale-toned on airphotographs.

Wallaroo rhyolite is probably of Late Carboniferous age, on the grounds of its geological relationships and its petrological and geochemical similarity to components of the Boonmoo Subgroup, in particular the Rock Hole Rhyolite.

Beapeo Rhyolite (Crb, Cdb) (new name)

Derivation of name. The name Beapeo is taken from the Parish of Beapeo, County of Hodgkinson, which extends in an 8 km-wide strip northward from the Walsh River to the Hodgkinson River, and westward from Bulluburrah Creek near Wolfram Camp.

Distribution. Beapeo Rhyolite crops out adjacent to the James Creek Granite, immediately northwest of the Wolfram Camp mine, and extends over an area of about 15 km^2 northwestward to the Little River area.

Type section. The most accessible section through the unit is along a mine-access track from GR7863-802154 (base) to -789169 (base of upper subunit) and to -788171, then westward from the track to the ridge crest at -784171.

Lithology. The formation consists of two unnamed subunits: a lower rhyolitic ignimbrite (Crb), and and upper dacitic ignimbrite (Cdb).

The lower subunit (**Crb**) consists of pale- to medium-grey, lithics-poor (in the east) to lithics-free, moderately crystal-rich to crystal-rich, rhyolitic ignimbrite. The crystal/crystal fragment population of the ignimbrite typically consists of 5-10% quartz, 5-10% K- feldpsar, 1-3% plagioclase, and ~1% biotite (± hornblende?). At its base, the ignimbrite also contains 1-2% small (≤2 cm) clasts of dark-grey, fine (meta-)sedimentary rocks. The ignimbrite is slightly to moderately altered to propylitic assemblages of sericite + calcite + chlorite + opaque oxide(s) ± epidote. Degree of alteration is greatest adjacent to the James Creek Granite, where the ignimbrite is also variably recrystallised and, in places, brecciated.

The upper subunit of the Beapeo Rhyolite (**Cdb**) is sheet of dark-grey, crystal-rich to very crystal-rich, hornblende-biotite-augite dacitic ignimbrite which concordantly overlies about 1.5 km of Crb in the northwest of the outcrop area of the unit. It contains crystals and crystal fragments of white plagioclase (≤1, rarely 3, mm; ~30%), quartz (3-7 mm; 5-7%), pink K-feldspar (1-6 mm; ~1%), and 2-4% ferromagnesian minerals (hornblende, biotite, and clinopyroxene). The ignimbrite is slightly to moderately altered to chlorite + opaque oxide(s) ± sericite ± calcite; in one area, it is cut by several shear zones, and contains Mn- stained gossans..

Beapeo Rhyolite is probably comagmatic with the spatially associated intrusive rocks, Worcester Granite and Bulluburrah Microgranodiorite. The Worcester Granite has an arcuate form which, especially in the north, resembles an incomplete ring intrusion, centred approximately on the Bulluburrah Granodiorite. It may define the margin of a caldera since overprinted by the James Creek Granite and the Featherbed Caldera.

Thickness. The lower subunit (Crb) ranges in thickness from about 100 m in the north to at least 220 m in the south; the dacitic upper subunit (Cab) is 60-80 m thick.

Structure and relationships. Beapeo Rhyolite forms a subhorizontal to gently east-dipping (in the northwest) sheet unconformably overlying tightly folded Hodgkinson Formation sediments. In the north, it is cut by the ring fracture-intrusion complex of the Worcester Granite, and in the south it is intruded by the Bulluburrah Granodiorite and almost certainly predates the James Creek Granite.

Topography. Crb is characterised by low to moderate relief, with some steep slopes in places at the margins, and by medium-sparse tree cover, medium-pale to pale regolith tones, and a variably mottled overall texture on airphotographs. Cab is more subdued, smoother-textured, and darker (browns) on airphotographs, and has a medium- dense cover of small trees and bushes. Outcrop is sparse, patchy, and bouldery.

Age. Its relationships to adjacent units and its chemical similarity to some units of the Boonmoo Volcanic Subgroup indicate a Late Carboniferous age, possibly about 300 Ma.

Synonymy. Most of the Beapeo Rhyolite was included by Branch (1966) and de Keyser & others (1971) in undivided "Featherbed Volcanics"; they interpreted much of the northern outcrop area as granitoid.

Jamtin Rhyolite (Cjr_{1-4}, Cjd) (new name)

Derivation of name. The name is derived from Jamtin Creek, which drains the northwestern part of the main outcrop area and joins Crooked Creek at GR7863-466001.

Distribution. Jamtin Rhyolite is a sequence of rhyolitic to dacitic ignimbrites that crop out over a total area of about 38 km^2 adjacent to the western margin of the Featherbed Caldera, about 20 km southeast of Chillagoe, and in a 3.7 x 0.5 km, northeast-trending strip through Chillagoe itself.

Type section. The type section is along Crooked Creek, between GR7863-479937 (base of Cjr_4) and -491982 (within Cjr_1); the top may not be exposed.

Lithology. Jamtin Rhyolite consists of a basal sequence of mafic rhyolitic and minor dacitic ignimbrites ($Cjr_{2,3,4}$) overlain by a dacitic ignimbrite unit (Cjd) and a felsic rhyolitic ignimbrite (Cjr_1). The basal ignimbrite sheet (**Cjr_4**) is at least 420 m, and possibly as much as 540 m thick. The subunit consists of medium to pale-grey, crystal-rich, hornblende- biotite or biotite rhyolitic ignimbrite which characteristically contains dark-grey pumice *fiamme* up to 3 cm long; the pumice clasts define a foliation which dips at between 50^o and 80^o. The groundmass is commonly recrystallised, especially near the base, and slight to moderate alteration to sericite and chlorite is ubiquitous. In an area of several hundred square metres near the junction of Bustard and Crooked Creeks (GR7963-450980), the ignimbrite is strongly altered to white mica (muscovite and/or sericite) and quartz, cut by numerous quartz veins, some of which contain tourmaline, and is gossanous in places; minor amounts of stibnite have been extracted from shallow pits in the area.

A 4 km-long, southeast-trending outlier of crystal-rich biotite-bearing rhyolitic ignimbrite at Chillagoe is correlated with Cjr_4: it is up to 500 m thick, and has a near-vertical pumice foliation.

Cjr_4 is overlain with apparent conformity by a second, slightly more felsic, coarser-grained, less crystal-rich ignimbrite - **Cjr_3** - at least 430 m, and possibly up to 620 m, thick. This unit is typically a pale to medium-grey, crystal-rich to moderately crystal-rich, hornblende(?)- biotite rhyolitic ignimbrite with generally conspicuous, dark-grey pumice *fiamme* ranging from a few millimetres to 10 cm long. It also contains white to pink K-feldspar crystals/crystal fragments that range up to 1 cm across (*e.g.*, at the base of the unit in Crooked Creek). The ignimbrite is slightly to strongly altered to propylitic assemblages of chlorite + sericite + calcite ± epidote + Fe oxide(s) ± quartz ± rare prehnite(?) ± rare tremolite- actinolite. In three areas - near the Gibralter (Cu, Au) mine, 1^2 km northwest of the Federal Flag (Au) mine, and 1 km northeast of Scardons Top Camp mine, Cjr_3 is intensely altered, fractured or sheared, cut by quartz veins in places, and partly gossanous. In the second area, the alteration grades into intense greisenisation close to a small cupola of Retchford Granite (Figure 1). Where Crooked Creek cuts the pumice-enriched top of the unit (GR7863-482946), it contains disseminated pyrite and a trace of molybdenite.

Cjr_3 includes, about 150 m above its base, a 70 m-thick sheet of dark-grey, recessive-weathering, moderately crystal-poor, hornblende(?)-biotite dacitic ignimbrite. This rock is slightly altered to sericite + chlorite + titanite + calcite, and in places, such as in Crooked Creek where it is intruded by a small body of granodiorite, it is extensively recrystallised.

Cjr_3 is overlain, apparently conformably, by a crystal-poor to moderately crystal-poor biotite-bearing rhyolitic ignimbrite, **Cjr_2**, between 430 and 630 m thick. This ignimbrite is pinkish, medium- to pale-grey, or purplish-grey, has an extensively recrystallised groundmass with a fine, saccharoidal texture, and, in places, contains dark-grey pumice *fiamme*, up to 1.5 cm long, which form a faint eutaxitic foliation. The rock is slightly to intensely altered to sericite + chlorite + calcite; at one locality on Crooked Creek (GR7863-485593), the ignimbrite is intensely altered to sericite + chlorite + muscovite + andalusite + calcite, and also contains disseminated pyrite.

The fourth subunit of the Jamtin Rhyolite, **Cjd**, overlies Cjr_2 also with apparent conformity, and is 500-600 m thick. It crops out in low-lying country on lower Convict Creek near its junction with Crooked Creek, and in the middle reaches of Pinchgut Creek, over an area of about 5 km^2. It is extensively intruded by Ruddygore Granodiorite, with which is generally has knife-sharp contacts; at GR7863-511021 in the Pinchgut Creek area, this contact is very well exposed, dips very gently westward, and cuts across the pumice foliation in Cjd at a small angle. Cjd is also intruded by rhyolite dykes, and, in Convict Creek, by a small, dyke- like body of biotite leucogranite (Retchford Granite). Small outliers of dacitic ignimbrite, correlated with Cjd, crop out at the junction of Crooked Creek with the Walsh River, and on the opposite bank of the Walsh River, 10-15 km northwest of the main outcrop areas. These rocks could equally be correlatives of part of the Redcap Dacite or part of the Doolan Creek Rhyolite, as discussed below.

Cjd consists entirely of typically dark-grey, variably recrystallised (commonly by contact thermal effects), moderately to very crystal-rich (rarely moderately crystal-poor), hornblende-biotite dacitic ignimbrite. Lithic clasts - angular fragments of andesite up to 1- 2 cm - were observed at only one locality, near Pinchgut Creek in the northeast. A well-developed eutaxitic foliation is present in most outcrops, due to the presence of moderately abundant, very dark-grey, pumice clasts; these tend to be more abundant and larger in the southwest (10-15%, up to 6 cm long) than in the northeast (5-10%; up to 3 cm long). The ignimbrite is slightly to very altered, predominantly to propylitic assemblages of sericite + chlorite + calcite $\pm$ epidote + Fe-oxide(s). Intermediate argillic alteration (sericite + chlorite + calcite $\pm$ titanite) is present in the lower Convict Creek area, and in the Gibralter mine area.

Cjr_1, the uppermost component of the Jamtin Rhyolite, overlies Cjd with apparent conformity. Preserved thickness ranges up to at least 160-180 m, but the top of the subunit is not exposed. Dips, as far as can be determined with a paucity of visible fabric indicators, are subhorizontal. The subunit consists predominantly of pale pinkish-grey to purplish-grey or dark-grey, crystal-rich to very crystal-rich (25-40% crystals) biotite-rhyolitic ignimbrite which in places contains rare (%) clasts of very dark-grey to black andesite(?). In the northeast, where it is preserved as small roof pendants overlying Ruddygore Granodiorite and Pinchgut Granite, red, almandine-rich garnet is sporadically present. At one locality in this area, probably close to the base of the subunit, it contains clasts of Cjd. Cjr_1 is in most part slightly to intensely recrystallised, notably in the northeast where it has been hornfelsed by intrusive rocks. Cjr_1 is similar in most respects to the Rock Hole Rhyolite, although the latter lacks garnet and andesitic lithic clasts.

The ignimbrite shows generally slight to moderate intermediate argillic or propylitic alteration to assemblages of sericite + chlorite + calcite, or sericite + clay + calcite + epidote. In a section along an unnamed tributary of Crooked Creek, between GR500950 and 513900, the ignimbrite shows strong to intense sericitic alteration, which is accompanied by extensive fracturing, shearing, quartz veining and sulphide mineralisation over an area 2 km long and at least 500 m wide; sulphide minerals identified include pyrite, galena, and stibnite. In one area (GR503985), the rock is brecciated, with subrounded to rounded ignimbrite clasts set in quartz, including much vuggy, crystalline quartz, and pyrite.

Thickness. Total thickness of the Jamtin Rhyolite is difficult to estimate because neither the top nor the base is exposed, and dip indicators such as eutaxitic layering are generally not well developed; exposed thickness is at least 2300-2500 m, and may be up to 3000m if the dip of the southwestern limb of the fold is significantly steeper than 50°.

Eruptive source(s). There is no clear indication of flow or source directions in the Jamtin Rhyolite; as discussed further below, it is likely that the ignimbrites are outflow equivalents of the Muirson Rhyolite (Cjr_4), Hopscotch Rhyolite (Cjr_3, Cjr_2), Adder Dacite and Verdure Andesite (Cjd), and Rock Hole Rhyolite (Cjr_1) of the Eight Mile Cauldron to the east.

Structure and relationships. The ignimbrites form an asymmetrical syncline, with a very gently, southwest-dipping eastern limb and a steeply northeast-dipping western limb; dips in the western limb range between 50° and 80°. Some subunits in the western limb are not represented in the eastern limb, most of which has been truncated by the Featherbed Caldera. The unit is intruded by Late Carboniferous Almaden Granodiorite, Ruddygore Granodiorite, Pinchgut Granite, Retchford Granite, and Convict Granite, by Early Permian Lags Microgranite, and by an andesite dyke of unknown age. It is in faulted contact with the Early Permian Featherbed Caldera.

Topography. Jamtin Rhyolite is characterised by moderately steep, rounded hills with a sparse cover of trees (eucalypts, acacias, grevillias, and "quinine bush") and mostly pale to very pale tones (buff or straw) on airphotographs; areas underlain by Cjd are more subdued, darker-toned (medium brown to red-brown), and distinctly more densely vegetated. The main belt of outcrop, southwest of the Jamtin Creek-Convict Creek valley, consists of a series of parallel strike ridges. Outcrop is moderate, and mostly in the form of clusters/patches of boulders.

Age. A sample from the uppermost subunit of the Jamtin Rhyolite yielded a biotite Rb-Sr age of 301 Ma and a whole rock-mineral Rb-Sr isochron age of 301±11 Ma (L.P. Black, pers. comm., 1990). This age is indistinguishable from that of the Almaden Granodiorite (302±5 Ma: Black, 1978) which, along with the coeval Ruddygore Granodiorite, intrudes, and must have at least partially isotopically reset, the Jamtin Rhyolite. 301±11 Ma must therefore be regarded as a minimum age.

Synonymy. Jamtin Rhyolite was included by de Keyser & Wolff (1964), Branch (1966) and de Keyser & Lucas (1968) in undivided "Featherbed Volcanics".

Redcap Dacite (Crv_{1-4}) (new name)

Derivation of name. The name is derived from Mount Redcap which is located within the unit at GR7763-267110.

Distribution. Redcap Dacite comprises a triangular-shaped block, about 18 km^2 in area, of rhyolitic to andesitic ignimbrites in the Mount Redcap area, about 10 km northwest of Chillagoe.

Type section. The type section of Redcap Dacite extends from GR7763-251114 (base of Crv_1) on the eastern side of Redcap Creek southwest through -267095 to Whitelaw Creek at GR7763-278078, and thence south to -278075.

Lithology. Redcap Dacite consists of four subunits, each of which is an ignimbrite sheet or relatively homogeneous cooling unit; in descending stratigraphic order, these are: Crv_1 and Crv_2 (predominantly rhyolitic), Crv_3 (mainly dacitic), and Crv_4 (andesitic).

The lowermost subunit, $\mathbf{Crv_1}$, is a medium to dark grey, crystal-rich, hornblende- biotite rhyolitic ignimbrite. In its lowermost parts it contains abundant lithic clasts, including microdiorite, sedimentary rocks, and possible volcanic rocks. Dark grey, fine-grained pumice *fiamme* up to 5-7 cm long are common in the uppermost parts of this subunit, along with rare, biotite-rich mafic clots which may represent reacted garnet xenocrysts. The ignimbrite is slightly to intensely altered to propylitic assemblages of sericite, chlorite, and calcite, and is also variably recrystallised. Thickness of this subunit is difficult to determine, for reasons mentioned above, but may be about 350 m.

The second subunit, $\mathbf{Crv_2}$, consists of dark grey, medium to coarse-grained, crystal-rich, hornblende-biotite (mafic) rhyolitic ignimbrite, which is slightly more mafic than the underlying subunit, and contains more hornblende. Crv_2 is generally very altered to propylitic assemblages similar to those in Crv_1. Crv_2 overlies Crv_1 with apparent conformity; its thickness is between 600 and 850 m, the true value depending on the exact dip of the ignimbrite sheet.

$\mathbf{Crv_3}$, the third subunit of the Redcap Dacite is a very dark grey, very crystal-rich, hornblende-biotite dacitic ignimbrite, which contains a chloritised ferromagnesian mineral, possibly pyroxene, and a few small, dark, pumice *fiamme*. It overlies Crv_2 with apparent conformity. Its thickness maybe as much as 1430 m, but, if the subunit is folded as may be implied from the opposing dips in the northeast and southwest, this thickness may be a gross over-estimate.

Crv_3, is overlain, with apparent conformity, by the uppermost subunit of the Redcap Dacite, $\mathbf{Crv_4}$. This unit is a very dark grey, medium to fine-grained, moderately crystal- poor, pyroxene?-hornblende dacitic to andesitic ignimbrite, containing conspicuous small, white, feldspar crystals. At one locality it contains highly compacted, wispy, very dark-grey pumice *fiamme* which indicate a steep dip to the northeast. Maximum thickness of Crv_4 is 980 m, but the top of the subunit is faulted out, and the dip is uncertain.

Thickness. Because of the variability and uncertainty of dips throughout the unit, thickness of the unit is difficult to determine; it may be as much as 3500 m in total.

Eruptive source(s). Evidence of flow direction and direction to source in the Redcap Dacite are obscure; however, like the Jamtim Rhyolite, it is likely that the subunits comprising the Redcap Dacite represent outflow equivalents of units in the Boonmoo Cauldron to the southeast.

Structure and relationships. The unit is mainly fault-bounded against sediments of the Hodgkinson Basin, although in the northeast, Crv_1 appears to overlie these rocks. The unit is intruded by the Ruddygore and Belgravia Granodiorites. Dip of the ignimbrite sheets is difficult to determine; in the northeast, it appears to be about 45^o to the southwest, whereas in the southwest it appears to be about 80^o to the northeast, and possibly overturned.

Topography. Redcap Dacite forms an area of moderately steep hills with relief of up to 150 m above the surrounding, mostly lower and flatter terrain. Tree cover is medium-sparse to medium density and medium height, and tones on airphotographs range from pale brown in the northeast to medium-dark brown in the southwest. Outcrop is moderate to moderately sparse, and mostly bouldery.

Age. Redcap Dacite has not been dated, but its lithological and geochemical similarity to units of the Boonmoo Volcanic Subgroup strongly suggest that it also is Late Carboniferous (*ca* 300-305 Ma) in age.

Synonymy. De Keyser & Lucas (1968) included the Redcap Dacite in the Nychum Volcanics, along with the Doolan Creek Rhyolite.

Boxwood Volcanics

The Boxwood Volcanics (de Keyser & Wolff, 1964; Branch, 1966), south of the Tennyson Caldera (Figs 1, 2) were not examined in detail during this study. Branch (1966; based mainly on de Keyser & Wolff, 1964) described the unit briefly, stating that the major component is "a massive grey rhyodacite welded tuff", accompanied by "subordinate flows of dacite and pink rhyolite". The "welded tuff" was reported by de Keyser & Wolff (1964) to commomly contain clasts of "quartzite, chert, fine-grained pink leucogranite or aplite, and andesitic or basaltic rocks". Total thickness of the eruptive rocks was estimated by de Keyser & Wolff (1964) to be 60- 90 m.

P. Donchak (Geological Survey of Queensland) examined the volcanics at several localities in 1982 and reported massive, lithics-poor, crystal (plagioclase)-rich dacitic ignimbrite, less common porphyritic dacite lava flows, minor dacitic to rhyolitic airfall tuffs, and rare fluviatile(?) sediments (arenite and breccia/conglomerate).

The Boxwood Volcanics have not been dated; however, petrological similarities to rocks in the Tennyson (about 300 Ma: Black, 1978) and Eight Mile (about 304 Ma: L.P. Black, pers. comm., 1990) sequences suggest an age of about 300 Ma. Ages of 295 ± 10 Ma for the Nanyeta Volcanics and 307 Ma for the Garrumba Ring Complex to the south (Black, 1978) lend further circumstantial support to this argument.

LATE CARBONIFEROUS TO EARLY PERMIAN

Timber Top Volcanic Subgroup

The Timber Top Volcanic Subgroup crops out on the northeastern margin of the Featherbed Cauldron complex (eastern margin of the Djungan Caldera), adjacent to the western and northern margins of the Mount Mulligan massif (Figs 1, 2). It comprises two principal extrusive units (Breccia Creek Rhyolite and Controversy Hill Rhyolite), a composite rhyolitic ignimbrite unit (mostly coarse and lithic-rich) that may be a correlative of the Fisherman Rhyolite (Yongala Volcanic Subgroup), several minor, unnamed rhyolite lava and ignimbrite units, and an extensive, high-level, intrusive unit (Maneater Granodiorite).

The igneous rocks are separated from the Djungan Caldera by a ring fault-dyke system in the west. They clearly predate the Djungan Volcanic Subgroup (280 Ma: L.P. Black, pers. comm., 1991), but, because of their geochemical similarity to the Early Permian rocks of the Featherbed cauldron complex (Yongala, Djungan and Wakara Volcanic Subgroups and associated intrusive rocks), are considered to be Late Carboniferous to (more likely) Early Permian in age. In the east, they are in part overlain by, and in part faulted against, the Permian-Triassic Mount Mulligan Coal Measures and Pepper Pot Sandstone (de Keyser & Lucas, 1968).

The geology of the Carboniferous-Permian igneous rocks and Permian-Triassic sedimentary rocks is described in detail by Oversby & others (in prep.).

EARLY PERMIAN

Featherbed Caldera - Yongala Volcanic Subgroup

The Featherbed Caldera comprises an elliptical collapse structure in the south, with a parallel-sided, graben-like extension to the north-northwest; its total area is about 1100 km^2. It is bounded by a ring-fault/discontinuous ring-dyke system on all sides except the north-northwest, where it is truncated by the Djungan Caldera and Wakara Caldera/Upper Doolan Fault Zone (Fig. 2). The Featherbed Caldera appears to have undergone trapdoor-like collapse, with maximum relative downward movement in the southeast, and a hinge line - the Combella Creek Hinge Zone - extending orthogonally across the north-northwestern "graben". Thickness of the extrusive sequence in particular, and the Arringunna Rhyolite in particular, increases considerably towards the southeast (see descriptions of individual formations, below).

The Combella Creek Hinge Zone comprises a broad zone of structural disturbance, principally faulting and tilting of blocks, thickness changes, and emplacement of dykes and stocks of microgranite. Structural disturbance and thickness changes are most apparent in the area around and to the south of the Walsh River-Hot Springs Creek junction (Hot Springs Fault Zone). The large dyke of Lags Microgranite extending east-northeastward from the Caldera margin near Pinchgut Pinnacle and the stocks and dyke of Lags Microgranite in the northeastern corner of the caldera adjacent to the Djungan Caldera most likely reflect emplacement into extensional fractures and zones of maximum tensional stress during or shortly after rotation on the hinge line. Down-faulting of a block of Arringunna Rhyolite in the northeastern corner is probably also the result of tensional stress on the hinge line.

The Featherbed Caldera cuts across the western Boonmoo Sag, the northern part of the Tennyson Caldera, the Jamtin Rhyolite sequence, intrusive rhyolite associated with the "Wallaroo" rhyolite, and the Maneater Granodiorite. The northeastern margin of the Featherbed Caldera merges with the southeastern margin of the Djungan Caldera in an area which has the additional structural complexity of being the eastern end of the Combella Creek Hinge Zone, as discussed above. The hinge zone obscures the margins of both calderas in this area.

The youngest dated rock amongst those cut by the Featherbed Caldera is *ca.* 300 Ma old, whereas the only isotopic ages obtained for the ring dyke (Lags Microgranite: Fig. 1; Mackenzie, in prep.) are *ca.* 280 Ma.

The Featherbed Caldera sequence consists, as recognised by Branch (1966), of three main lithological groupings: (1) a discontinuous string of sparsely porphyritic rhyolite flows and domes intercalated with rhyolitic ignimbrites and very minor tuffs, and overlain by massive, commonly lava-like (modified by rheomorphic flow), crystal-rich rhyolitic ignimbrites (**Fisherman Rhyolite**); (2) an intermediate sequence of relatively thin-bedded, less crystal-rich, commonly very noticeably altered, rhyolitic ignimbrites (**Combella Rhyolite**) which contains extensive glassy horizons (vitrophyre); and (3) a thick, massive, upper sequence of very dark grey, very crystal-rich rhyolitic ignimbrite (**Arringunna Rhyolite**). The extrusive sequence is intruded by a discontinuous ring dyke and a cross-cutting dyke of porphyritic microgranite (Lags Microgranite), and by a high-level, resurgent-type, porphyritic microgranodiorite (St Helena Monzogranite). In the north, the Featherbed sequence is faulted against ignimbrites of the Djungan Caldera, and in the northwest, it is overlapped by the Wollenden Rhyolite, the lowermost exposed ignimbrite unit of the Wakara Caldera.

Fisherman Rhyolite (Pfl, Pfi, Pff) (new name)

Derivation of name. The name Fisherman is taken from Fisherman Waterhole on the Walsh River, 14 km northeast of Chillagoe. There is abundant outcrop of typical Fisherman Rhyolite (ignimbrite component) in the Fisherman Waterhole area.

Distribution. Fisherman Rhyolite crops out discontinuously around the margins of the Featherbed Caldera, over a total area of about 80 km^2. The main area of outcrop is a triangular area on the western side of the Caldera, flanking the Walsh River. Fisherman Rhyolite also crops out along most of the southwestern margin of the Caldera, in a 16 km - long strip along the southeastern margin, adjacent to the Boonmoo Sag, in several small slivers along the eastern margin in the Wolfram Camp area, and in the upper Combella Creek area.

Type section. The type section of Fisherman Rhyolite begins near Fisherman Waterhole (GR7863-436124; contact between basal lava [Pfl] and ring dyke) and extends along tracks through -436126 (flow-banded lava) and rheomorphically deformed ignimbrite to -442130 (typical undeformed ignimbrite), then across country to -439140 devitrified glassy ignimbrite) to -440141 (weathered crystal-poor ignimbrite - top of unit). A supplementary section, which includes lava at the base, lithic-rich ignimbrite, and coarse volcanic rudite as well as typical ignimbrite (Pfi), extends along a small gully from GR7863-473084 (contact between lava and ring dyke) to -476086 (lithic-bearing ignimbrite), and thence to -478091 (oxidised, but otherwise typical Pfi).

Lithology. Fisherman Rhyolite consists of two main parts: (1) a sequence dominated by rhyolite lava flows and domes, with minor rhyolitic ignimbrite (Pfl), and (2) a sequence dominated by rhyolitic ignimbrite which is generally lava-like (Pfi).

Lava flows and domes (Pfl) are concentrated almost exclusively in the lowermost part of the sequence, adjacent to the caldera margins; their location indicates that most originated from vents along the caldera margin. Lava flows are most extensive in the northeast of the Featherbed Caldera, along the middle and upper reaches of Combella Creek (around GR7863[BB]-620170). Along the southern side of Combella Creek, cavernous-weathering, partly brecciated, flow-banded rhyolite with large (up to about 1 m) gas cavities forms cliffs up to 30 m high. The lava pile is at least 100-200 m thick, and may be up to 500 m thick; it is overlain by a thin horizon of lithics- rich rhyolitic ignimbrite, which is in turn overlain by partly brecciated, sparsely porphyritic rhyolite with contorted flow banding. In places, the rhyolite contains sparsely distributed to abundant clasts of dark grey, very fine-grained rhyolite, and fine, dark grey laminae, which contrast with the pale buff to cream colour of the bulk of the outcrop; spherulites are also locally common.

Several lenticular bodies of sparsely porphyritic rhyolite are scattered along the western margin of the Featherbed Caldera: their volume and abundance decreases southeastward. The rhyolite ranges from massive to finely flow banded/laminated, and is commonly intensely altered (mainly to sericite) and/or brecciated; it contains up to 10% colourless quartz, white to pink or red K-feldspar and white to pale green plagioclase phenocrysts averaging about 1 mm across.

In the outcrop area cut by Wild Cow Creek, the breccias are marginal to massive rhyolite, indicating a flow or, more likely, a dome carapace origin. To the northwest, the dome(?) merges imperceptibly into a series of lava flows which extend about 5 km to Doolan Creek. A small (500x150 m) lens (dome?) of rhyolite immediately east of Pinchgut Pinnacle (GR7863[BB]-07043) is intensely altered to sericite $\pm$ clay(s) and carries anomalous concentrations of uranium.

A large body of sparsely porphyritic rhyolite with fine, folded to contorted flow banding/lamination crops out in the Bismarck mine area, on the southwestern margin of the Featherbed Caldera. It extends from the old mining camp southeastward along the caldera margin for about 4 km (about 3 km^2), and may be up to 250 m thick. The rhyolite is brecciated in places; spherulites and amygdales are rare.

Clastic, including pyroclastic, rocks other than ignimbrites are very rare in the Featherbed Volcanic Group, and within the Yongala Volcanic Subgroup are restricted to the lowermost part of the Fisherman Rhyolite. The most extensive of these occurrences is to the east of Pinchgut Pinnacle (between GR7863-503054 and -512032): the rock is a pale cream, fine to very fine-grained, rhyolitic fine-ash (crystal-)vitric tuff which is thin-bedded to massive, laminated in part, and generally deeply weathered and/or intensely altered.

Ignimbrite component (Pfi). The upper, and major, part of the Fisherman Rhyolite consists predominantly of moderately crystal-rich to crystal-rich rhyolitic ignimbrite which characteristically has a highly attenuated, generally very laterally persistent, eutaxitic foliation that strongly resembles flow banding. The ignimbrite overlies, disconformably or unconformably, the lava-rich lower part of the unit, or, in a few places (*e.g.*, the southeastern margin of the Featherbed Caldera in the Eight Mile area), abuts the ring fault/dyke. It is overlain disconformably, or, more commonly, with angular unconformity, by Combella Rhyolite. Thickness of the ignimbrite sequence is very difficult to estimate because of the structural complexity (see below): maximum thickness is at least 600 m, and may be well in excess of 1 km in the type area.

The ignimbrite has a wide range of colours in outcrop, the most common being brown, pinkish-brown, purplish-grey, pink, orange-pink to brick red or red-brown, purplish-brown, cream, pale to dark greenish-grey, and grey. In most outcrops, it is also characterised by prominent, mostly prismatic, crystals (or, uncommonly, crystal fragments) of pink K- feldspar up to 6-8 mm long.

In places near the base of the ignimbrite sequence, such as near the western margin of the caldera south of Fisherman Waterhole (GR7863-457105), rocks with highly attenuated pumice foliation grade downward over a few tens of metres into ignimbrite with well- preserved pumice clasts ranging up to about 10 x 2 cm; these rocks commonly also contain up to 10% by volume small clasts of sparsely porphyritic rhyolite. Ignimbrite near the base of the sequence also tends to be less crystal-rich than most of the overlying ignimbrite.

A section through the basal part of the Fisherman Rhyolite near GR7863-472088 exposes the following sequence (from the base):

(i) intensely altered and stockworked, moderately crystal-rich ignimbrite,

(ii) flow-laminated, sparsely porphyritic rhyolite and rhyolite breccia,

(iii) devitrified ex-glassy, moderately crystal-poor rhyolitic ignimbrite (vitrophyre),

(iv) sparsely porphyritic rhyolite with contorted flow lamination,

(v) quartz-hematite-altered lithics-rich, moderately crystal-poor ignimbrite,

(vi) coarse volcanogenic rudite containing clasts up to 1 m across and layers a few centimetres thick of fine, crystal-rich surge deposit material,

(vii) several thin sheets of pinkish to purplish-grey, lithics-bearing, moderately crystal-rich rhyolitic ignimbrite;

(viii) massive, moderately crystal-poor to -rich rhyolitic ignimbrite with well developed, variably attenuated and deformed pumice foliation.

The top of the Fisherman Rhyolite near GR7863-500107 is marked by a pumice-concentration zone a few metres thick overlain by poorly-welded to unwelded, strongly spherulitic ignimbrite (Fig. 5A). Immediately beneath the overlying Combella Rhyolite, this ignimbrite is intensely fractured, altered, and weathered; it may have been close to a palaeo-weathering surface.

Small outliers 3 km southwest of Muirson Pinnacle represent an horizon, up to 200 m thick, of very dark-grey, fine-grained, crystal-poor, rhyolitic ignimbrite similar to some relatively unaltered parts of Pff_i. This rock has a fine, highly attenuated eutaxitic texture - characterised by abundant streaked-out pumice clasts up to 4 mm thick and 10 cm or more long - which is folded or contorted in places and resembles flow banding; it also contains scattered small (up to 1 cm) clasts of cream to brown, sparsely porphyritic rhyolite.

The massive, lava-like ignimbrite portion of the Fisherman Rhyolite is a single cooling unit, and may well also be a single ash-flow unit. Flow directions and pointers to eruptive source locality/ies of the ignimbrite are difficult, if not impossible, to determine because of the structural complexity. The bulk of the ignimbrite appears to be located in and to the southeast and east of the type area, and the unit as a whole thins away from this area: it is therefore likely that the western margin of the Featherbed Caldera in the Fisherman Waterhole-Pinchgut Pinnacle area is the source of the ignimbrite.

Undivided Fisherman Rhyolite (Pff). Exposures of Fisherman Rhyolite in an area of complex geology near Convict Creek (around GR7863-520950) include, overlying a basal sequence of fine-ash tuff, lithics-rich ignimbrite, and "typical" lava-like ignimbrite, extensive volcanogenic rudites and/or breccias and flow-banded rhyolite intercalated with, or faulted against, brecciated or

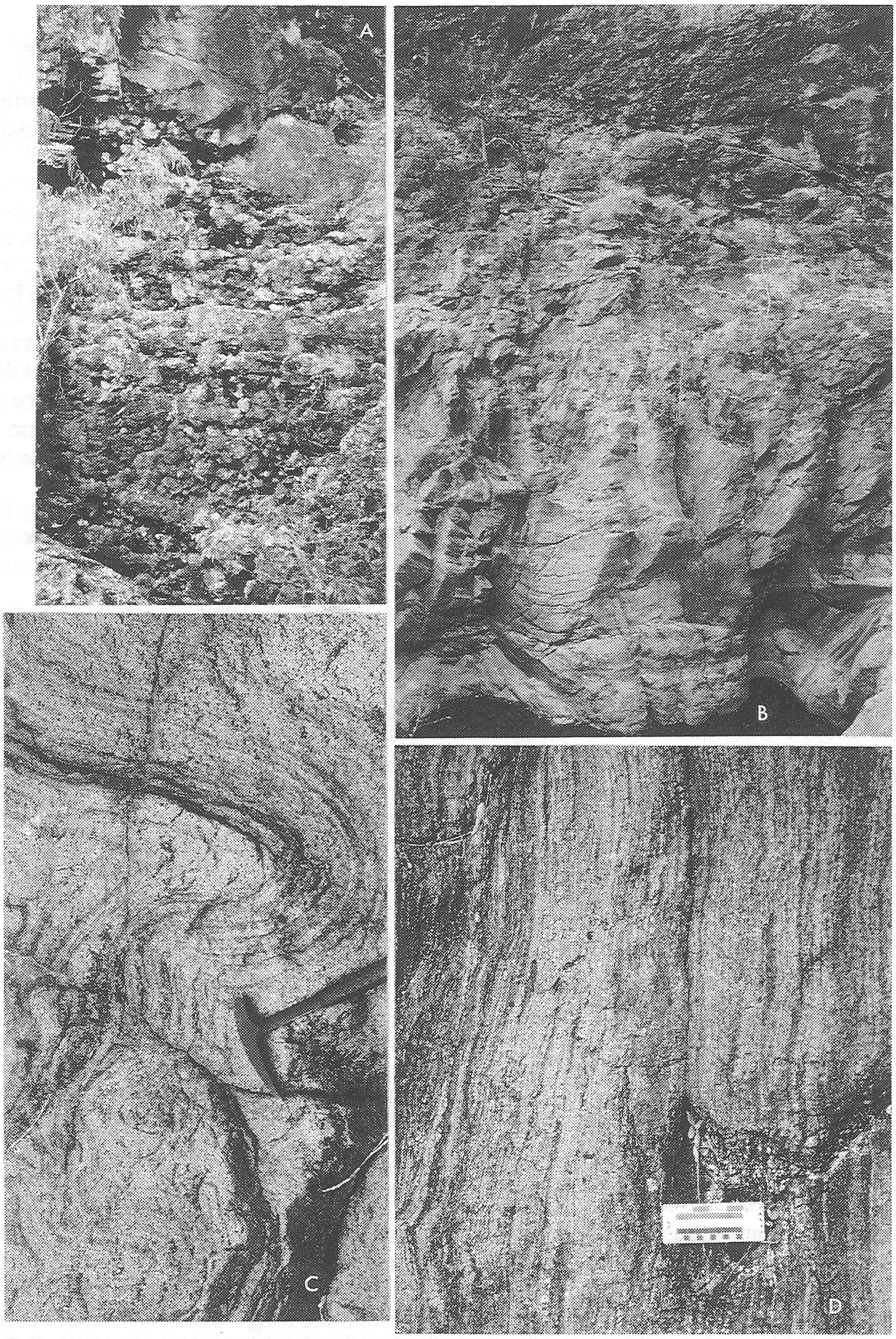

Figure 5.

A. Unwelded/poorly welded, pumice-rich rhyolitic ignimbrite near base of Fisherman Rhyolite, Yongala Volcanic Subgroup, Featherbed Caldera. Tributary of Pichgut Creek, GR7863-505052.

B. Large-amplitude folds in rheo-ignimbrite, Fisherman Rhyolite(?), Lightning Creek, Djungan Caldera. GR7864-504404. Welded rheo-ignimbrite grades upward into poorly welded and gas-cavity-rich ignimbrite (top of photograph); the darker colour is due to the relative abundance of unrecrystallised devitrified glass.

C. Mesoscopic folds in rheo-ignimbrite (locality as for B).

D. Detail of streaked-out pumice foliation in rheo-ignimbrite (locality as for B).

sheared rhyolitic ignimbrites. Outcrop at GR7863-530942 is a matrix- supported rudite/breccia consisting of angular clasts of flow-banded rhyolite up to 2 m across in a "sandy", crystal-rich matrix: this may be either the proximal part of an ignimbrite sheet, or a proximal co-ignimbrite deposit. These mixed rocks extend south-southeastward to about GR7863- 600870.

Rocks mapped as Fisherman Rhyolite crop out over an area of about 18 km^2 in the Bismarck mine area, farther to the south-southeast, include a variety of rhyolitic ignimbrites intercalated with (predominantly - 30-40% of the sequence) flow-banded, sparsely porphyritic rhyolite. The ignimbrites are crystal-poor to moderately crystal-poor, and range from lithics-free to lithics-rich: abundance and size of lithic clasts tend to increase upward, with maximum clast size reaching ~10 cm near the top of the sequence. In some places, the ignimbrite has a well-developed pumice foliation which has been streaked out and contorted, in similar fashion to, but not to the same degree and extent as, ignimbrite in the type area. Other lithologies present include massive volcanogenic rudite made up of clasts of ignimbrite up to 1 m across, and very rare dacite/andesite.

Alteration. Another of the characteristics of the Fisherman Rhyolite is that it is ubiquitously altered, such that primary ferromagnesian minerals are very rarely preserved. Mention has already been made of the characteristic pink (altered) K-feldspar prisms: green, highly altered plagioclase crystals and crystal fragments are also a common feature. Propylitic assemblages (combinations of sericite, chlorite, calcite, and Fe-oxides) are predominant, but there are significant areas of clay-quartz and quartz-hematite alteration, for example 4.5 km SE of Fisherman Waterhole (GR7863-472088), along much of the sector of the southwestern margin of the Featherbed Caldera between GR7863-520010 and -530920, and along the eastern margin from the Walsh River to the Eight Mile Waterhole area.

The degree of alteration is generally greatest in the lowermost parts of the unit, nearest the caldera margins, and generally least in the uppermost parts of the of the unit, most noticeably where it is (or, at least, appears to be) thickest.

Thickness. Fisherman Rhyolite is probably about 1200-1500 m thick, and may be considerably thicker, but estimation of thickness is made very difficult by the widespread rheomorphic deformation of the ignimbrites and the general structural complexity.

Eruptive source(s). The lava component of Fisherman Rhyolite (Pfl) was extruded from numerous vents scattered along the western margin of the Featherbed Caldera. Coarse volcanogenic rudites or lithic-rich ignimbrites, with clasts up to 2 m or more, crop out in several places within the basal part of Pfi. The most extensive of these occurrences are 5 km southeast of Fisherman Waterhole, 2 km northeast of Pinchgut Pinnacle, and in Crooked Creek, 11 km east-northeast of Almaden. The locations of these deposits coincides with the thickest parts of the ignimbrite component of the Fisherman Rhyolite, and is a strong indication that the ignimbrites were erupted from along the southwestern margin of the Featherbed Caldera.

Relationships. In each area, the lower boundary of Fisherman Rhyolite is either a fault - generally a major ring-fault - or a dyke of Lags Microgranite, or both; no underlying "basement" (*e.g.*, Hodgkinson Formation) has been observed within the bounds of the caldera. Fisherman Rhyolite is overlain by Combella Rhyolite or, along the eastern margin and in places along the southwestern margin, by Arringunna Rhyolite; contacts with the overlying units are generally disconformable, or, more commonly, unconformable.

Topography. Fisherman Rhyolite is characterised by a sparse, generally stunted, tree cover, and a relatively light cover of grasses dominated by "kerosene" grass which has very pale tones during the dry season. This pale colour, plus the pale tones of the rock outcrops, results in a very pale buff or straw, almost white tone on airphotographs or when viewed from a distance. Outcrop morphology of the unit is also characteristic: the lavas/domes form rounded, rubbly hills of steep whalebacks with large areas of rock pavement; the main ignimbrite forms a variety of terrains, ranging from low and undulating, with low, smooth whalebacks and rock pavements, to irregular, very rocky, hilly terrain with abundant ragged hogback to whaleback-like outcrops. The overlying Combella Rhyolite is, in contrast, relatively smooth-textured and darker-toned.

Age. The unit has not been isotopically dated: an Rb-Sr isochron age of 267±7 Ma for rocks in the Fisherman Waterhole area obtained by Black (1978) included samples from the Arringunna Rhyolite and possibly also the Combella Rhyolite as well as the Fisherman Rhyolite.

Synonymy. De Keyser & Wolff (1964) delineated most of the Fisherman Rhyolite in the type area, and parts of it in other areas, as an unnamed subdivision (one of three) of the "Featherbed Volcanics". Branch (1966) more accurately described the three-fold subdivision, which approximates to that now recognised, but also included part of the Fisherman Rhyolite in undivided "Featherbed Volcanics".

Fisherman Rhyolite equivalents(?) in the Djungan Caldera

Rocks correlated with Fisherman Rhyolite crop out extensively around the northern and southeastern margins of the Djungan Caldera. They include flow-banded, sparsely porphyritic rhyolite lavas, which are extensively brecciated and/or altered, and lava-like, moderately crystal-poor to -rich rhyolitic ignimbrite generally with highly attenuated, commonly deformed, pumice foliation similar to that described above. It is on the basis of this lithological similarity, and on their geological relationships that these rocks are correlated with Fisherman Rhyolite. The lavas and ignimbrites are overlain with apparent angular unconformity by crystal-rich ignimbrites of the Djungan Volcanic Subgroup (the uppermost formation of which - Lumma Rhyolite - is dated at ~280 Ma, and are intruded by high-level microgranite dykes (including the main ring dyke) and a stock of microgranite similar to the Lags Microgranite and similarly dated at ~280 Ma. However, the possibility that these rocks are not correlatives of the Fisherman Rhyolite but, like the overlying Lumma Rhyolite, significantly younger and coincidentally similar in so many respects cannot be discounted.

The main development of rocks equivalent to the lower part of the Fisherman Rhyolite in the Djungan Caldera is in the southeast, around GR7864[BB]-620200. Sparsely porphyritic rhyolite, generally with contorted flow banding or lamination, crops out over an area of about 8 km^2; it is brecciated over large areas (flow-front or carapace breccias), and moderately to intensely altered to combinations of sericite, silica, clay(s) and hematite. Columnar jointing, with columns up to about 10 cm in diameter is evident in places. It is not known with any certainty whether these rocks are predominantly flows or domes: both are most likely represented.

Sparsely porphyritic rhyolite also crops out in the north and northwest of the Djungan Caldera. In the northwest, rhyolite crops out extensively along the margins of the caldera adjacent to the Big Watson Granite complex (see below), straddling Big Watson Creek. The rhyolite crops out over an area of about 6 km^2, and ranges up to about 350 m thick. The rocks are purplish or brownish-grey to pink, flow-laminated in part, sparsely to moderately porphyritic (K-feldspar, quartz, and plagioclase phenocrysts), and moderately to extremely altered to combinations of sericite, quartz, calcite, clay(s), chlorite, and hematite. Rhyolite along the northern margin of the Djungan Caldera is confined to a belt about 1.2 km long and up to 100 m thick straddling Lightning Creek. The rocks are green to cream or off-white, sparsely porphyritic, brecciated in places, and very to extremely altered. Alteration assemblages are sericite with clay(s), quartz, and hematite, or clay(s), quartz and hematite without sericite; the clay-quartz-hematite alteration appears to overprint sericitic alteration. In neither locality is it clear whether the rhyolites are in the form of flows, or domes, or a mixture of both; however, the general distribution and morphology of the rocks, and the distribution of breccias suggest that flows are predominant.

In both the northern areas, the rhyolites are overlain with apparent unconformity by rhyolitic ignimbrites: the contact ranges from very steeply to gently southward to southeastward-dipping. In the southeast of the Djungan Caldera, the relationship is not so well exposed, but appears to be similar, with the ignimbrites dipping northwestward.

In the southeast of the Caldera, around GR7863-590180, the upper part of Fisherman Rhyolite(?) consists predominantly of red-brown to grey or greenish-grey, moderately crystal-rich, rhyolitic ignimbrite with dark grey or brown to red-brown pumice clasts up to 7 cm long and characteristic pink to red K-feldspar prisms up to 6-7 mm long. The uppermost parts of this ignimbrite consists of poorly-welded, devitrified vitrophyre which characteristically weathers to a "knobby" (resembling a coarse, semiconsolidated conglomerate with ellipsoidal clasts) or cavity-strewn surface. Pumice foliation varies from moderately compacted (l = 5 x t) and planar to moderately attenuated (l = 20 x t) and variably (not universally) deformed. A thin (m) bed of lithic clast-bearing, moderately crystal-poor vitric ash tuff (or volcanogenic arenite), of either co-ignimbrite airfall or base-surge origin, crops out at GR7864- 597192, about 60-80 m below the top of the sequence.

Dykes of similar material ("tuffisite"), probably injected upward from this, or other, similar, beds are common in the overlying ignimbrite. Lower in the sequence, the ignimbrite is more intensely welded, a little less crystal- rich, and has increasingly attenuated and deformed pumice foliation, resembling that in the type area of Fisherman Rhyolite. Total thickness of the ignimbrite sequence in this area is difficult to estimate with any precision; maximum thickness is probably between 200 and 300 m.

In the north of the Djungan Caldera, transected by Lumma and Lighting Creeks, is a sequence at least 250 m thick, and possibly up to 500 m thick, of grey to greenish-grey weathering to pink, crystal-poor to moderately crystal-rich rhyolitic ignimbrite very similar to Fisherman Rhyolite in the type area. This ignimbrite overlaps the lens of lava, *etc*., described above, and is cut by the marginal ring dyke along most of the arc of outcrop. At the base of the ignimbrite is a thin-bedded, spherulite/gas cavity-rich horizon which dips gently south (Fig. 4D). It is overlain in the west by Scrufflem Rhyolite, generally with apparent conformity (disconformity?), and in the east, clearly unconformably, by Lightning Creek Rhyolite and Lumma Rhyolite. Outcrop area is about 11 km^2. To the southeast, near upper Little Watson Creek (GR7864-613323), similar lava-like ignimbrite, which is brecciated in part, crops out as a lens about 2 km long and up to perhaps 150 m thick. The lens is bounded by a fault and a ring dyke on the east, and unconformably overlain by Lumma Rhyolite to the west.

The ignimbrite is typically lava-like, with a highly attenuated, semi-continuous pumice foliation folded on scales of tens of metres to a few centimetres (Figs 5B-D), but in places is massive and apparently lacking foliation, and in other places (*e.g.*, GR7864-490400, -533409) is brecciated. Towards the top of the unit, lava-like ignimbrite can be seen to grade upward into poorly welded to unwelded, "rubbly" ignimbrite commonly with abundant gas cavities and/or amygdales/spheruloids (*e.g.*, in Lightning Creek, at GR7864-507392; Fig. 5B); this horizon is generally well layered, and dips moderately to gently to the south. In the eastern branch of Lighting Creek, immediately beneath an outlier of Scrufflem Rhyolite (Pda; GR7864-509604), ignimbrite with increasingly abundant (upward) gas cavities and amygdales (or spheruloids) also contains a few lithic clasts.

The basal part of the unit includes in some places a succession of thin (a few metres), lithic clast-bearing ignimbrite sheets: at GR7864-521417 crystal-poor, lava-like rhyolitic ignimbrite is overlain by a few metres of moderately crystal-poor ignimbrite with a well-developed eutaxitic foliation, formed by pumice clasts up to 3 cm x 1 cm, and a pumice concentration zone at the top. This is overlain by a sheet of lithic clast-poor ignimbrite, about 30 cm of well-layered, very crystal-rich volcanogenic arenite (base surge?), about a metre of poorly/un-welded, lithics-rich ignimbrite, a few metres of moderately lithics-rich to -poor ignimbrite, and by an unknown thickness of brecciated lava-like ignimbrite with clasts up to ~30 cm.

Ignimbrites similar to those along the northern margin of the Djungan Caldera crop out over an area of about 3.5 km^2 farther to the southwest, in the Big Watson Creek area. The main exposure is to the west of Big Watson Creek, where the ignimbrite ranges up to at least 200 m thick. It disconformably overlies the altered rhyolites described above, and is partly overlain unconformably, and partly faulted against Scrufflem Rhyolite and Lighting Rhyolite. To the east of Big Watson Creek, the ignimbrite crops out as a thin (up to ~50 m) lens about 1.5 km long disconformably(?) overlying Fisherman Rhyolite equivalent(?) rhyolites, and overlapped (unconformably) by an unnamed ignimbrite of the Djungan sequence (Pdd). The rocks are crystal-poor, rarely lithics-bearing, and almost universally have highly attenuated, flow banding-like pumice foliation; fracturing and brecciation are more common than to the northeast. The lens to the east of Big Watson Creek displays a sequence of poorly welded ignimbrite with a strong, "streaky" pumice foliation (formed by pumice clasts up to 5 x 0.5 cm) grading up into a welded ignimbrite with extremely attenuated pumice foliation, then devitrified vitrophyre with obscure banding, and finally brecciated lava-like ignimbrite.

In all the areas described above, the ignimbrite sequence probably comprises several ash flows, but they have generally behaved as a single cooling unit. Extreme attenuation of pumice clasts, the mimicking of flow banding by the resultant streaked-out foliation, and the rheomorphic flow and folding are the results of relatively hot, low-viscosity magma, rapid extrusion and consolidation of and accumulation hot ash flows so that cooling is slowed, and instability caused by caldera collapse.

This phenomenon is discussed in more detail in a later section. Indications of flow direction and eruptive vent location are not evident.

Like the rhyolite component described above, the Fisherman Rhyolite equivalent(?) ignimbrite in the Djungan Caldera is ubiquitously altered: alteration is most intense in the north of the Caldera, near the ring dyke, and least intense (moderate) in the southeast. Alteration assemblages are predominantly clay(s), quartz and hematite, generally with variable amounts of sericite; sericite is rare or absent in rocks from the northwestern margin (Big Watson Granite area). Calcite was observed in significant quantities at only one locality in Lightning Creek. Ferromagnesian mineral(s) - biotite and possibly ortho(?)pyroxene - are completely replaced, commonly so that no trace remains; feldspars are largely to completely replaced by sericite and/or clay(s), plagioclase generally being more affected than K-feldspar in less intensely altered rocks.

Fisherman Rhyolite equivalents(?) in the Wakara Caldera

Rocks correlated with the Fisherman Rhyolite also extend in a belt about 6 km long and up to 750 m wide westward from Doolan Creek, at the northwestern extremity of the Featherbed Caldera, into the Wakara Caldera. Like Fisherman Rhyolite, it consists of a lower rhyolite (lava, *etc.*) and an upper ignimbrite component. The lower part of the succession in the east, near Doolan Creek, is apparently continuous with Fisherman Rhyolite (rhyolite Member) to the south, and may be up to 150-200 m thick. It is intruded by porphyritic microgranite correlated with Lags Microgranite of the Featherbed Caldera, and is overlain, probably unconformably, by ignimbrite. Rhyolite also occurs at the western end of the belt, where geological relationships are similar. The rhyolite component consists of partly brecciated, sparsely porphyritic rhyolite with contorted flow banding; it is not known whether these rocks represent flow(s) or dome(s), or both. The upper, more westerly, and major part of the sequence has a maximum thickness of at least 450 m, possibly up to 650-750, and is overlain disconformably(?) by Stuarts Rhyolite and younger rhyolite bodies of the Wakara Volcanic Subgroup. It consists mainly of green-grey, moderately to intensely altered (sericitised), moderately crystal-poor to moderately crystal-rich rhyolitic ignimbrite, most of which has deformed, attenuated pumice foliation. Gas cavities (near the top), brecciation, and "tuffisite" dykes were observed in the thickest part of the ignimbrite sequence, around GR7864-347205, and columnar jointing, with columns ~20 cm thick, was observed in Doolan Creek. At the base of the ignimbrite at GR347202, is a lens about 1 km long and up to 100 m thick of black, partly devitrified, lithics-poor, moderately crystal-poor, glassy rhyolitic ignimbrite, or vitrophyre. Lithic clasts include recrystallised sparsely porphyritic, very fine-grained rhyolite, and vitrophyre. Crystals/crystal fragments are quartz, K-feldspar (sanidine), sodic plagioclase, fayalite, and augite.

Rheomorphism in the Fisherman Rhyolite

Viscous laminar flow in ignimbrites is a well known, though not commonly recognised phenomenon (*e.g.*, Hoover, 1964; Sargent & others, 1965; Walker & Swanson, 1968; Anderson, 1970; Hargrove & Sheridan, 1984; Ekren & others, 1984). It is generally agreed (*e.g.*, Wolff & Wright, 1981; Hargove & Sheridan, 1984; Ekren & others, 1984) that rheomorphism occurs in ash-flow sheets when temperatures remain above a threshold value (between 500° and 550°C according to Riehle, 1973) for sufficiently long after welding for flow to take place before the whole sheet becomes rigid. An obvious prerequisite for flow is gravitational instability: this may be caused by disturbance, such as caldera collapse or seismic activity, and/or emplacement on a slope. In the case of the Fisherman Rhyolite, it is likely that the ignimbrite was emplaced as a very thick, hot flow or rapid series of flows, and that the pile responded to simultaneous or immediately subsequent caldera collapse by slumping towards the interior of the caldera. A similar model was proposed by Hargrove & Sheridan (1984) for the Calavera Caldera (part of the McDermitt Caldera), Nevada.

Combella Rhyolite (Pfc) (new name)

Derivation of name. The unit is named from Combella Creek, which joins the Walsh River within the Featherbed Caldera at GR7863-547117 and traverses Combella Rhyolite over a considerable proportion of its course.

Distribution. Combella Rhyolite overlies Fisherman Rhyolite in the gorges of the Walsh River and Combella Creek, and along parts of the western margin of the Featherbed Caldera; it does not crop

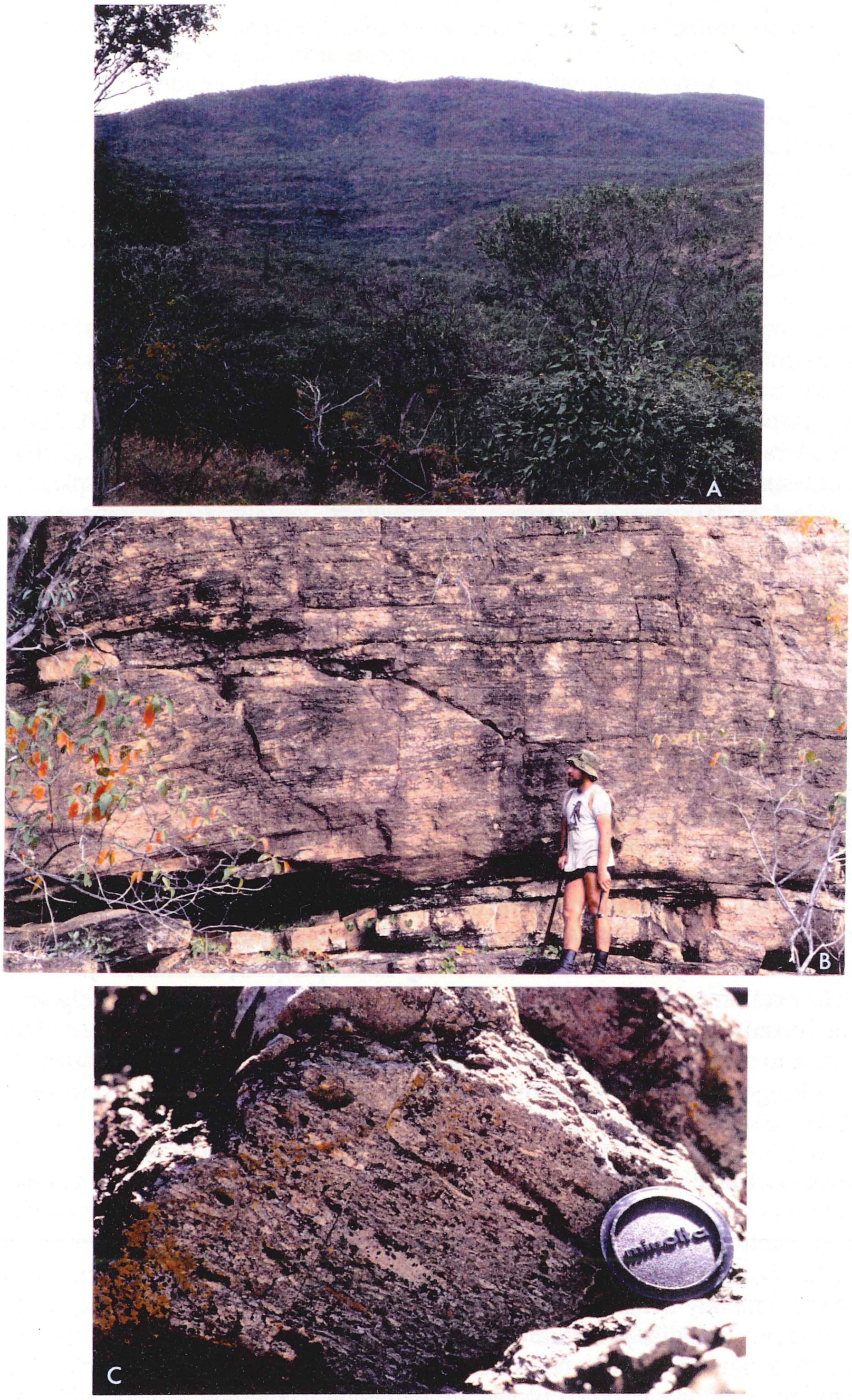

Figure 6.

A. Typical terrain in the Featherbed Range, showing multiple, subhorizontal ignimbrite sheets of the Combella Rhyolite (middle distance) overlain by massive Arringunna Rhyolite (on skyline).

B. Highly attenuated pumice foliation, Combella Rhyolite, lower Combella Creek (GR7863-561126); some pumice clasts have been streaked out to several metres in length.

C. Pumice *fiamme*, Combella Rhyolite, western margin of Featherbed Caldera (GR7863-472087).

out along the eastern margin of the caldera. Total exposed area of the unit is about 104 km^2, almost all of this in a continuous area of outcrop flanking the Walsh River and Combella Creek.

Type section. A complete section through the Combella Rhyolite is well exposed between GR7863-553092(base) and -570075 (top); the stratigraphy here is described in general terms below. A much more accessible, but less well exposed and thinner section is located near an exploration track, 2 km east-northeast of Fisherman Waterhole, between GR7863-46451330 (base) and -46251365 (top).

Lithology. Combella Rhyolite is made up of several thin ash-flow sheets and some lava flows (Fig. 6A); in the type area, at least, it may be subdivided into three main units. The lowermost is a multicoloured, highly altered ignimbrite with a vitrophyre horizon near the base and an unwelded top. The middle unit is characterised by abundant spherulites and gas cavities, and contains a thin layer of volcanogenic siltstone near the top. The uppermost unit is series of thin, altered, spherulitic ignimbrite sheets and vitrophyre horizons.

A notable characteristic of the Combella Rhyolite as a whole is the high proportion of glassy rocks in various stages of hydration, devitrification, and recrystallisation: spherulites and "thunder eggs" are also very common, and, along with gas cavities or amygdales variably filled with agate, chalcedony, jasper, or quartz crystals, are also a characteristic feature of the unit. The rocks are also typically moderately to intensely altered: this, combined with the abundance of glassy rocks results in a characteristically multicoloured sequence dominated by greens, pinks, purple, and red-brown, and by the black to dark grey of relatively pristine glassy ignimbrite (vitrophyre) and lava.

Black, optically isotropic, hydrated vitrophyre containing 10 to 25% crystals (or phenocrysts, in rare cases) is preserved in all parts of the unit, except along the southwestern margin of the Featherbed Caldera. Glassy rocks are most extensively preserved in the thickest parts of the sequence, in the southeast: for example, a vitrophyre horizon 10 m thick is exposed in the southern lip of the gorge of Combella Creek at GR7863-582124. More typically, however, several horizons 1-3 m thick, and extending laterally for several kilometres, are exposed in the area to the south, between lower Combella Creek and Little Silent Waterhole on the Walsh River.

Rhyolite lava is most abundant in the northeast, to the south of middle Combella Creek (GR7863-635155), where it occurs in flows up to a few metres thick throughout all but the uppermost and lowermost parts of the sequence; one of these flows (at GR7863-635154) is a moderately sparsely porphyritic obsidian containing phenocrysts of quartz, sanidine, plagioclase, and augite. Rhyolite lava is also present in the southwest, near the caldera margin, but is very rare or absent elsewhere. Layers of fine-ash tuff, very rare lapilli tuff, and fine, crystal-rich base-surge material a few centimetres to a few tens of centimetres thick are present sparsely and sporadically throughout the unit; they may be more common than is readily apparent because of their relatively low resistance to weathering and erosion. In places there is evidence of injection or limited mixing (resulting in irregular masses of introduced material up to ~40 cm across) of fine tuff or base-surge material into the overlying ignimbrite.

The ignimbrites range from crystal-poor to crystal-rich, with the majority being in the range moderately crystal-poor to moderately crystal-rich (10-25% crystals). Crystals are mostly quartz (up to 10%), sanidine (up to 10%), and minor plagioclase (up to 3-4%); ferromagnesian minerals are rarely preserved, most having been altered to chlorite, sericite, or clay(s). Quartz crystals/crystal fragments are generally small ($\leq$2 mm); plagioclase crystals/crystal fragments, which range from clear (in vitrophyre/obsidian) or white to pale green (strongly sericitised), are mostly 1-3 mm, rarely up to 4 mm, long. Sanidine, in contrast, commonly occurs as prisms 6 mm to 1 cm or, in one example, 1.5 cm long; these large sanidine crystals are particularly common and conspicuous towards the base of the unit in the southeastern part of the outcrop area. Sanidine in the glassy rocks is clear or white, but in the devitrified ignimbrites is generally pink, orange, or red; their size, and the colour contrast with the host rock (greenish tones are most common) makes the sanidine crystals a very prominent and characteristic feature of the Combella Rhyolite. Ferromagnesian minerals identified (chiefly in the glassy rocks) are biotite, augite, orthopyroxene (probably hypersthene), and, rarely, fayalite; allanite is a conspicuous and abundant accessory mineral in some rocks, and zircon, apatite, and opaque Fe-Ti oxide(s) are ubiquitous minor accessory phases.

Lithic clasts are present sporadically in the unit: in the northeast, some ignimbrite sheets, mainly towards the top of the unit, contain up to a few percent (by volume) of subangular to angular clasts, ranging up to 30 cm across (at GR7863-579161), of sparsely porphyritic rhyolite and rhyolitic ignimbrite.

Highly attenuated pumice foliation showing various degrees of deformation due to plastic flow is a feature of a small proportion of ignimbrite sheets in most parts of the unit (Fig. 6B), but particularly in the extreme northeast. Pumice clasts are not discernible in the vitrophyres, but other ignimbrite sheets contain pumice "fiamme" up to 5 cm long and 0.5-1 cm thick (Fig. 6C); pumice fragments up to 20 cm long and 5 cm thick were recorded at one locality (GR7863-487114) near the base of the unit.

Spherulitic devitrification texture, including "thunder eggs", and gas cavities are very common and characteristic features of the Combella Rhyolite; they tend to be more common towards the top of the unit over most of its exposed area. Spherulites range up to 20 cm in diameter, and contain gas cavities of various sizes variably filled by quartz crystals, jasper or chalcedony, or by horizontally or concentrically banded agate; spherulitic intervals range up to 15 m thick (*e.g.* at GR7863-546124, near Hot Springs Creek.

Alteration in the Combella Rhyolite, as mentioned above, is widespread and characteristic. It ranges from intense to moderate throughout most of the unit to slight in some of the glassy horizons; totally unaltered glassy rocks are rare. The degree and type of alteration is highly variable both laterally and vertically. Clay-quartz-hematite alteration is common, especially in the northeast and east, and in the Lags Creek area; it is responsible for much of the pink, red, red-brown, and purplish colours common in the unit. Sericitic alteration, which is generally responsible for the green tones also common in the rocks, is also very widespread. Chlorite is not common, and there is no unequivocal evidence of propylitic assemblages.

Thickness ranges up to at least 250 m on the northern side of the Walsh River, west of Hot Springs Creek. South of the Walsh River and west of St Helena Creek, thickness ranges up to 180 m, but is highly variable because of the irregular surface developed on the top of the Fisherman Rhyolite. Farther east, thickness ranges from about 260 m around GR7863-600100 to about 100 m at the northeastern extremity of the outcrop area. A narrow, fault- bounded strip of rocks in the Bismarck mine area mapped as Combella Rhyolite is only a few tens of metres thick.

Eruptive source of the Combella Rhyolite is probably in the northeast to east, based on its thickness, which decreases in all directions away from that general area, on the abundance and size of lithic clasts, and on the relative abundance/volume of lava. A secondary vent area may have existed near the southwestern margin of the Featherbed Caldera (between Convict Creek and the Bismarck mine), based on the presence in that area of coarse rudites and coarse lithic clasts.

Relationships. The contact relationship between Combella Rhyolite and Fisherman Rhyolite is disconformable, or, in some areas (*e.g.*, near Lags Creek, and southeast of Pinchgut Pinnacle) clearly uncomformable (angular unconformity). Combella Rhyolite is overlain with apparent conformity (disconformity?) by Arringunna Rhyolite, and is intruded by Lags Microgranite.

Structure of the Combella Rhyolite is relatively simple. It is essentially flat lying over most of the outcrop area, with steepened dips only along the western caldera margin - where they range from 30° to 80° - and at the eastern outcrop limit (dips up to 40-50°). The unit is cut by several faults of various magnitudes and displacements. The most important of these are (1) a pair of north-northwesterly trending faults in the northeast which are part of a major fault system transecting the entire Featherbed Volcanic Complex; (2) a northwesterly trending, less "fundamental" fault in the extreme northeast; and (3) a major, almost northerly trending fault along Hot Springs Creek. Structure is discussed in more detail in a later section.

Topography. Combella Rhyolite has a light-medium cover of low trees and a moderately dense cover of "speargrass" and other grasses: these combine to produce a pale-medium greenish-brown tones on airphotographs. Relative to the Fisherman Rhyolite, terrain underlain by Combella Rhyolite is smooth and undulating, broken only by curving breaks in slope or low escarpments (or, less commonly, where dips are significant, by low ridges) marking the edges of flow or cooling units (Figure 6A). The overlying Arringunna Rhyolite forms much steeper, hillier, and more bouldery terrain, with darker tones on airphotographs.

Age. Rb-Sr isotopic dating of two samples of Combella Rhyolite produced an average age of 284$\pm$4 Ma (Black & Mackenzie, in prep.).

Synonymy. De Keyser & Wolff (1959; 1964) and Branch (1966) recognised most of the Combella Rhyolite in the Walsh River-Hot Springs Creek area as a distinct subunit, but did not delineate it on any map, and included it in undivided "Featherbed Volcanics".

Arringunna Rhyolite (Pfa, Pfa_1) (new name)

Derivation of name. The name is derived from Arringunna Mountain, which is located within the unit in the northeast of the Featherbed Caldera, at GR7863-802071.

Distribution. Arringunna Rhyolite is the main caldera-filling unit of the Featherbed Caldera (Yongala Volcanic Subgroup), and by far the most extensive and (on the basis of present outcrop) voluminous; it crops out over about 750 km^2, approximately 80% of the area of the Featherbed Caldera.

Type section. The type section of the unit extends from GR7863-53389378 (base) upstream along a tributary of Crooked Creek to the watershed at -57279500, then to St Helena Creek at -60709550 (faulted[?] boundary with Pfa_1), and then to -63809600.

A supplementary section from 70750320, near the Walsh River, to 71309935 exposes a section through 520 m of Pfa_1.

Lithology. Arringunna Rhyolite consists of numerous flow units of predominantly massive, crystal-rich to very crystal-rich rhyolitic ignimbrite which form essentially a single cooling unit over most, if not all, of the area. Discontinuities, such as unwelded/poorly welded intervals, airfall beds or surge layers are absent or very rare and obscure, and compaction and welding are uniformly intense. The unit may be divided into a lower, less mafic, subunit (Pfa) and an upper, more mafic, subunit (Pfa_1): in some areas, such as immediately east of St. Helena Creek, the transition is quite abrupt and can be mapped with relative ease, but in other areas, particularly in the east, the transition is gradational and difficult to place with any certainty.

The lower subunit of Arringunna Rhyolite (Pfa) consists of dark to very dark grey, less commonly medium to pale grey, crystal-rich to very crystal-rich (25-50% crystals) rhyolitic ignimbrite; moderately crystal-rich ignimbrite (<25% crystals) is rare. Glassy rocks (vitrophyres) are rare relative to the Combella Rhyolite, and are found mainly at or near the base of the unit; the best-preserved vitrophyre horizon seen is to the west of middle Combella Creek, at GR7863-578163, and is 1-3 m thick. However, much of the Arringunna Rhyolite appears to have been originally glass-rich: the darkest rocks (other than the undevitrified vitrophyres) are generally the least affected by recrystallisation, and there is a progressive increase in the degree of recrystallisation in increasingly pale-coloured rocks.

The base of the Arringunna Rhyolite is marked in places by very to extremely crystal-rich tuff or surge layers. At GR7863-508121 a bedded, extremely crystal-rich, glassy (devitrified) horizon 1-2 m thick forms the base of the unit; it resembles an ignimbrite, but could be a compacted and partly welded airfall tuff. At GR7863-577162 the base is marked by a layer about 0.7 m thick of very crystal-rich, ignimbrite-like, "volcanogenic arenite" with fine, low-angle cross-bedding: it is probably of base-surge origin. A thin (3-5 m) horizon of pale pink- grey, poorly-welded, crystal-rich ignimbrite is present at or near the base of the unit in many (but not all) areas: it probably corresponds to the zone of partial welding of Smith (1960), or possibly to zone 2a of Sparks & others (1973).

A characteristic of the unit is the common presence of pale grey to white, strongly porphyritic lenses and pods or "blebs". These are generally a few (<5) centimetres long, but in some places, chiefly at or near the base of the unit, up to 15 cm long; at one locality, on Combella Creek (GR7863-594175), they reach 40 cm long. Some, including most or all of the larger (longer) bodies, are almost certainly pumice clasts, but others may be lumps of non-vesicular magma: they show little or no flattening, and those that have been examined in thin section have the texture of porphyritic microgranite/microgranodiorite. Subangular to angular lithic clasts are present in about

10% of the subunit, mainly at or near its base. The overwhelming majority are dark grey, aphanitic to sparsely porphyritic rhyolite about 1 cm, rarely up to 2.5 cm, across; at one locality, near the Walsh River-Hot Springs Creek Junction (GR7863-534122), the ignimbrite contains clast of crystal-poor rhyolitic ignimbrite up to 15-20 cm across.

Crystal content of the lower member ranges from about 20% to about 50% by volume, with the bulk being in the 25-40% range and the average about 30%. Apart from the thin crystal-rich basal horizons observed at some localities, crystal content commonly shows a general slight increase upward in the sequence. However, crystal content in many sections through the unit shows no systematic variation.

The crystal population is dominated by quartz and sanidine (or orthoclase, where re-equilibrated) in subequal amounts (10-20% of each), with lesser amounts (2-5%) of plagioclase. Quartz ranges up to 5 mm in diameter, averaging about 3 mm; sanidine ranges up to 5-7 mm, with occasional crystals up to 1 cm or more, and averages ~3 mm; plagioclase ranges up to 4 mm and averages close to 2 mm - smaller crystals are more common than in the case of sanidine (Table 2). Content of ferromagnesian and accessory minerals also tends to increase slightly upward, ranging from % to about 2%, and comprises various combinations and proportions of:

- orthopyroxene (hypersthene) -	ubiquitous, commonly the most abundant ferromagnesian mineral;
- fayalite -	generally present, commonly more abundant than augite, and predominant in some rocks;
- augite -	generally present, commonly minor relative to orthopyroxene;
- biotite -	generally present, mostly fringing pyroxene and fayalite, with unequivocal primary biotite relatively uncommon;
- garnet -	present sporadically and sparsely as megacrysts up to 2 cm, variably reacted to biotite, plagioclase and opaque oxide(s);
- hornblende -	present as a late-stage mineral fringing pyroxene and fayalite in hornfelsed or otherwise strongly recrystallised rocks;
- allanite -	generally present, usually as an accessory mineral, but a conspicuous minor mineral in some rocks;
- magnetite -	the predominant opaque oxide, associated with minor ilmenite;
- zircon -	an abundant accessory mineral, forming crystals up to 0.3 mm;
- apatite -	similarly, an abundant accessory mineral; crystals up to 0.2 mm.

In most rocks, pyroxenes have been partly to completely altered (generally to combinations of chlorite, calcite, and Fe-Ti oxide[s]) and have partly to completely reacted to combinations of biotite, hornblende, and plagioclase (Table 2). The degree of reaction is commensurate with the degree of post-devitrification recrystallisation. Rocks which are intensely recrystallised, either as a result of high emplacement temperatures and rapid, deep burial by successive flows, or as a result of thermal metamorphism by shallow intrusions (*e.g.*, St Helena Monzogranite), generally also contain up to ~1% subhedral crystals of biotite and/or hornblende in the groundmass. Fayalite is commonly altered to bowlingite (chlorite and Fe oxide[s]), or iddingsite, or both; it is also fringed by hornblende and/or biotite in some rocks. Allanite, which forms crystals up to 1 mm long in some rocks, ranges from pristine, and generally strongly zoned, to completely altered.

Table 2. Abundances, sizes, and alteration/reaction products of crystals/crystal fragments in the Arringunna Rhyolite

Mineral		size		reaction	alteration
	abundance	maximum	average	products	products
quartz	10-25%	5 mm	3mm		
sanidine	10-20%	1 cm	3 mm		sericite
					kaolinite
					hematite
plagioclase	2-5%	4 mm	2 mm		sericite
					calcite
					clay(s)
orthopyroxene	<1%	2 mm	0.5 mm	biotite	chlorite
				h'blende	calcite
				plag.	opaques
garnet	trace	2 cm	~1 cm	plag.	chlorite
				biotite	
				pyroxene	

The upper subunit of the Arringunna Rhyolite (Pfa_1) overlies the lower subunit over a total area of about 380 km in the southeastern and eastern parts of the Featherbed Caldera (Figure 1). Its preserved thickness ranges from at least 520 m in a section southeastward from Windy Waterhole to between 50 and 100 m in the northeast. However, the top of the subunit is not preserved, and in the southeast its base is not exposed. Original thicknesses were considerably greater than now preserved, as judged from the degrees of welding, recrystallisation and mineralogical reconstitution (discussed below) observed in the uppermost preserved parts of the subunit, and thickness is probably significantly greater than 520 m in the southeastern extremity of the caldera.

As mentioned above, the boundary between the upper and lower subunits is generally diffuse, with mafic mineral content increasing gradually over a few tens of metres of vertical section, with no evidence of a break. However, in some places, the transition is an abrupt one, over a few metres or less, suggesting that a discontinuity may exist locally.

Like the lower subunit, the upper subunit of the Arringunna Rhyolite consists of numerous flow units of crystal-rich to very crystal-rich rhyolitic ignimbrite containing scattered lithic clasts. Crystal content ranges from 25% to 45%, with most rocks in the range 30-35%; moderately crystal-rich ignimbrite (~20% crystals) is rare. Abundances and sizes of crystals/crystal fragments, other than those of ferromagnesian minerals, are similar to those of the lower subunit (Table 2). However, ferromagnesian minerals, particularly orthopyroxene (up to 2-3% in some rocks) and garnet (present in almost all outcrops; up to 2 cm in diameter), are more abundant than in Pfa, and the whole-rock composition is more mafic than the lower subunit. Allanite does not appear to be quite as abundant as in Pfa.

The upper subunit is typically completely devitrified and moderately to intensely recrystallised; undevitrified glassy rocks (vitrophyres) are rare or absent. Paradoxically, recrystallisation is particularly intense in the most elevated parts of the subunit near the Walsh River, where it is at least 600 m thick.

Lithic clasts are scarce, making up generally much less than 1% of the rock by volume; they are mostly about 1 cm across, rarely up to 7.5 cm in length (in the east), and the predominant lithology is pale to mid-grey, sparsely porphyritic rhyolite. Clasts of biotite-rich schist or gneiss are commonly present, but are not easily distinguished from fully reacted garnet. Other, much scarcer clasts include fine, aphanitic to weakly porphyritic andesite, meta-sandstone and -siltstone (Hodgkinson Formation?), and dark grey quartzite (Chillagoe/Hodgkinson Formation?). The pale, strongly porphyritic lava and/or pumice clasts that characterise the lower subunit are also present, and reach 50 cm in length. In some exposures, they make up as much as 10% of the outcrop surface area.

Alteration. Both the upper and the lower subunits of the Arringunna Rhyolite are generally only very slightly altered. Alteration is very largely restricted to ferromagnesian minerals, which are variably replaced by combinations of chlorite, opaque oxide(s), calcite, epidote, and sericite; very slight alteration of feldspar, particularly plagioclase, is common. More intense alteration is apparent near major fault zones, notably the Hot Springs, northern St Helena and Upper Doolan Fault Zones (Figure 1), on the northeastern margin of the Featherbed Caldera between Wolfram Camp and Wallaroo Creek, and in parts of the southwestern margin, near Convict Creek. Clay-hematite and clay-silica alteration are present in a few areas, notably in the northeast (Wolfram Camp-Wallaroo Creek sector) and on the eastern margin of the caldera, north of the Walsh River.

A noteworthy feature of the Featherbed Caldera sequence is the contrast between the Fisherman and Combella Rhyolites, which are generally highly fractured and obviously altered (to pale colours), and the Arringunna Rhyolite, which is massive, relatively little-fractured, very dark grey, and fresh in appearance. The Arringunna Rhyolite appears to have behaved in large part as a relatively impermeable "cap" to hydrothermal activity that affected the underlying rocks.

Thickness of the Arringunna Rhyolite ranges from 150-200 m in the northwest to at least 900 m in the east and southeast. However, the top of the unit is not preserved, and original thicknesses were probably several hundred metres greater than at present.

Eruptive source(s) of the Arringunna Rhyolite cannot be determined with any confidence because of the general lack of indicators of direction and/or proximity to source. The largest lithic clasts are found in the east - although there is no convincing pattern of size increase - and the unit is thickest in the east and southeast: these observations are circumstantial evidence (at best) that the vent, or vents, that produced the Arringunna Rhyolite are on or near the southeastern or eastern margin of the Featherbed Caldera.

Relationships. In most areas where the contact is exposed, Arringunna Rhyolite overlies Combella Rhyolite with apparent conformity (Figure 1). However, relationships in some areas indicate a more complex, probably disconformable or unconformable contact: in the extreme northwest (Wild Cow Creek area) and southwest (Convict Creek area), and along parts of the eastern caldera margin, Arringunna Rhyolite overlaps Combella Rhyolite to rest directly on Fisherman Rhyolite; and along the Walsh River near Little Silent Waterhole, subhorizontal Arringunna Rhyolite overlies Combella Rhyolite which is apparently folded about a north-south axis.

In the extreme northeast of the Featherbed Caldera, a block of Arringunna Rhyolite is in faulted contact on at least three sides with Fisherman Rhyolite. On the eastern side, the contact with Fisherman Rhyolite dips moderately steeply westward and resembles a stratigraphic contact. However, Combella Rhyolite, which is 100 m thick only a kilometre to the south, is not present between these two units; this fact, and the colinearity of the boundary between the and a major fault suggest that it is probably also faulted.

Arringunna Rhyolite directly abuts the ring fault-dyke system along much of the northeastern, eastern, and southeastern margins of the Featherbed Caldera, and may be intruded by the ring dyke (Lags Microgranite); it is intruded by St Helena Monzogranite, and by numerous minor dykes of rhyolite, dacite, and (rare) andesite.

In the north, Arringunna Rhyolite is faulted against Lumma Rhyolite along the structural boundary between the Featherbed and Djungan Calderas. In the extreme northwest, Arringunna Rhyolite is overlain unconformably by the Wollenden Rhyolite of the Wakara Caldera and intruded by Yokas Granite.

Structure. Dips of flow sheets/cooling unit(s) in the Arringunna Rhyolite are subhorizontal or gently dipping over most of its outcrop area. Dips are steepened (up to 70°) inward along the northeastern, eastern, and southeastern margins of the caldera, and up to 40° eastward between

Combella Creek and Little Silent Waterhole. Dips are also steepened to 10-20^{o} around lower Hot Springs Creek, on either side of the Hot Springs Fault. Moderate to steep, highly variable dips in the Arringunna Rhyolite in an area of structural disturbance farther south near a probable extension of this fault, immediately west of the Walsh River-St. Helena Creek junction, may be the result of slumping during or immediately after compaction and welding, while the rocks were hot and capable of plastic deformation. Dips of pumice foliation are also highly variable in some other areas. However, gross structure of the flow units, as indicated by breaks in slope and benches at subtle breaks between them, is generally relatively undisturbed and subhorizontal: variable dips of pumice foliation are in many instances probably the result of plastic deformation within subhorizontal flow sheets.

Columnar jointing is common in the Arringunna Rhyolite: it is generally vertical or steeply dipping, and columns range from 30 cm to about 1 m in diameter, and up to 40-50 m long. The most spectacular examples of columnar jointing seen are along the eastern side of the Walsh River gorge in the Windy Waterhole area.

The Arringunna Rhyolite is cut by numerous faults, most of which are northerly or northwesterly trending, and most of which do not appear to have undergone displacements of more than a few tens of metres. The most signficant faults are:

(1) the Hot Springs Fault and its probable extensions to the south, which have caused obvious structural disturbance in the Arringunna Rhyolite; and

(2) the north-northwesterly trending Swagmans Camp Fault, which cuts the entire Featherbed Volcanic Complex and juxtaposes the lower and upper subunits of Arringunna Rhyolite (implying vertical movement).

These, and the other faults cutting Arringunna Rhyolite are discussed more fully in a later section (STRUCTURE).

Topography. The Arringunna Rhyolite is characterised by rugged, bouldery topography with relief of up to 600 m and a medium-sparse to medium-dense cover of trees about 10- 20 m high, thick grass cover, and, on the wetter east-facing slopes, scattered cycads. The unit is also characterised by deep, steep-sided, linear, fault- or joint-controlled valleys and gorges, and by a "mottled" pattern on airphotographs due to the interaction of denser tree growth along fractures and on steeper slpoes with a tendency for vegetation cover to be relatively sparse on curved benches that may mark flow-unit boundaries. Another prominent feature of the ignimbrite is the numerous rocky bluffs and cliffs, which commonly display columnar jointing, bare-rock whalebacks and rock pavements, and tors; boulders range up to several metres in diameter, but are generally less than 1 m. Tones on airphotographs range from medium-pale grey-brown to medium reddish-brown (on the upper part of the unit, **Pfa$_1$**).

Age. Rb-Sr isotopic dating of two samples of Arringunna Rhyolite produced ages of 288±17 Ma and 290±12 Ma, placing it at the base of the Early Permian; the error is large, but consistent with the age obtained for the underlying Combella Rhyolite.

Synonymy. Arringunna Rhyolite was included by de Keyser & Wolff (1964) and Branch (1966) in undivided "Featherbed Volcanics".

Djungan Caldera - Djungan Volcanic Subgroup (new name)

The Djungan Caldera is the northeasternmost component of the Featherbed Cauldron Complex. The main part of the caldera has the shape of a crude ellipse which is flattened along its eastern (against the Mulligan Caldera) and southern (against the Featherbed Caldera) sides. On its western side, the caldera has a northwesterly, graben-like extension with a rounded termination; this may be a secondary caldera, or a deformation of the main caldera in response to regional tectonic stresses. Maximum collapse of the caldera was in the east, as judged from distribution and thickness of extrusive units, and it is likely that the northwestern lobe of the caldera is the hinge zone of a trapdoor-like structure, similar to the Featherbed Caldera. There is evidence of arching about a roughly north-northwesterly trending axis between Native Cat and Bustlem Creeks, and the location of the Bustlem Microgranite in this area is consistent with emplacement contolled by tensional stress.

Total area of the Djungan Caldera, not including any possible outflow facies, is about 350 km^2. The Djungan Volcanic Subgroup sequence consists of:

(1) An unnamed dacitic unit of very restricted distribution;

(2) Rhyolite lava and ignimbrite similar to and possibly correlatable with the Fisherman Rhyolite of the Featherbed Caldera;

(3) A series of rhyolitic ignimbrite units, comprising

Scrufflem Rhyolite,

Aroonbeta Rhyolite,

two unnamed units,

Lightning Creek Rhyolite, and

Lumma Rhyolite (top).

Total thickness of the eruptive succession is at least 750 m in the central parts of the main caldera.

The **unnamed dacitic unit** (**Pd**) crops out over an area of less than 1 km^2 near the margin of the Djungan Caldera, half way between Big Watson and Scrufflem Creeks, and at point where a major north-trending fracture system (the northern extension of the Combella-Swagman Fault Zone - Fig. 3) intersects the caldera margin. It consists of dark green-grey to greenish-brown, fine- grained, sparsely porphyritic dacite with no apparent directional fabric; it is probably lava. However, the apparent structural control of its location may be evidence of a post- or late-volcanic intrusive origin. Fisherman Rhyolite(?)

The lowermost exposed ignimbrite unit in the Djungan Caldera is tentatively correlated with the Fisherman Rhyolite of the Featherbed Caldera, as discussed above. However, no isotopic age data are available for Fisherman Rhyolite(?) in the Djungan Caldera, and despite its similarity to the Featherbed Caldera rocks described above, it may be a separate, younger, unit.

Scrufflem Rhyolite (Pda) (new name)

Derivation of name. The name "Scrufflem" is derived from Scrufflem Creek, which is a tributary of Little Watson Creek, and traverses the unit near GR7864-475385.

Distribution. Scrufflem Rhyolite overlies Fisherman(?) Rhyolite in the Djungan Caldera. It crops out over a total of about 15 km^2 in three areas of the Caldera: a ~6 km^2 area in the extreme west, straddling Elizabeth Creek; a lens about 6.5 km long and up to 1 km wide which extends from 3.5 km east of the Nightflower mine to 1 km east of Big Watson Creek; and three outcrop areas near the northern caldera margin, the largest of which is 5 km long and up to 700 m wide and is cut by Scrufflem and Lightning Creeks.

Type section. The most accessible section through typical Scrufflem Rhyolite is along Elizabeth Creek between GR7864-375320 and -38403275. At each end of this section, the ignimbrite is overlain by an unnamed lithic-rich unit, Pdc, and the section is incomplete; however, complete sections elsewhere show that the unit is relatively homogeneous. The most accessible complete section through the unit (supplementary section) is exposed along Big Watson Creek, between GR7864-445339 and -436333.

Lithology. Scrufflem Rhyolite is a crystal-rich rhyolitic ignimbrite resembling the Arringunna Rhyolite of the Featherbed Caldera. It consists mainly of dark to very dark grey, medium-fine to medium-grained, lithics-free to lithics-poor, moderately crystal-poor to very crystal-rich (20-55% crystals & crystal fragments) rhyolitic ignimbrite. Finer-grained, less crystal-rich (~15%), and generally more altered ignimbrite occurs near the top of the unit in the northwestern extremity of the Elizabeth Creek inlier, where it reaches 10-20 m thick, and about 50 m above the base of the unit in the wedge west of Big Watson Creek (up to 50 m thick). Some of the finest-grained material in these intervals resembles base-surge deposits. Pale green, highly altered (sericitised) breccia, with subrounded to subangular clasts ~10 cm in diameter, occurs near the top of the unit near the western end of the central belt, but its relationship with the remainder of the unit is unclear.

Scattered lithic clasts are present in various parts of the ignimbrite, mainly in the southwest and at the top of the unit elsewhere. Most are less than 1 cm long; clasts up to 1.5 cm were observed at only one locality. The most common clast lithologies are sparsely porphyritic to aphanitic, commonly flow-laminated rhyolites; rhyolitic ignimbrite is the most common clast lithology at one locality in the extreme southeast (south of Elizabeth Creek: GR7864-447259), and this rock also contains clasts of fine-grained andesite.

Pumice clasts are rarely visible to the unaided eye in the Scrufflem Rhyolite; an exception is near Big Watson Creek (GR7864-447340), where pumice clasts, which grade from about 2 to 6 cm long near the middle of the section to around 20 cm at the top, are etched out on the outcrop surface and define a prominent, gently southward-dipping foliation.

The Scrufflem Rhyolite is mineralogically similar to the Arringunna Rhyolite: the predominant crystals/crystal fragments are quartz, sanidine (in places variably inverted to orthoclase) and plagioclase; other minerals are, in descending order of abundance, orthopyroxene, clinopyroxene (not present in all samples), fayalite, biotite, allanite, hornblende, garnet, zircon, apatite, and Fe-Ti oxide (magnetite?). Quartz and feldspar grains range up to 3 mm (rarely up to 5 mm), and average about 2.5 mm across; pyroxene and other mineral grains are generally less than 1 mm long, with rare crystals up to 2 mm. Most of the garnet has been replaced by biotite, feldspar, and pyroxene, resulting in aggregates resembling clasts of biotite schist/gneiss up to 1.5-2 cm across.

Alteration. Most of the unit shows only very slight to slight alteration (probably deuteric) to propylitic assemblages dominated by chlorite, but also generally including sericite and calcite. Ferromagnesian minerals, particularly orthopyroxene, are most affected, and complete replacement by chlorite and opaque oxide(s) is common. Plagioclase commonly contains traces or small quantities of sericite, and K-feldspar is commonly turbid, mainly due to hematite ± kaolinite(?). All of the hornblende and about 30-50% of the biotite are the result of post-depositional deuteric or metasomatic processes, and, as described in the Arringunna Rhyolite, the abundance of secondary hornblende and biotite is directly proportional to the degree of recrystallisation. At one locality (near Elizabeth Creek, GR7864-376317), near the top of the unit, all ferromagnesian minerals have been replaced/pseudomorphed by hornblende and biotite. The locality is close to a partly concordant, partly cross-cutting sheet of highly altered volcanic breccia (part of the Wollenden Rhyolite of the Wakara Caldera) which may have been a channel for hydrothermal fluids. Moderate hydrothermal alteration, possibly combined with weathering, to chlorite + sericite + calcite + clay was noted near Big Watson gorge and in the extreme south (GR7864-447259). More intense hydrothermal alteration, to complex assemblages including sericite-hematite-clay-quartz-albite and hematite-quartz-clay-sericite(?) is confined to the finer-grained, less welded horizons in the area to the west of Big Watson gorge.

Thickness. The westernmost inlier is of unknown thickness because its base is not exposed, but is at least 50 m thick. The lens that extends westward from Big Watson Creek is at least 175 m, and possibly up to 450 m, thick, and the lens in the northeast of the Djungan Caldera is about 75-100 m thick.

Structure and relationships. The westernmost outcrop, straddling Elizabeth Creek, is folded into a gentle anticline about a north-northwest-trending axis: there appears to be only one flow sheet *cum* cooling unit. It is overlain with apparent conformity by Aroonbeta Rhyolite, overlain paraconformably or unconformably by Wollenden Rhyolite (Wakara Caldera), and intruded by Bustlem Microgranite and a dyke of sparsely porphyritic rhyolite. The outcrop extending westward from Big Watson Creek dips gently to the south-southwest. At least two flow sheets, probably representing separate cooling units, are present, divided by an horizon of less welded, finer-grained ignimbrite. The "lens" overlies Fisherman Rhyolite(?) in an apparently concordant, but probably non/unconformable, relationship, and is overlain by Aroonbeta Rhyolite, with apparent conformity, and by Pdc, Pdd and Lightning Creek Rhyolite paraconformably or unconformably. The third body of Scrufflem Rhyolite is a lens which dips gently (10-15^{o}) to the south. It apparently consists of a single flow-cooling unit, and overlies Fisherman Rhyolite(?) unconformably, and is overlain (non/unconformably) and overlapped by Lightning Creek Rhyolite.

An inlier of ignimbrite correlated with Scrufflem Rhyolite, slightly less than 1 km^2 in area, is located in the extreme northeast of the Wakara Caldera (around GR7864-432247). It is overlain by Aroonbeta Rhyolite, faulted against (and overlain by?) Wollenden Rhyolite, and intruded by Bustlem Microgranite.

Eruptive source(s). There is little indication in the Scrufflem Rhyolite of direction to, or proximity of, vent area, other than an apparent eastward diminution in abundance of lithic clasts and a southward to southeastward decrease in thickness. No rocks were observed that could be interpreted as proximal facies. The presence of andesitic lithic clasts, which are common in rocks of the Wakara Caldera but generally rare or absent in rocks within the Djungan Caldera suggests that there is a possibility that part of the succession in the southwest of the Djungan Caldera, including the Scrufflem Rhyolite, is outflow from the Wakara Caldera. However, it is also possible that, given its very small extent, the inlier of Scrufflem Rhyolite in the northeastern corner of the Wakara Caldera is outflow from the Djungan Caldera.

Topography. Terrain underlain by the Scrufflem Rhyolite ranges from low, rounded, hills with a gently "knobby" appearance to almost flat, recessively weathering terrain (on finer-grained, more altered rocks. A swirling pattern formed by curved terraces, relatively sparsely vegetated and/or with bare-rock pavements, is common. Tone on airphotographs is slightly darker than the surrounding volcanic lithologies, but slightly paler (and smoother) than on the Bustlem Microgranite.

Age. The Scrufflem Rhyolite has not been dated isotopically, and its age is uncertain: it is probably (but by no means certainly) younger than the Arringunna Rhyolite (*i.e.*, < 290 Ma), and older than Lumma Rhyolite (281 ± 2 Ma).

Synonymy. Rocks now mapped as Scrufflem Rhyolite were included in undivided "Featherbed Volcanics" by Branch (1966) and de Keyser & Lucas (1968).

Aroonbeta Rhyolite (Pdb) (new name)

Derivation of name. The name Aroonbeta is taken from Aroonbeta Holding, a pastoral holding which covers the Featherbed Caldera north of the Walsh River and the Djungan Caldera eastward from Scrufflem Creek.

Distribution. Aroonbeta Rhyolite crops out over an area of about 8 km^2 in the southwest of the Djungan Caldera, close to Elizabeth Creek. Rocks tentatively correlated with Aroonbeta Rhyolite also crop out in thin slivers faulted against Lumma Rhyolite and Lightning Creek Rhyolite(?) eastward along the upper reaches of Elizabeth Creek. A very small (100 m^2) inlier of ignimbrite tentatively correlated with Aroonbeta Rhyolite crops out near the northwestern margin of the Djungan Caldera, 2.5 km northeast of where the margin is cut by Big Watson Creek.

Type section. A complete section through Aroonbeta Rhyolite is exposed along a small tributary of Elizabeth Creek, from GR7864-41652865 (base, probably faulted, but no loss of section) to 42152860, and thence to -424287 (top).

Lithology. The Aroonbeta Rhyolite consists of lithics-poor to lithics-rich, moderately to very crystal-rich, rhyolitic ignimbrite. Degree of welding ranges from poor, in the most lithics-rich rocks, to moderately intense in the least lithics-rich rocks. The ignimbrite is moderately to very altered, and, in most outcrops, slightly to moderately weathered: colours range from mid to dark grey or, much more commonly, greenish grey, to shades of brown and purple. Dykelets and irregular thin horizons of fines-depleted, very crystal-rich material ("tuffisite") were observed in one area, around GR7864-419277: they are probably the result of gas discharge (streaming).

Crystal content ranges from 25% to 40%, and comprises quartz, sanidine/orthoclase and plagioclase, all of which range up to ~3 mm and average ~2 mm, minor amounts of ferromagnesian minerals and garnet, and accessory minerals. Ferromagnesian minerals are generally completely altered; where they are preserved, the assemblage is, in order of decreasing abundance: orthopyroxene, fayalite, clinopyroxene, biotite (partly post-magmatic), and hornblende (mostly or entirely post-magmatic). Garnet is present sporadically, and is invariably replaced by/altered to biotite-feldspar-pyroxene or chlorite ± biotite assemblages; original crystals were up to 1 cm in diameter. Accessory minerals are allanite, which is commonly metamict or altered, zircon, apatite, and magnetite(?).

Lithic clast content ranges from about 10% to about 25-30%, and are greatest towards the top of the unit and towards the east - the most lithics-rich rocks are in upper Elizabeth Creek, around GR7864-490260. Clast size ranges from an average of 1 cm or less to about 20 cm, and also tends to increase upward in the unit, again with the largest clasts towards the east, along upper Elizabeth Creek (GR7846-468263, -490259, and -507260). The rock at locality 7864-490259 contains in excess of 25% angular lithic clasts commonly up to 20 cm across, and could be described as a matrix-supported volcanic breccia. Clast lithologies are predominantly very fine-grained, sparsely porphyritic rhyolite with or without flow banding, and crystal-poor to moderately crystal-poor rhyolitic ignimbrite; dacite, rhyolitic fine-ash tuff, and siltstone (in order of decreasing abundance) are much less common.

Alteration. The Aroonbeta Rhyolite is extensively altered, more so than any other unit of the Djungan Caldera. Given its relatively high porosity and permeability (due to the degree of welding) and the abundance of faults cutting the ignimbrite, the alteration is probably mainly the result of hydrothermal, rather than immediately post-magmatic deuteric (autometasomatic), effects. Intensity of alteration varies from slight to moderately intense (mostly the latter), without any discernable pattern. Alteration assemblages are dominated by chlorite, hematite, sericite, and possibly clay(s); alunite(?) was recorded in one sample, collected from near a fault (at GR7864-472260), while another sample from adjacent to the same fault (GR7864-463264) is moderately altered to biotite (early, higher-temperature, potassic alteration?) plus hematite and clay (later, lower-temperature alteration?). Superimposed on the alteration is slight to moderate weathering, the intensity of which tends to increase with increasing degree of alteration: the resultant clay(s) and hematite are difficult to distinguish from the products of the hydrothermal(?) alteration.

Thickness of the Aroonbeta Rhyolite ranges from 20 m or less in the north to at least 60 m (but probably no more than 80 m) on the eastern side of Elizabeth Creek around GR7864-417273. Thickness decreases rapidly to the north, but only gradually to the east along Elizabeth Creek; this may reflect some structural control on deposition of the ignimbrite.

Relationships. The ignimbrite overlies Scrufflem Rhyolite with apparent conformity, and is overlain and overlapped by Lightning Creek Rhyolite; the upper contact is probably either a nonconformity, a low-angle unconformity, or both. A small inlier in the extreme northeastern corner of the Wakara Caldera (GR7865-430250) is overlain, with apparent concordance (possibly a nonconformity or very low-angle unconformity) by Wollenden Rhyolite. Aroonbeta Rhyolite is also intrude by Bustlem Granite.

Topography. The Aroonbeta Rhyolite is characterised by low but moderately rugged, rocky terrain, a sparse cover of stunted trees, bushes, and grass, and very pale tones on airphotographs. Low, ragged, commonly terraced, outcrops are abundant, but are generally more weathered than those of neighbouring formations. The underlying Scrufflem Rhyolite is less rugged and more densely tree-covered, and is darker in tone on airphotographs; the Lightning Creek Rhyolite has more relief, and is slightly darker in tone.

Structure. The principal structural feature of the Aroonbeta Rhyolite is the apparently strong control on its distribution and present outcrop pattern by a major east-west fault system along Elizabeth Creek, the Elizabeth Creek Fault Zone. This fault zone forms most of the southern boundary of the unit, and has produced some sequence repetition along fractures parallel to this boundary. It is probable that earliest movements on the fault zone predate the Aroonbeta Rhyolite and partly controlled its distribution and thickness; it is also possible that the fault zone was an eruptive source for all or part of the unit. The ignimbrite is also cut by several cross-faults, most of which are northwesterly trending. Dips are to the northeast at the western end of the main outcrop area, and gently to the north (within the fault-bounded triangular block) or the west (beneath Wollenden Rhyolite) in the small inlier in the Wakara Caldera. Dips are moderate to gentle to the north along much of the Elizabeth Creek Fault Zone, decreasing to subhorizontal(?) at the eastern extremity of outcrop.

Age. Aroonbeta Rhyolite has not been isotopically dated: it is younger than Arringunna Rhyolite (289 ± 10 Ma) and older than Lumma Rhyolite (281 ± 2 Ma).

Synonymy. Rocks now assigned to the Aroonbeta Rhyolite were included by Branch (1966) and de Keyser & Lucas (1968) to undivided "Featherbed Volcanics".

Unnamed unit Pdc

Distribution. Unnamed ignimbrite unit Pdc crops out over about 3.5 km^2 in the northwest of the Djungan Caldera. It extends from near Elizabeth Creek, about 3 km south of the Nightflower mine, 5 km to the east and, discontinuously, 4 km south to Bustlem Creek.

Type section. The type section of Pdc is north of Elizabeth Creek, between GR7864-376325 (base) and -368330 (faulted contact with Nightflower Dacite; close to top). A supplementary section through the basal rudite is between GR7864-38753250, close to Elizabeth Creek, and -38803255.

Lithology. Pdc comprises basal, massive, moderately to poorly welded, lithics-rich ignimbrite and volcanogenic rudite overlain by massive, poorly welded, crystal-rich ignimbrite. The upper ignimbrite layer is absent in the narrow strip of Pdc that extends southward from Elizabeth Creek. The predominant lithologies in the basal layer are red, brown, pale green, or brick-red mottled with green, clast-supported volcanogenic rudite and/or very lithic-rich ignimbrite. In the area south of the Nightflower mine, the rudite is composed almost entirely of subangular to angular clasts of flow-banded, sparsely porphyritic rhyolite; clasts of rhyolitic ignimbrite and pumice are also present at one locality (GR7864-388326). Subangular clasts of dark grey rhyolitic ignimbrite are much more abundant farther east, where the clast-rich rocks can more confidently be identified as ignimbrite because of the presence of collapsed pumice clasts and other evidence of welding and/or compaction, and of sorting. These rocks grade upward with decreasing size and abundance of lithic clasts into, lithic-poor, medium-fine, moderately crystal-rich ignimbrite. Clast size ranges up to about 20 cm in the northwestern part of the outcrop area, up to 1 metre near Elizabeth Creek (GR7864-388326), and up to 0.5 m near the base of the eastern part of the unit.

The upper layer of Pdc is medium-grey to purplish-grey, structureless, and weathers to a cavernous or "nobbly" appearance, commonly with highly irregular pits up to 15 cm across. The "nobbly" response to weathering may be due to variable devitrification, and the pits probably represent gas cavities.

Thickness of the unit is highly variable and difficult to estimate because of the lack of layering. However, it is probably at least 150 m thick in the type area; the basal layer in the supplementary section is about 25 m thick.

Relationships. The basal layer of Pdc is probably a proximal (near-vent) or ground-lag deposit, and is possibly a near-vent-facies correlative of the Aroonbeta Rhyolite. Pdc overlies Scrufflem Rhyolite with apparent conformity (nonconformity?), and is overlain, also apparently conformably, by an ignimbrite unit correlated with Lightning Creek Rhyolite.

Age. Like the Aroonbeta Rhyolite, Pdc is between 281 and 289 Ma old.

Unnamed unit Pdd

Distribution and thickness. Pdd crops out over a total area of about 1.4 km^2 northeastward from Big Watson gorge, between GR7864-448340 and -481364. It is in the form of a lens with an outcrop width of up to 400 m and a true thickness of up to 200 m.

Type section. The type section of Pdd is between GR7864-467356 (base) and -46803545 (top), 2.6 km east-northeast of the point where Big Watson Creek crosses the margin of the Djungan Caldera.

Lithology. The unit consists of dark grey, massive, lithics-poor to lithics-free, crystal-rich to moderately crystal-rich, rhyolitic ignimbrite in a (probably) single flow sheet and cooling unit. Crystal content ranges from 20% to about 35%, and comprises: quartz (10-15%), sanidine (6-12%), plagioclase (3-5%; all $\leq$3 mm), 1-3% ferromagnesian and other minerals including (in order in decreasing abundance) orthopyroxene, fayalite, clinopyroxene, biotite, garnet (mostly reacted to biotite or chlorite-dominant assemblages), hornblende, allanite, zircon, apatite, and magnetite(?). As in previously described units, some of the biotite and all of the hornblende are of post-magmatic origin.

Size and abundance of lithic clasts tend to increase downward in the unit: most are 1 cm or less in diameter, but some larger clasts (up to 3-5 cm) occur near the base. Clasts are absent at the top of the thickest part of the sheet, indicating that it has probably been partly eroded during emplacement of the overlying ignimbrite (Lightning Creek Rhyolite). Clast lithologies are predominantly of rhyolite lava, with significantly less abundant rhyolitic ignimbrite. Pumice clasts are generally not apparent, but outcrops at the top of the sheet show a fine, streaky pumice foliation, with pumice *fiamme* up to 2 cm long and 3 mm thick. The rocks appear generally to be only slightly altered (*e.g.*, chlorite after ferromagnesian minerals).

Eruptive source. There are no clear indicators of direction or proximity to vent area(s). However, its confinement to the west of the Caldera suggests a source in the west, and the possibility that it is outflow from the Wakara Caldera (equivalent to part of the Wollenden Rhyolite (Pwa_2) cannot be ruled out.

Relationships and structure. Pdd overlies Scrufflem Rhyolite, Fisherman Rhyolite, and Aroonbeta Rhyolite in a discordant, presumably unconformable, relationship. It is overlain, either disconformably or unconformably, by Lightning Creek Rhyolite. Dip of the sheet is about 15° to the southwest.

Age. The age of the ignimbrite is between 289 and 281 Ma, probably closer to the latter.

Lightning Creek Rhyolite (Pde) (new name)

Derivation of name. The name is derived from Lightning Creek, which traverses Lightning Creek Rhyolite near GR7864-508390; it is a tributary of Little Watson Creek.

Distribution. Lightning Creek Rhyolite crops out over a total of about 37 km^2 almost continuously from the upper Elizabeth Creek area in the southwest of the Djungan Caldera in a semi-circle to the eastern margin of the Caldera at GR7864-587367, then discontinuously along the eastern and southeastern caldera margins (between GR7864-592358 and -600350, and between -606344 and 7863-590180).

Type section. The type section of Lightning Creek Rhyolite is on the western side of Lightning Creek, between GR7864-49803865 (base) and -50053780 (top). A supplementary section, in which it can be clearly seen that crystal content increases gradually upwards, then decreases near the top, is between -531408 and -530403, to the east of Lightning Creek. A further supplementary section, in which a basal vitrophyre is well exposed, is between -61232033 and -608205, 26 km west-northwest of Wolfram Camp.

Lithology. Lightning Creek Rhyolite consists predominantly of brown, brown-grey, purplish-grey, or dark grey, lithics-bearing to moderately lithics-rich, very to moderately crystal-rich, rhyolitic ignimbrite. Most of the unit is moderately to intensely welded and thoroughly recrystallised, such that the matrix is generally a very fine quartz-feldspar mosaic. A lens about 30-40 m thick and 3.4 km long of brown to cream, altered, poorly to moderately welded, lithics-rich ignimbrite crops out about 20 m above the base of the unit in the west, near Elizabeth Creek. A lens of similar material about 1 km long and up to 50 m thick occurs at the base of the unit 1 km west of lower Jacks Creek (~GR7864-420330). Glassy ignimbrite (vitrophyre) was recorded in only one area: in the southeast, at and near the base of the unit.

Crystal content ranges from about 20% in some of the more lithics-rich rocks to about 50%, and tends to increase upward as lithic content decreases. In the area between Lightning and Lumma Creeks (first supplementary section, above), crystal content decreases again near the top of the unit, where there is another more lithic-rich horizon.

Major crystal/crystal fragment species are quartz (10-20%, ≤3 mm), sanidine (or orthoclase, or both: 7-18%; ≤3 mm; commonly pale pink), and plagioclase (3-6%; ≤2-2.5 mm; generally white to pale green). Various combinations of (primary) orthopyroxene, clinopyroxene and fayalite (up to 1.5 mm), biotite (<1 mm), garnet (up to 1 cm), and allanite (<<1 mm) are present in minor amounts, along with accessory zircon, apatite, and magnetite(?). Post-magmatic biotite and hornblende are moderately common, replacing primary ferromagnesian minerals and forming small euhedra in the groundmass of the more intensely recrystallised rocks. Garnet (pink almandine-spessartine) is rare and sporadically distributed, and is almost all reacted to biotite-feldspar-pyroxene assemblages, and/or altered to chlorite + opaque oxide(s).

Lithic clast content ranges from 20-25% to <<1%, with the most lithics-rich rocks being generally at or near the base of the unit. Clast sizes range from about 20 cm, generally in the lowermost parts of the unit, to $\leq$1 cm (commonly) at and near the top; the majority of clasts in most of the sequence are $\leq$5 cm. An extreme case is the lithics-rich lens near Jacks Creek: it contains clasts up to a metre in diameter. Thin, lithics-rich horizons also occur in the middle parts of the unit. In lower Jacks Creek, for example, there are two lithics-rich horizons, 2-3 m thick, about two-thirds of the way up the section: the lower horizon contains clasts up to 20 cm long, the upper one clasts up to about 10 cm long. A layer 2.5 to 3 m thick near the top of the Lightning Creek Rhyolite in Big Watson Creek itself contains subrounded to rounded clasts up to 20 cm long.

The lithic clasts are predominantly angular to subangular and composed of sparsely porphyritic to aphanitic rhyolite with or without flow banding. Clasts of rhyolitic ignimbrite are moderately common; andesite, dacite(?), fine-grained metasediments (derived from the Hodgkinson Formation), and biotite schist are much rarer.

Pumice clasts are rarely evident, partly due to their generally small size (<1 cm), but mainly due to the degree of recrystallisation. Pumice *fiamme* up to 10 x 1 cm were observed in a lithics-rich horizon the base of the ignimbrite in the northeast (GR7864-57333782), and coarsely porphyritic pumice clasts up to 8 cm long occur near the base in the southwest, near Elizabeth Creek (GR7864-435266).

Alteration. Slight to moderate propylitic alteration (chlorite + sericite $\pm$ calcite) is ubiquitous in the Lightning Creek Rhyolite. It is probably mainly the result of immediately post-emplacement deuteric alteration/"autometasomatism", but later hydrothermal alteration cannot be discounted. An overprint of clay mineral(s), generally accompanied by hematite or goethite, or both, is present in some rocks from most areas, particularly the southwest and northeast. While this is probably in most cases the product of weathering, a common association with similar alteration in stratigraphically lower rocks (especially the Fisherman(?) Rhyolite) suggests the possibility of a low-temperature hydrothermal overprint.

Thickness of the Lightning Creek Rhyolite ranges up to between 100 and 140 m in the west, increasing to as much as 850 m in the section along Big Watson Creek, then decreasing gradually eastward to about 50-80 m in the northeast; in the southeastern area, thickness varies widely over short distances up to a maximum of about 150 m.

Eruptive source(s). Thickness variations and the size distribution of lithic and pumice clasts suggest that the Lightning Creek Rhyolite may have been erupted from at least two vent areas: in the southwest (in or near the Elizabeth Creek Fault Zone?), in the northwest (the very coarse lithics-rich lens 1 km west of the Jacks Creek is likely to be proximal to a [minor?] vent), and possibly in the northeast.

Relationships. The ignimbrite overlies Scrufflem Rhyolite, Aroonbeta Rhyolite, and the unnamed ignimbrite, Pdd in a locally concordant - but actually paraconformable - and regionally unconformable relationship. It is overlain concordantly, and probably conformably (possibly paraconformably - see below), by Lumma Rhyolite. Lightning Creek Rhyolite is intruded by a small stock of porphyritic microgranite equated with the Bustlem Microgranite in upper Elizabeth Creek, and by dykes of similar microgranite near the northeastern caldera margin.

Structure of the Lightning Creek Rhyolite is simple: over most of the area, it dips gently towards the centre of the Djungan Caldera, or is subhorizontal; dips range up to 20-30° in the northeast. The Elizabeth Creek Fault Zone cuts the ignimbrite, but does not appear to have affected its thickness; it is also cut by several other faults, including the Swagman's Camp Fault, but none has a significant displacement. Along the eastern caldera margin, it is faulted against Lumma Rhyolite and Fisherman Rhyolite(?) in places, and in other places is down-faulted below the present level of exposure, beneath Lumma Rhyolite.

Topography of the Lightning Creek Rhyolite is similar to that of the Arringunna Rhyolite described above: moderately rugged, bouldery hills, steep-sided, fault- or joint-controlled valleys, and a moderate cover of grass and medium-height trees. It differs from the Scrufflem Rhyolite and Pdd in having more relief, slightly paler soil/grass tones (due in part to the characteristically common pale pink to tan colour on weathered surfaces), and taller tree cover; the Aroonbeta Rhyolite has much lower relief, sparser, shorter vegetation, and paler airphoto tones. The overlying Lumma Rhyolite has generally slightly darker soil/grass tones and greater relief.

Age. For reasons which are detailed below, the Lightning Creek Rhyolite is regarded as being effectively the same age as the Lumma Rhyolite: 281 ± 2 Ma.

Synonymy. Lightning Creek Rhyolite was included in undivided "Featherbed Volcanics" by Branch (1966) and de Keyser & Lucas (1968).

Lumma Rhyolite (Pdl) (new name)

Derivation of name. The name Lumma is taken from Lumma Creek, which joins Little Watson Creek at GR7864-522443, and crosses the lower boundary of the Lumma Rhyolite at -538408, in the northeast of the Djungan Caldera.

Distribution. Lumma Rhyolite is the uppermost preserved ignimbrite unit of the Djungan Caldera, and by far the thickest and most extensive. It crops out over an area of about 250 km^2, throughout the central, eastern, southeastern, and southern parts of the caldera.

Type section. A complete section through Lumma Rhyolite is not preserved; the most accessible representative section is along and close to Big Watson Creek: from GR7864-482332 (base) along the creek to -491318, then to -500324 at the top of a hill. A supplementary section, which shows grainsize variations in the lower part of the unit and excellent examples of gas-streaming features, abuts the type section of Lightning Creek Rhyolite: from GR7864-50053780 (base) to -513371, thence to -523361 (Lightning Creek), thence to -524353 (Lightning Creek), and finally to -527352 (top of ridge).

Lithology. Lumma Rhyolite consists of dark to very dark grey, intensely welded, crystal-rich to very crystal-rich rhyolitic ignimbrite, much of which, particularly towards the base, is lithics-bearing to lithics-poor. Over most of the outcrop area, there is little or no change in the degree of welding, nor any other evidence of breaks between flow sheets: the ignimbrite appears to have behaved generally as a single cooling unit. However, in some areas, there is evidence of several relatively thin flow sheets: in the southwest, around GR7864-597202, a thin (<1m) layer of fine plinian ash separates two flow sheets; nearby, a layer a few tens of centimetres thick of extremely crystal-rich material separates two intensely welded sheets. Elsewhere, such as along upper Big Watson Creek, the appearance, or sudden increases in the abundance, of lithic clasts or, in one locality (see below), large pumice clasts, probably indicates a new flow sheet, but there is no change in the degree of welding.

In some areas, the base of the unit is marked by an horizon of variable thickness - generally only a few tens of centimetres to a metre or so - of variably devitrified, altered, and/or weathered (to characteristic brick-red colours) vitrophyre. In the southeast (around GR7864-605205), this basal vitrophyre (now largely devitrified) is up to 10 m thick. In this same general area, the lowermost parts of the unit also contain thin intercalations of flow-laminated rhyolite. Dark-grey, flow-laminated, sparsely porphyritic rhyolite also forms an irregularly-shaped, dyke-like body about 2 m wide, and tongues and lenses up to 2 m long and 15 cm thick in the lowermost few metres of the Lumma Rhyolite at GR7864-619255 on upper Branch Creek, near the southeastern caldera margin.

Irregular dykes, veins, and sills of tuffisite occur sporadically, mostly in the uppermost parts of the unit. A lens about 450 m long and 40 m thick of moderately lithics-rich, crystal-rich (30%) rhyolitic ignimbrite, a little finer than its host, near upper Little Watson Creek (GR7864-601323): this body appears to dip steeply more towards the west than the surrounding ignimbrite, and may be intrusive. Adjacent to the lens, but not intruding it, is a dyke about 300 m long and 10 m wide of weakly porphyritic andesite containing enclaves of rhyolitic ignimbrite.

Crystal/crystal fragment content ranges from 35% to 50% or possibly 55%, with the bulk of the unit in the range 40-45%. In some areas, notably where the ignimbrite is lithics-bearing at the base, crystal content tends to increase upward. In upper Big Watson Creek, for example, crystal content shows an overall upward increase from 40% at the base to 50-55%. The crystal population consists of quartz (≤4 mm; 15-30%), sanidine/orthoclase (≤3-4 mm; 12-20%), plagioclase (≤2-3 mm; 3-5%), and small (generally <1mm) crystals of orthopyroxene, clinopyroxene, fayalite (not present everywhere), and allanite amounting to between 1 and 5% of the total. Garnet, almost entirely reacted to biotite + feldspar + pyroxene, is present sporadically (<<1%) as megacrysts up to 1 cm in diameter. Accessory minerals are zircon, apatite, and Fe(-Ti) oxide (probably magnetite). The feldspars are commonly slightly altered to sericite and/or clay(s), fayalite is completely altered to iddingsite or chlorite in most rocks, pyroxenes are variably altered to chlorite and opaque oxide(s), and allanite is chloritised or metamict in some rocks.

Lithic clasts are common near the base of the Lumma Rhyolite, and in the south and southeast, but they are rare or absent in most of the upper parts of the unit, and near its northeastern and western margins. Where they are present, the abundance and size of lithic clasts show a general decrease upward from the base. Clast abundance is generally ≤5%, and sizes range from ≤5 cm at and near the base; higher in the unit, abundances fall to <1% and sizes to ≤1 cm. Exceptionally coarse, lithics-rich horizons occur near the base of the unit in upper Big Watson Creek (GR7864-460334), and in upper Branch Creek (-619255; referred to above). The former is 2.5-3 m thick, and contains about 70% of subrounded to rounded clasts up to 20 cm long of sparsely porphyritic rhyolite and rhyolitic ignimbrite; it may be the product of a debris flow. The latter contains about 20% irregularly-shaped clasts, as well as possibly intrusive bodies, referred to above, of flow- laminated, sparsely porphyritic rhyolite up to 2 m long.

Clast lithologies are predominantly sparsely porphyritic rhyolite with or without flow banding/lamination, and moderately crystal-poor to crystal-rich rhyolitic ignimbrite. Sparsely porphyritic andesite occurs rarely and sporadically: at one locality (7864-567303), these clast have crenulated margins, suggesting that they were still in a plastic state during or shortly before eruption. Clasts of even-grained biotite granite were noted in another outcrop in the same general area (560328). Other rare clast lithologies include microgranodiorite and metasediment (fine plagioclase-biotite-muscovite-magnetite-[browish-green] spinel-hornblende-quartz-calcite schist).

Clasts up to 10 cm long of strongly porphyritic garnet-pyroxene-biotite microgranite similar to Bustlem Microgranite, and similar in general appearance to pumice clasts observed in some outcrops, also occur sporadically. These clasts are probably non-vesiculated equivalents of the "coarse-porphyritic" pumice described below.

Pumice *fiamme*, and hence pumice foliation, were observed in only a few outcrop areas of the Lumma Rhyolite, mostly relatively high in the sequence, or near the base. However, the most notable example of a pumice-enrichment zone is about 150 m above the base of the unit, in Big Watson Creek: the zone is about 4 m thick, and contains pumice clasts up to 28 x 10 cm. A second pumice-rich horizon, with clasts up to 5 cm long, crops out farther up Big Watson Creek, 150 m higher in the sequence. Most of the pumice clasts - or, at least, most of those that are apparent in outcrop - are pale grey, strongly porphyritic, and of (micro)granitic composition. They consist of about 10-15% white phenocrysts of K-feldspar and plagioclase up to 1 cm (rarely 1.5 cm) in diameter, grey to colourless quartz up to 8 mm in diameter, and ferromagnesian crystals (mostly ortho- and clinopyroxene) up to 3 mm set in a very pale grey, microcrystalline groundmass. Garnet megacrysts (or xenocrysts?) up to 1.5 cm in diameter, and mostly reacted to biotite-rich assemblages, were observed in a few of the larger of these "coarse-porphyritic" pumice clasts.

The Lumma Rhyolite is almost entirely devitrified, and slightly to moderately affected by recrystallisation, the main manifestation of which is reconstitution of the matrix to a very fine to moderately fine-grained mosaic of quartz, feldspars, commonly biotite, and, less commonly, hornblende. As in the Arringunna Rhyolite of the Featherbed Caldera, the extent of development of post-magmatic biotite and hornblende is directly proportional to the degree of recrystallisation; hornblende is generally found only in the most intensely recrystallised rocks.

Alteration. The Lumma Rhyolite is very slightly to moderately affected by propylitic(?) alteration, which has resulted in ferromagnesian minerals having been variably chloritised and feldspars - particularly plagioclase - slightly sericitised. Hematite and/or clay mineral(s) are present in trace amounts in some rocks, particularly in the southeastern corner of the caldera and near the eastern margin: the confinement to these areas suggests a low-temperature hydrothermal overprint, but weathering cannot be excluded. Oxygen-isotope studies presently in progress should help to resolve this problem.

Thickness. The maximum preserved thickness of the Lumma Rhyolite is at least 300 m (the maximum relief on the unit), and possibly as great as 1 km; thickness increases towards the east and south(?). However, the most elevated, and presumably the stratigraphically highest, preserved parts of the ignimbrite, are intensely welded and finely recrystallised, indicating that a significant thickness of ignimbrite - perhaps hundreds of metres - has been removed by erosion.

Relationships. Lumma Rhyolite overlies Lightning Creek Rhyolite in a concordant and possibly conformable relationship. The base of the Lumma Rhyolite is marked by abrupt increases in crystal content and size, and, commonly, lithic clast content and size relative to the underlying Lightning Creek Rhyolite, which is also generally paler in colour. In several areas, the base is also marked by a thin (<1m) vitrophyre horizon. The top of the unit is not preserved.

Lumma Rhyolite is intruded by several bodies of porphyritic microgranite equated with Bustlem Microgranite: the largest of these is in the headwaters of Little Watson Creek (around GR7864-570320); another is in upper Elizabeth Creek (GR7864-500260); and several dykes, sills, and very small bodies with highly irregular margins intrude the ignimbrite in upper Big Watson Creek, around GR7864-4980320. It is also intruded by the peripheral ring dyke (**Pmg**) in two segments of the eastern caldera margin, where Lightning Creek Rhyolite is presumably down-faulted and concealed beneath Lumma Rhyolite.

Structure. The Lumma Rhyolite dips gently (up to 10°) inwards towards the centre of the caldera around its northern and western margins, and is essentially subhorizontal over most of the inner portions of the caldera. Dips are steepened up to 40-50° against the eastern caldera margin. The ignimbrite is cut by numerous faults and fractures, including the Swagman's Camp Fault Zone and the Elizabeth Creek Fault Zone, but, with one exception, none appears to have resulted in major displacement, change in thickness, or change in facies. The exception is the eastern caldera-margin ring fault-dyke system, in part a continuation of the Retina Fault, which juxtaposes Lumma Rhyolite against Fisherman Rhyolite(?), Maneater Granodiorite, and the ring-dyke microgranite.

Eruptive source. A general paucity of source proximity and flow direction indicators makes the identification of eruptive vent location(s) for the Lumma Rhyolite difficult. Lithics- and pumice-enriched horizons exposed in Big Watson Creek may be relatively proximal to source: it is possible that the main eruptive source is buried beneath a thick pile of ignimbrite in the central part of the Djungan Caldera.

Topography. Topographic expression of the Lumma Rhyolite is similar to that of the Arringunna Rhyolite of the Featherbed Caldera. When compared to the Lightning Creek Rhyolite, it has greater relief, steeper slopes, slightly denser and taller tree and grass cover, and generally a slightly darker, browner tone on airphotographs (if photographed in the dry season - deeper green during the wet season).

Age. Two samples of the Lumma Rhyolite from the southeastern corner of the Djungan Caldera (GR 7864-54932153 and -61232038) have been dated by the whole rock-mineral Rb-Sr isotopic method and yielded an average age of 281±2 Ma, or Early Permian (L.P. Black, pers. comm., 1991.). This is significantly younger than the Arringunna Rhyolite, which the Lumma Rhyolite strongly resembles, both physically and chemically, but indistinguishable in age from the Ticklehim Rhyolite of the Wakara Caldera, which almost certainly is stratigraphically higher. Lumma Rhyolite is also indistinguishable in Rb-Sr isotopic age from the Bustlem Microgranite which intrudes it.

Synonymy. Lumma Rhyolite was included by Branch (1966) and de Keyser & Lucas (1968) in undivided Featherbed Volcanics.

Wakara Caldera - Wakara Volcanic Subgroup

The Wakara Caldera is the northwesternmost and, stratigraphically, at least, youngest caldera of the Featherbed Cauldron. It has a rounded, pillow- or lozenge-like shape, with a pronounced bulge in the north, and covers an area of about 350 km^2. In the southeast and east, the lowermost exposed rocks overlie rocks of the Featherbed and Djungan Calderas respectively, and dip gently northwestward to westward. The remainder of the perimeter of the caldera is fault- and ring-dyke-bounded: the ring fault juxtaposes Doolan Creek Rhyolite, Nychum Volcanics and Nightflower Dacite, as well as Hodgkinson Formation (Kitoba Member) against the Wakara Volcanic Subgroup.

Like the Djungan and Featherbed Calderas, the Wakara Caldera appears to be a trapdoor-like structure, but, unlike them, is a complex, composite one. The southeastern margin, where Wakara Subgroup rocks overlap those of the Featherbed Caldera and are intruded by an arcuate body of Bustlem Microgranite, appears to be a hinge zone: the degree of post-Featherbed Caldera (see below) increases to the west from this hinge(?) zone, along the southern caldera margin. The central and northern parts of the Caldera form a secondary collapse structure, with maximum collapse in the north. This structure is bounded by an arcuate body of at least partly intrusive, coarse to very coarse, lithics-rich ignimbrite or breccia in the southeast, the main southern caldera margin (approximately), and an irregularly-shaped, also partly to wholly intrusive body of even coarser lithics-rich ignimbrite/breccia in the southwest (Figs 1, 2). Within these boundaries, the arcuate distribution and inward (northwestward to northeastward) dips of the ignimbrite units clearly define, especially on Landsat TM scenes, a basin-like structure with a truncated, curved, northern margin. The Wakara Caldera sequence consists of, from the base upward, the following rhyolitic ignimbrite (unless otherwise identified) units:

Yongala Volcanic Subgroup (?)

Fisherman Rhyolite (Featherbed Caldera) equivalent(?),

Wakara Volcanic Subgroup

Unnamed rhyolite lava flows and domes,

Wollenden Rhyolite (Pwl, Pwa_{1-3}; 6 subunits),

Stuarts Rhyolite ($Pwb_{1,2}$, Pwc; 4 subunits),

An unnamed unit (Pwd),

An unnamed ignimbrite/breccia unit (Pwx)

Gavin Rhyolite (Pwe_{1-3}; 5 subunits),

Two unnamed units (Pwf, Pwg)

Unnamed minor tuff (Pwt) and rhyolite lava (Plh) units,

Unnamed unit (Pwh),

Ticklehim Rhyolite (Pwi), and

Rackarock Rhyolite (Pwj, Pwk, Pwm).

Total thickness of the succession is very difficult to estimate: it is probably in the order of 1500-2000 m.

Fisherman Rhyolite(?)

Rocks correlated with the Fisherman Rhyolite of the Featherbed Caldera crop out over an area about 6 km long and 500 m wide along the extreme southeastern margin of the Wakara Caldera, westward from Doolan Creek (Figure 1). This lens consist of a lower lava component and an upper ignimbrite component, as described for the Fisherman Rhyolite.

The lower component is confined to the southeast, and is apparently continuous across Doolan Creek with the lowermost part of the Fisherman Rhyolite in the Featherbed Caldera. It is a flow(?) of partly flow-banded, sparsely porphyritic rhyolite up to 130 m thick which is extensively sheared and altered. In Doolan Creek hosts several warm to cold springs, some with well-developed travertine deposits (see below: p. 95).

The upper, major component of the unit consists of welded, moderately crystal-poor to -rich rhyolitic ignimbrite up to 250 m thick. Most of the ignimbrite is intensely sericitised, and in places shows abundant evidence of gas or auto-brecciation: the base of this altered interval contains angular blocks are up to 70 cm across. Below the altered rocks is a lens about 1 km long and up to about 30 m thick of poorly to moderately welded, lithics-poor, moderately crystal-poor/rich rhyolitic vitrophyre containing a few percent by volume of small (<1cm) clasts of sparsely porphyritic rhyolite and ~15% crystals (≤5-7% quartz 2 mm, 4-6% sanidine ≤6 mm, 1-2% plagioclase ≤3 mm, and ≤1% fayalite, augite, and orthopyroxene? <<1 mm). The basal few metres of this vitrophyre horizon is poorly welded, fractured or brecciated, and intensely altered like the main body of ignimbrite.

Unnamed rhyolite lavas and domes

The perimeter of the Wakara Caldera is dotted with a number of small bodies of rhyolite and rare dacite, of which some are probably domes, some are probably dome-flow composites, and a few may be flows. Their main properties are summarised below.

Pla is a pale brown, or buff, to white, flow-laminated rhyolite lava flow which crops out in a crescent-shaped area of about 1 km^2 on the southwestern margin about 3 km east of Walsh Crossing (crossing of the Walsh River by the Burke Developmental Road). Flow-margin/flow-front breccia crops out around much of the margin of the flow, and parts of the interior are also brecciated. In the south, the flow grades into a massive breccia composed of blocks up to 5 m across of brecciated, flow-laminated lava set in a crystal-rich ignimbrite-like matrix: this may be a later proximal lag breccia or a vent deposit related to the Gavin Rhyolite, which overlies Pla; alternatively, it may be a proximal epiclastic (talus?) deposit.

Plb crops out over a crudely triangular area of about 1.6 km^2 on the southwestern margin 5.5 km east-southeast of Walsh Crossing. It consists of dark grey-green to dark-grey, extensively brecciated, flow-banded, aphyric to finely and very sparsely porphyritic dacite to rhyolite, and is probably a dome. Tongues of similar rock, each about 1.5 km long and 400 m wide, crop out 2 km and 3 km farther to the east: they are probably flows. Plb is overlain by Gavin Rhyolite, and in part overlies Plc.

Plc is a brown to red-brown, mostly autobrecciated, sparsely porphyritic rhyolite which crops out 7 km east of Walsh Crossing. It underlies an area of about 1.7 km^2 and extends about 2 km northward from the southern caldera margin. Its form, and the extent and distribution of brecciation suggest that it is a dome, perhaps with some associated short flow(s). It is overlain by a flow of Plb, and by Gavin Rhyolite, and intruded and/or overlain by Pwx.

Pld crops out 13 km east of Walsh Crossing, close to the southern caldera margin. It forms two irregularly-shaped, east-west elongated bodies - the western one 2.5 km long and up to 1.1 km wide, the eastern one 2.0 km long and up to 750 m wide - connected by a 150 m-wide "neck". Total area is a little less than 4 km^2, but thickness is uncertain because of the lack of attitude/dip indicators: maximum thickness is likely to be at least 350 m.

Pld consists of grey-green to (shades of) brown, red-brown, or purplish, sparsely porphyritic rhyolite characterised by relatively (compared to other peripheral rhyolite bodies) large - up to 3 mm - phenocrysts of quartz and pink feldspar. Flow banding and brecciation are widespread, though not ubiquitous.

Pld is clearly overlain by the upper unit of Gavin Rhyolite, but is apparently underlain by rocks correlated with the lower unit of Gavin Rhyolite and overlain(?) by rocks correlated with Pwx. The gross morphology and the outcrop-scale texture of Pld suggest that it is largely a composite of two lava domes, possibly associated with very short lava flows. The lower subunit of Gavin Rhyolite is probably partly butted against and partly draped over Pld, and it is likely that the body of Pwx is at least partly intrusive. However, the possibility that Pld is intrusive cannot be excluded.

Ple is the most extensive of the peripheral rhyolite bodies. It extends about 6.5 km from a point on the caldera margin 15 km east of Walsh Crossing eastward towards Doolan Creek, ranges up to 1.0 km wide, and underlies an area of about 5 km^2.

Ple consists of brown to buff or cream, sparsely porphyritic rhyolite which is characterised by well-developed fine flow banding/lamination. It is very extensively brecciated, with clasts reaching 1 m across in the central area. Thickness of the unit is uncertain: it is probably at least 500 m.

The overall form of the rhyolite body and the coarseness of the breccia in the central area suggest a composite lava dome-flow origin. Ple is separated from the Fisherman Rhyolite(?) by a dyke of microgranite, which probably also intrudes it, and is overlain unconformably by Gavin Rhyolite.

Plx is a 500 m long, 200 m wide, lozenge-shaped pod of rhyolite located 200 m inside the northwestern margin of the Wakara Caldera near Dinner Creek, 7 km northeast of Walsh Crossing. The rhyolite is largely massive, altered, buff or brown to brick-red or purple-grey, and sparsely but coarsely porphyritic: it contains scattered phenocryst of pink K(?)-feldspar up to 1 cm and quartz up to 6 mm. The pod is cut by zones of brecciation and by a dyke of porphyritic microgranite, and overlain unconformably by coarse, lithics-rich, rhyolitic ignimbrite (Pwx). It is probably a exogenous dome, although an intrusive origin cannot be dismissed.

Plg is a lens about 400 m long and 75 m wide of pale brown to off-white, flow-banded, partly brecciated, sparsely porphyritic rhyolite located on the northwestern caldera margin 9.5 km northeast of Walsh Crossing; it is probably (part of?) a lava flow. The rhyolite is bounded by the caldera-margin ring fault on the northwest, and overlain by Gavin Rhyolite in the southeast. Thickness is less than 75 m and probably less than 65 m.

Pli is a lenticular body about 700 m long, 200 m wide and up to about 100 m thick, located on the northwestern caldera margin 8 km southwest of "Nychum" homestead. It consists of buff, greenish, or purple-grey aphanitic to sparsely porphyritic rhyolite with minor intercalations of grey, bedded, sandy volcanogenic siltstone. The rhyolite is extensively fractured to brecciated, especially at the northern end. It appears to overlie Plv in the northwest, but most of its boundaries are faulted: against Pwg in the east and Nychum Volcanics in the west. Pli may be a composite body: an exogenous dome merging at its northern end into lava flow(s) with intercalated epiclastic sediments.

Plt crops out as a small (350 m x 100 m), fault-bounded lens 9 km southeast of "Nychum", and about 300 m inside the caldera margin. It consists of grey to buff, aphanitic to very sparsely porphyritic, rhyolite to dacite(?). It is flow-banded in part, very extensively brecciated, and strongly sheared in places; it is faulted against Nychum Volcanics and a fault-bounded wedge of Pwg in the west, and against Pwg in the east. Plt is probably (part of) a lava flow.

Plv is a pillow-shaped body, about 400 m long, 100 m wide, and 50 m thick located on the northwestern caldera margin 7.5 km southwest of "Nychum". It consists of brown, greenish, red-brown, buff, or white, intensely but variably altered, very fine, sparsely porphyritic rhyolite with contorted flow lamination in places. Brecciation is extensive at the northern end. Alteration is mainly propylitic (chlorite, sericite and calcite), but the presence of post-magmatic biotite suggests earlier(?) potassic alteration. Parts of the body have been ferruginised, probably after the propylitic alteration event. It is not clear whether this body is a flow or a dome: the former seems more likely given its shape, distribution of brecciation, and the extent of alteration.

Plw is a wedge-shaped body about 450 m long, 150 m wide, and of uncertain thickness (<100 m) located adjacent to the Caldera margin 7 km southwest of "Nychum". It consists of pale pink to buff and purple-pink banded, sparsely porphyritic rhyolite lava(?) apparently overlying a lens about 300 m long and up to 50 m thick of greenish-buff to pink-buff rhyolite breccia, and pale green-grey to purple-grey rhyolitic volcanogenic arenite and polymictic pebbly volcanic arenite. These rocks are overlain by a small fault slice of Pwg; they are also faulted against Pwg in the east, and are in faulted contact with Nychum Volcanics to the west.

Plk is a lenticular to ovate body, about 80 m x 40 m, of medium to dark grey, very fine, sparsely porphyritic to aphanitic rhyolite located on the caldera margin 6.5 km southwest of "Nychum". It is faulted(?) against Nychum Volcanics in the west and Pwg in the east. The form and size of this body suggest a lava dome origin.

Plm crops out along the northern caldera margin about 5 km south-southwest of "Nychum". It is a pillow-shaped body, with tail-like extensions at either end, about 2.7 km long and up to 500 m wide. Its thickness is uncertain because of a lack of dip indicators: it is probably about 200-250 m at the thickest point. The body consists of white to pale brown, sparsely porphyritic rhyolite which is very extensively brecciated, and intensely altered to sericite and/or clay(s). The bulbous shape of the main part of the body and the extent of brecciation are suggestive of a dome; the southern "tail" may be an associated flow. The northern "tail" consists of angular clasts from 3 to 50 cm across set in a fine, sandy-textured, moderately crystal-rich matrix: it may be vent-breccia.

Plm is faulted against and/or overlain by Ticklehim Rhyolite, and intruded(?) by Yokas Microgranite.

Pln forms an irregularly-shaped strip about 3 k long and up to 600 m wide along the northern caldera margin about 2.5 km south of "Nychum". It consists mostly of very pale brown or cream to mid-brown, brecciated, sparsely porphyritic rhyolite, which probably represents a lava flow. A more abundantly and coarsely porphyritic rhyolite (or microgranite) apparently intermingled with the rhyolite, particularly in the east, may be intrusive. Thickness is uncertain and highly variable: it ranges from about 40 m or less up to as much as 250 m. The rhyolite is fault-bounded to the north, and dips at about 40° southward beneath the unconformably overlying Rackarock Rhyolite. It is intruded by dykes of porphyritic microgranite similar to the ring dyke that discontinuously encircles the Wakara and Djungan Calderas.

Plo crops out as a lens about 2 km long and up to 230 m wide along the northeastern margin of the Wakara Caldera 5 km southeast of "Nychum". It consists of pale buff or cream to brown, intensely altered (to clay(s) and/or sericite), sparsely porphyritic rhyolite lava(?) which is flow-laminated in part, and extensively brecciated. The rhyolite is faulted against Nightflower Dacite on the northeast, and intruded by Yokas Microgranite on the southwest.

Plr is an elliptical, plug (or dome)-like body, about 200 m long and 100 m wide, located on the northern margin of the Nightflower Dacite, 7.5 km east-northeast of "Nychum". It is composed of dark bluish-grey, finely flow-laminated, sparsely porphyritic rhyolite with about 5% of quartz and white feldspar phenocrysts up to 1 mm in diameter, and scattered, angular clasts of meta-arenite and metasiltstone (Hodgkinson Formation) up to 2 cm long.

Age of the rhyolite (and dacite?) bodies is uncertain: they are younger than rocks interpreted as Fisherman Rhyolite, and older than Ticklehim Rhyolite which has been dated isotopically at 278 ± 3 Ma (L.P. Black, pers. comm., 1991); *i.e.*, they are probably between 280 and 290 Ma old.

The domes and flows around the perimeter of the Djungan Caldera match the pattern seen in the "classic" calderas of the southwestern USA (*e.g.*, Lipman, 1984) where extrusion of rhyolitic domes and (short) flows is generally the earliest phase of caldera-related activity.

Wollenden Rhyolite (Pwa_{1-3}) (new name)

Derivation of name. The name is derived from Wollenden pastoral holding, which covers the northern part of the outcrop area of the unit, and from the Parish of Wollenden, County of Hodgkinson, immediately to the east.

Constituent units. Wollenden Rhyolite consists of a basal lava (Pwl) and three unnamed ignimbrite members: Pwa_1, Pwa_2, and Pwa_3.

Distribution. Wollenden Rhyolite is the lowermost exposed unit of the Wakara Volcanic Subgroup; it crops out in the extreme southeast of the Wakara Caldera in two areas. The larger area extends from near the intersection of the caldera margin by Doolan Creek north- northeastward towards Elizabeth Creek, then north-northwestward to cross Elizabeth Creek south of the Nightflower mine. The second, smaller area is between Doolan and Wild Cow Creeks, overlapping part of the Featherbed Caldera sequence. Total area underlain by the unit is about 35 km².

Type section. The type section is along Doolan Creek, between GR7864-44001973 and -38402120, interrupted by Bustlem Microgranite between 42902040 and 40882120.

Lithology. Wollenden Rhyolite consists of three rhyolitic ignimbrite sheets (of Member status) underlain in the southwest (about 1 km northeast of the margin of the Featherbed - Wakara Caldera margin, between Doolan and Wild Cow Creeks) by a lens of rhyolite. The first (lowest) ignimbrite sheet crops out entirely in the area between Doolan and Wild Cow Creeks, to the south of a body of microgranite correlated with Bustlem Microgranite. It is separated from the second sheet in the extreme southwest by a thin lens of rhyolite breccia. The bulk of the second sheet crops out on the western side of the microgranite pluton, extending, along with the third sheet, from Doolan Creek in the south to within 1 km of Elizabeth Creek in the north. The second and third sheets are separated from one another by a coarse, lithic clast-rich ignimbrite or volcanogenic breccia sheet.

All internal boundaries of the Wollenden Rhyolite are concordant, and no evidence was seen to indicate that they are other than conformable or, perhaps, in the case of the Pwa_2-Pwa_3 boundary, paraconformable. Pwa_1 and Pwa_2 are in large part separated by a shallow-level pluton of Bustlem Microgranite.

The lowermost component of the Wollenden Rhyolite (**Pwl**) is a pale grey to buff, flow-laminated, sparsely porphyritic rhyolite about 15-35 m thick over most of its 2 km strike length.

The lowermost Member of the Wollenden Rhyolite (**Pwa$_1$**) is a very dark to medium grey, or, rarely, pale grey (depending on the degree of welding, alteration and weathering), very lithics-poor to moderately lithics-rich, very to extremely crystal-rich, rhyolitic ignimbrite. At the base of the subunit is a thin (a few centimetres to a few tens of centimetres), discontinuous horizon of fine rhyolitic (crystal-) vitric tuff.

The ignimbrite contains between 40% and 60% crystals/crystal fragments, comprising quartz (15-25%; $\leq$3 mm), sanidine and/or orthoclase (15-25%; $\leq$4mm), plagioclase (4-6%; $\leq$2 mm), and about 5% ferromagnesian and other minor minerals. The last category comprises, in approximate order of decreasing abundance, orthopyroxene, fayalite, clinopyroxene, biotite, allanite, garnet, magnetite, zircon, and apatite; biotite is not present in all samples. As in previously described ignimbrites (*e.g.*, Arringunna Rhyolite), fayalite, orthopyroxene, and, to a lesser degree, clinopyroxene, are commonly partly to completely altered to chlorite and opaque oxide(s) $\pm$ Ti oxide(s) and/or reacted to lower-temperature phases. Garnet, which occurs as megacrysts up to 1.2 cm in diameter, is variably reacted to biotite-rich assemblages, or altered to chlorite + opaque oxide(s). Crystal content increases upward, reaching a maximum (about 60%) towards the centre, then decreasing again towards the top.

Lithics content decreases from about 15-20% at the base to 1-2% at the top of the sheet. Clasts tend also to be largest at the base - commonly up to 8-10 cm, but up to 50 cm in the extreme southwest. They decrease in size to $\leq$5 cm (mostly ~1 cm) in an interval 30-70 m above the base, but then increase again to $\leq$8-10 cm in the central, most crystal-rich interval before decreasing to $\leq$4-5 cm near the top. Most clasts are dark to pale grey, sparsely porphyritic or aphanitic rhyolite, some of which show flow lamination; clasts of sparsely porphyritic andesite are rare.

Pumice clasts are not particularly common or obvious in the ignimbrite; "coarse-porphyritic" pumice clasts (a little paler than the host rock and containing ~10% phenocrysts including prominent white feldspar prisms up to 1 cm long - *cf.* Arringunna Rhyolite), are, however, commonly present. These are most common, and largest (up to 15 cm long), in the central parts of the unit.

Pwa_1 is about 190 m thick in the southwest, and about 250 m thick in the Doolan Creek type section. It appears to be a single cooling unit, but the irregular variations in the sizes and abundances of lithic clasts and pumice fragments, and in crystal content suggest that at least two pyroclastic flow sheets may be represented.

Pwa$_2$ (with breccia screen in Figure 1), the first of the two mappable lithics-rich horizons dividing Wollenden Rhyolite, is a lens about 1200 m long and 5-10 m thick of rhyolite lava breccia made up of angular clasts of flow-banded, sparsely porphyritic rhyolite between 10 and 50 cm across. It is located in the southwestern extremity of the unit, about 4 km east-southeast of the intersection of the caldera margin by Doolan Creek.

Pwa$_2$ (proper) consists of dark to very dark grey or black, very lithics-poor to moderately lithics-rich, crystal-rich, rhyolitic ignimbrite. The lowermost 30-50 m is generally vitric (undevitrified), and richest in lithic clasts: it contains up to 10-15% by volume of angular clasts of dark grey, aphanitic to sparsely porphyritic rhyolite, and rare andesite, up to ~5 cm. Abundance and size of lithic clasts decrease upward, and most of the unit contains less than 1% of (predominantly rhyolite) clasts up to 2-3 cm. Crystal content increases slightly upward, from ~35% at the base to ~40% near the top: minerals species and their relative proportions are the same as in Pwa_1. Thickness of Pwa_2 is about 330 m in the type section, decreasing to about 175-200 m in the north. The contact between the ignimbrite and the underlying rhyolite breccia is sharp; that with Pwa_1 is more subtle, and marked by an abrupt increase in the abundance of lithic clasts accompanied in places by the appearance of black, undevitrified glass.

Separating Pwa_2 from Pwa_3 is a 15 to 20 m-thick layer (**Pwa_3** with breccia screen in Figure 1) of grey or greenish-grey to pale brown, massive, poorly to moderately(?) welded, lithics-rich to lithics-poor, moderately crystal-rich to crystal-rich rhyolitic ignimbrite. This sheet contains clasts up to 50 cm across (20 cm in the north, near Elizabeth Creek) of sparsely porphyritic rhyolite, rheomorphosed moderately crystal-poor/rich rhyolitic ignimbrite, crystal-rich rhyolitic ignimbrite, and rare andesite. In Doolan Creek, it is cut by numerous irregular dyke-like, pipe-like, and sill-like bodies of tuffisite with coarse sand and fine sand to silt grainsize, attesting to copious gas streaming during compaction. Contact with underlying Pwa_2 is sharp, and with the overlying Pwa_3 proper is gradational over a few metres. This relatively coarse, lithics-rich layer appears to be missing over the southernmost ~1 km of the contact between Pwa_2 and Pwa_3.

Pwa_3 (proper) consists of a thin (1-2 m), discontinuous, basal horizon of dark grey, crystal-rich vitrophyre overlain by dark to pale grey or greenish-grey, moderately lithics-poor to lithics-poor, moderately crystal-rich to crystal-rich rhyolitic ignimbrite. Welding is intense over most of the unit, but rocks correlated with Pwa_3 north of Elizabeth Creek are poorly welded. The subunit ranges from about 80 m thick in the south to a maximum of about 300 m in the central area; thickness in the north is unknown because of intrusion by Bustlem Microgranite and faulting.

The main ignimbrite contains about 25-30% crystals and crystal fragments, comprising quartz (~10-12%), sanidine/orthoclase (10-12%) and plagioclase (2-4%), all of which are $\leq$3 mm, and orthopyroxene, fayalite, clinopyroxene, biotite, allanite, garnet, magnetite, zircon, and apatite - in general order of decreasing abundance - amounting to about 2% by volume. As in the remainder of the unit, fayalite, orthopyroxene, garnet, and, to a lesser degree, clinopyroxene, are extensively altered or reacted, or both.

Lithic clast content decreases from about 5% near the base to about 1% towards the top, and clast size decreases in parallel from $\leq$3 cm to $\leq$1 cm. Lithic clasts are rare and small ($\leq$1.5 cm) to absent in the extreme north, near Elizabeth Creek. Clast lithologies include sparsely porphyritic rhyolite (with or without flow banding), very fine-grained, aphanitic to sparsely porphyritic andesite, porphyritic dacite, devitrified perlitic rhyolite, and fine-ash tuff(?) or volcanogenic siltstone/fine sandstone. Pumice fragments are generally evident: "coarse-porphyritic" pumice clasts up to 10 cm long are abundant in the middle parts of the sheet north of Doolan Creek; and north of the northern splay of the Upper Doolan Fault Zone, abundant, small, strongly flattened *fiamme* up to 1 cm x 3 mm define a fine pumice foliation in rocks near the top and the base (? - truncated[?] by Bustlem Microgranite) of the sequence.

Alteration. The degree of alteration in the Wollenden Rhyolite ranges from slight to intense, and is greatest in the less welded, coarser, more lithics-rich parts of the unit. Style of alteration is typically propylitic (chlorite, sericite, Fe-oxide(s), and commonly calcite), with some clay-hematite/goethite alteration and/or weathering superimposed in places, chiefly in the lithics-enriched horizons.

Thickness. Total thickness of the Wollenden Rhyolite ranges up to about 700 m in the central and southern areas, decreasing to about 250 m or less in the north.

Eruptive source(s) of the Wollenden Rhyolite was probably in the southwest (relative to its present distribution), judging from the trends of increasing thickness and increasing size and abundance of lithic clasts towards the south/southwest, but no precise direction to source indicators were recorded.

Relationships. In the southern and central parts of the outcrop area, the basal lava and the lowermost ignimbrite sheet unconformably overlie Arringunna Rhyolite of the Yongala Volcanic Subgroup (Featherbed Caldera), and the uppermost ignimbrite sheet is overlain in most places apparently concordantly, but in some in a clearly cross-cutting relationship, by the basal(?) lithics- rich/breccia unit of Stuarts Rhyolite (Pwb_1).

In the north, near Elizabeth Creek, relationships are more complex. Pwa_1 is not present beneath Pwa_2, which appears to directly overlie (unconformably) Aroonbeta Rhyolite. On the northern side of a major fault, which is a splay of the Upper Doolan Fault Zone (but colinear with and possibly related to the Elizabeth Creek Fault Zone - Figure 2), thickness of the Wollenden Rhyolite is significanly reduced, and Pwa_3 rests directly on ignimbrite correlated tentatively with Scrufflem Rhyolite of the Djungan Volcanic Subgroup. Pwa_3 steepens and thins northward from the Elizabeth Creek Fault Zone, and the main part of the subunit is missing from the succession in parts of this area. Rocks tentatively correlated with the lithics-enriched basal zone of Pwa_3 extend to within 0.5 km of the faulted southeastern margin of the Nightflower Dacite (Figure 1); ignimbrite tentatively correlated with the main body of Pwa_3 are juxtaposed against Nightflower Dacite by the same fault, and against Pdc by a fault orthogonal to it.

Wollenden Rhyolite is also intruded and disrupted by a body of Bustlem Microgranite, and is cut by several minor faults sub-parallel to the Upper Doolan Fault Zone.

Topography. The Wollenden Rhyolite has produced terrain with relatively modest relief (up to 200 m) but moderate to high ruggedness, characterised by prominent dip slopes and extensive pavements, benches, and large, low whalebacks of bare rock and/or sparse grass cover. The sparse, stunted tree cover is concentrated along fractures and joints, and on steeper slopes - commonly edges of flow sheets or cooling units (underlain by more permeable material), giving the unit a characteristically pale, patchy, almost "tweedy" appearance. The relatively poorly welded lithics-rich horizons form long, narrow valleys with darker tones on airphotographs. The underlying Arringunna Rhyolite is more rugged and rocky, but without recognisable layering, and slightly darker in tone. The overlying Stuarts Rhyolite is much darker-toned, less obviously layered, and has less bare rock.

Age of the Wollenden Rhyolite is not certain: it is between 289 ± 10 Ma, the age or the Arringunna Rhyolite, and 278 ± 3 Ma, the age of the Ticklehim Rhyolite, higher in the Wakara sequence.

Synonymy. Branch (1966) and de Keyser & Lucas (1968) included the Wollenden Rhyolite in undivided "Featherbed Volcanics".

Stuarts Rhyolite (Pwb_1, Pwb_2, Pwc)

Derivation of name. The name is derived from Stuarts Creek, which drains southward through the unit to join Doolan Creek at GR7864-36852070.

Constituent units. Stuarts Rhyolite comprises three unnamed Members: Pwb_1, Pwb_2, and Pwc.

Distribution. Stuarts Rhyolite extends from 1 km north of the intersection of the caldera margin and Doolan Creek to the Watson Fault in the north, a strike length of 14.5 km; it crops out over an area of about 32 km^2. A fault-bounded sliver about 1 km long and up to 200 m wide crops out on the northeastern caldera margin, near Elizabeth Creek (GR7764-310337).

Stuarts Rhyolite consists of:

(1) a basal lithics-rich horizon, or volcanogenic breccia (Pwb_1);

(2) a thin sheet of rhyolitic ignimbrite (Pwb_2);

(3) a thick ignimbrite sheet with a basal vitrophyre *cum* lithics-enriched horizon.

Pwb_1 extends from the junction of Doolan and Pandanus Creeks in the south to Elizabeth Creek in the north, cropping out as a belt up to 1 km wide. Pwb_2 and the basal vitrophyre of Pwc extend from the junction of Doolan and Stuarts Creeks, about 1.3 km inside the caldera margin, in the south to the northern splay of the Upper Doolan Fault Zone/western extension of the Elizabeth Creek Fault Zone (GR7846-397262), across which it pinches out.

Type section. The type section extends from GR7864-384212 in Doolan Creek west-northwest, approximately orthogonal to the strike, to 7764-356220.

Lithology. The basal lithics-rich subunit of Stuarts Rhyolite, **Pwb_1**, consists of pale brown, green, green-grey, or red-brown, moderately lithics-rich to lithics-rich, moderately crystal-rich to crystal-rich, rhyolitic ignimbrite. It is moderately to poorly welded, and generally intensely altered (to sericite-calcite-chlorite assemblages). Apparent thickness ranges up to 200 m in the south (150 m in the type section), up to 280-300 m immediately north of the line of the Elizabeth Creek Fault Zone, and 100-150 m in the north, near the Native Cat Creek-Elizabeth Creek junction.

Lithic clast content at the base ranges from about 15% in the south (near Doolan Creek) to about 40% in the north (near Native Cat Creek), where it also decreases slightly upward/westward to between 10 and 20%. Clast content remains about 15-20% to the south of the line of the Elizabeth Creek Fault Zone. Rocks near the base in this area contain clasts generally less than 2.5 cm across; most clasts near the top are about 3 cm, but some range up to about 1 m. North of the fault zone, clast sizes tend to decrease in size upward/westward. Clast lithologies are dominated by sparsely porphyritic, commonly flow-banded, rhyolite; very fine-grained andesite, and rare mudstone/ siltstone(?) and laminated tuff(?) were also recorded. Crystal content, comprising quartz, K-feldspar, plagioclase, unidentified, totally altered ferromagnesian grains, and rare, mostly altered garnet, ranges between 20 and 30%, tending to increase upward/westward.

Pwb_1 is generally very altered to propylitic assemblages of calcite, sericite, and chlorite.

Pwb_2. The second subunit of Stuarts Rhyolite is a massive, dark grey to black, intensely welded, very to moderately lithics-poor, moderately crystal-rich to crystal-rich, rhyolitic ignimbrite; vitrophyre is present in places (*e.g.*, GR7846-386246) at the top of the subunit. The ignimbrite contains between 20 and 27% crystals (quartz, K-feldspar and plagioclase $\leq$3 mm; altered/reacted ferromagnesian minerals including pyroxene(s) and biotite <1mm), and between 1 and 5% by volume small (generally <1cm) angular clasts of sparsely porphyritic flow-laminated rhyolite, fine andesite, and rare perlitic rhyolite. Both size and abundance of lithic clasts decrease steadily upward. Alteration, to combinations of chlorite, sericite, Fe-Ti oxide(s) and clay(s), is slight, but has destroyed all primary ferromagnesian minerals. The ignimbrite sheet ranges up to 120 m thick (about 70 m in the type section).

Pwc, the main subunit of the Stuarts Rhyolite consists of a mainly glassy lower layer and an upper ignimbrite sheet.

The lower layer consists mainly of black to very dark grey, moderately to poorly(?) welded, very lithics-poor, moderately crystal-rich to crystal-rich vitrophyre (glassy ignimbrite). In the north (*e.g.*, around GR7864-385247), is intercalated with irregular lenses and pods of brown to pale grey, intensely altered, poorly welded, moderately lithics-poor to -rich, crystal-rich rhyolitic ignimbrite. The subunit is about 60-80 m thick in the north, and about 50 m thick in the type section.

The vitrophyre contains 20-25% crystals comprising quartz (8-10%), sanidine (8-10%) and plagioclase (2-4%), all of which average 2-3 mm, and about 1-3% of, in order of decreasing abundance, clinopyroxene, fayalite, orthopyroxene, allanite, zircon, magnetite, and apatite. The lithic clasts, which make up to ~5% of the rock by volume, are angular, fine-grained rhyolite and (minor) andesite up to about 1 cm across. The groundmass is (apparently) undevitrified - *i.e.* clear, colourless to very pale brown, and isotropic in thin section - or slightly devitrified (turbid).

The coarse, relatively lithics-rich component contains about 25% crystals and up to 10% by volume clasts of pale grey to white, aphyric rhyolite ranging up to 1 m across; it also contains scattered small (<1 cm) nodules of fine-grained graphite.

The upper ignimbrite sheet of Pwc is a very dark to (rarely) medium grey, intensely welded, lithics-free to moderately lithics-poor (mostly very lithics-poor to lithics-poor), crystal-rich to very crystal-rich rhyolitic ignimbrite. It strongly resembles Lightning Creek Rhyolite of the Djungan Caldera. Crystal content ranges from 20-25% to about 45-50%, and shows an upward-decreasing trend in some sections. The crystal population comprises quartz (8-22%), sanidine/orthoclase (7-20%) and plagioclase (3-5%; all $\leq$3 mm), with up to 3% of, in order of decreasing abundance, orthopyroxene, fayalite, clinopyroxene, garnet, allanite, magnetite, zircon, and apatite. The ferromagnesian minerals are extensively altered (*e.g.*, to chlorite and Fe-Ti oxide) or reacted (to hornblende and/or biotite $\pm$ chlorite); garnet, which occurs as equant megacrysts (xenocrysts?) commonly up to 1 cm and rarely up to 3 cm, is largely reacted to biotite-rich assemblages, as previously described. Lithic clast content ranges from <<1% to about 5%, and generally decreases upward. However, in the south, near Pandanus Creek, content and size of lithic clasts increase slightly at the top of the sheet. Also in the south, near Doolan Creek, a thin (1-2 m) lens of green, altered, lithics-rich ignimbrite crops out near the base of the subunit. Clast sizes range generally from $\leq$5cm to <1cm: sizes tend to decrease upward in most sections; however, at the top of the unit, clasts up to 5 cm were recorded in Pandanus Creek, and clasts up to 30 cm were observed at GR7864-357236 near Stuarts Creek. Most clasts are dark, fine-grained rhyolite, but andesite(?) is also present, and granite clasts up to 10 cm across were recorded at a locality in the middle of the ignimbrite sheet near Native Cat Creek (GR7864-374292). Sparsely scattered pumice fragments, with the "coarse porphyritic" texture observed in the Arringunna Rhyolite and several other ignimbrite units, up to 7 x 2 cm were recorded from several localities, chiefly towards the top of the sheet.

In the fault-bounded wedge adjacent to Elizabeth Creek in the north, a lithics-rich layer up to 10 m thick, containing angular clasts of a variety of felsic volcanic rocks up to 1 m across, is exposed (Bultitude & Domagala, 1988). Abundance and size of lithic clasts decrease abruptly at the top of this layer, and it is overlain by typical Pwc - intensely welded, very crystal-rich, rhyolitic ignimbrite containing garnet megacrysts up to 3 cm in diameter - with a well-developed pumice foliation; the lithics-rich layer is most likely a basal ground-lag deposit.

Alteration in Pwc is mainly very slight, although the uppermost and lowermost, less intensely welded, parts of the sheet are moderately altered in places. The alteration assemblage is chlorite, calcite, sericite and, commonly, clay(s) (*i.e.*, propylitic); hematite is also present in some rocks. It is not certain whether the propylitic alteration is immediately post-depositional deuteric or later hydrothermal, or to what extent the clay(s) and hematite are the products of weathering.

The ignimbrite sheet is about 520 m thick in the area of the type section, and 400 m or more thick in the north (Native Cat Creek area). It contains no apparent breaks between flow sheets, such as unwelded/poorly welded intervals or lithics-concentration zones (other than that near the base mentioned above), and appears to be a single cooling unit and essentially a single flow sheet. However, the non-regular variations in lithic clast abundance and size with stratigraphic height suggest that more than one flow is present.

Thickness. Total maximum thickness of the Stuarts Rhyolite is probably in excess of 700 m in the south near the type section, decreasing southward to zero over less than 2 km. To the north of the "Elizabeth Creek-Upper Doolan" fault, maximum thickness is about 1100 m, decreasing northward to about 250 m near Elizabeth Creek.

Eruptive source(s). The location of the eruptive source(s) of the Stuarts Rhyolite is uncertain, but the proximal nature of the lithics-enriched horizons and the lateral variations in lithic clast abundance and size suggest that the unit may overlie its own vent. It is possible that the vent is essentially co-extensive with, and overlain or partly buried by, the basal lithics-rich horizon, Pwb_1.

Structure. Stuarts Rhyolite dips at between 10^o and 15^o to the west-northwest in the southern half of its outcrop area, steepening to about 40^o on the northern side of the Elizabeth Creek-Upper Doolan fault. Dip decreases again to about 15^o near Elizabeth Creek. The unit is cut by several faults related to the Upper Doolan Fault Zone, none of which significantly displace it. The "Elizabeth Creek-Upper-Doolan" fault (splay of the Upper Doolan Fault Zone) marks the disappearance of the lowermost subunits of the Stuarts Rhyolite, and increases in thickness and dip of Pwb_2.

Relationships. Pwb_1 overlies Wollenden Rhyolite concordantly, and, apparently, conformably. However, there are indications of cross-cutting, even intrusive relationships between this subunit and stratigraphically lower rocks in the north, near Elizabeth Creek. Relationships within Stuarts Rhyolite appear to be conformable in the south, but the disappearance of Pwb_2 and the basal vitrophyre of Pwc indicate a discordance at the base of the main ignimbrite sheet of Pwc. The non-continuance of the basal vitrophyre north of the Elizabeth Creek/Upper Doolan fault may be evidence that it is not, as interpreted above, a quenched basal part of the thick overlying ignimbrite sheet and that it is, rather, part of the underlying Pwb_2. However, the vitrophyre merges imperceptibly into the overlying, more intensely welded, devitrified ignimbrite, and is a similar brown tone on airphotographs, in contrast to the pale greenish-straw tones of Pwb_2.

Topography. Stuarts Rhyolite is characterised by a variety of topographic expressions. Pwb_1 is distinguished by subdued terrain, with low, rounded hills, large areas of rock pavements and low whalebacks (elongated parallel to strike), a moderately sparse, even cover of short trees and medium-height grass, and medium-brown tones on airphotographs. Pwb_2 is distinguished by moderately prominent scarps and smooth dip slopes, with very sparse, patchy tree cover (concentrated on steeper slopes and along fractures, *etc.*), partial cover of short grasses ("kerosene grass" is common), and very pale brown to straw tones (speckled with green) on airphotographs. The basal part of Pwc has formed low, generally recessive terrain, with few areas of outcrop and a smooth, brown-green, evenly tree-covered appearance on airphotographs. The main part of Pwc is distinguished by moderately rugged terrain, with up to 200 m of relief, and medium-dark greenish-brown tones on airphotographs. Areas of sparse tree cover and abundant outcrop interspersed with areas of relatively dense tree cover concentrated mainly on steeper slopes and along faults, lineaments and joints, give a characteristic patchy or mottled appearance: it is similar in appearance from the air, on airphotographs, or on Landsat TM imagery to Lumma Rhyolite and the upper part of Arringunna Rhyolite (Pfa_1).

Age. Stuarts Rhyolite is between 289 ± 10 Ma and 278 ± 3 Ma, and slightly older than Wollenden Rhyolite.

Synonymy. Branch (1966) and de Keyser & Lucas (1968) included Stuarts Rhyolite in undivided "Featherbed Volcanics".

Unnamed unit Pwd

Pwd is a body of coarse, mainly lithics-rich, ignimbrite-like material that extends as an irregular belt up to 2 km wide from south of Pandanus Creek, near the southeastern caldera margin, to the junction of Elizabeth and Native Cat Creeks.

Type section. Typical Pwd is well exposed about 1 km north of Pandanus Creek, between GR7864-353217 and -348220. A supplementary section, in which gas-escape deposits ("tuffisites") are well exposed, is between -364258 and -356257.

Lithology. Pwd consists of pale to medium grey, green, or brown, poorly sorted lithics-rich to moderately lithics-poor, crystal-rich rhyolitic ignimbrite or volcanogenic rudite/breccia (Fig 5). It is poorly to moderately welded, with the greatest degree of welding in the finest, least lithics-rich rocks near the base in the north, and the least welded rocks weathered to a characteristic deeply pitted to cavernous appearance. The rocks are also commonly characterised by a thick coating of black lichen on weathered surfaces.

Lithic clast content ranges from 5-10% (near the base in the north) to more than 80%; clast size ranges from less than 5 cm to about 20-30 cm at the base and up to 50 cm at the top of the unit (Fig. 8A). The clasts are angular to subangular, and the dominant lithology is sparsely porphyritic rhyolite; rhyolitic ignimbrite is also common in the south, and andesite is rare. "Coarse- porphyritic" pumice *fiamme* are visible in some outcrops near the base.

The crystal/crystal fragment component of Pwd is of coarse sand to silt grainsize; crystal content tends to increase downward, along with the degree of welding. Pwd also contains numerous small, irregular to tabular or dyke-like, cross-cutting bodies of tuffisite or volcanogenic arenite.

Thickness. Pwd ranges up to 420 m in apparent thickness in the southern half of the belt, and may range up to 600 m in the north.

Eruptive source(s) of Pwd is probably in or directly beneath the present outcrop area.

Relationships. Despite its strongly ignimbrite-like characteristics and grossly concordant aspect, Pwd clearly cuts across the upper boundary of Stuarts Rhyolite and the lower boundary of the overlying Gavin Rhyolite in several places. The upper part of the Stuarts Rhyolite has been extensively invaded by irregular masses and narrow, dyke-like bodies of Pwd, and, in places, blocks of Pwc up to about 1 km^2 are completely encircled. It also partly overlies(?) and partly intrudes one of the early lava bodies, Ple.

Pwd is therefore interpreted to be, at least in part, an intrusive or vent-filling ignimbrite, and to mark the eastern segment of the margin of a secondary caldera collapse structure centred on the headwaters of Dinner Creek.

Topography. Pwd is characterised by very subdued to flat terrain with scattered rock pavements, a medium to sparse, even tree cover, and medium-pale tones on airphotographs that contrasts strongly with that of the Stuarts Rhyolite to the east and, to a lesser extent, with the Gavin and Ticklehim Rhyolites to the west.

Age of Pwd is uncertain: it is certainly younger than Stuarts and Gavin Rhyolites, and is probably older than Ticklehim Rhyolite, *i.e.*, older than 278 ± 3 Ma.

Unnamed unit Pwx

Pwx comprises several irregularly shaped bodies of coarse, lithics-rich ignimbrite or volcanogenic rudite that crop out in the southwestern part of the Wakara Caldera. By far the largest of these crops out along the valley of the Walsh River and along lower Dinner Creek; it covers an area of about 20 km^2. Four much smaller bodies crop out in the same general area: the largest of these (~1.3 km^2) crops out to the southwest of the main body, around GR7764-185190; a body of about 0.5 km^2 crops out to the north of the main body around GR7764-205263; and a highly irregularly-shaped body of about 1 km2 crops out to the east, around GR7764-253207. The fourth body is a 2 km x 0.5 km strip of rocks, mainly similar to those of the main body, that crops out along the southwestern caldera margin straddling the Walsh River. Its southern end is connected to the southwestern extremity of the main body in the Walsh River by an arcuate, 250 m-wide strip of lithics-rich ignimbrite which may also be part of Pwx (see **Relationships**, below).

Type area. It is not possible, or relevant, to define a type section for this unit; however, the best-exposed and most informative outcrop area is near the junction of Dinner Creek and the Walsh River, at GR7764-185228.

Lithology. Pwx consists almost entirely of very lithics-rich to lithics-rich (rarely moderately lithics-rich to -poor), moderately crystal-rich to crystal-rich ignimbrite (or ignimbrite-like breccia) in which the lithics clasts are set in a crystal-rich matrix of coarse sand (mainly) to medium sand grainsize.

Lithic clast content ranges up to 50% or more, and comprises, over most of the unit, angular to subangular fragments generally up to 30 cm and commonly up to 2 m long. Smaller clast sizes are confined to isolated "pockets" a few metres to tens of metres across. Larger clasts are more widespread, and achieve apparently maximum dimensions in the Walsh River-Dinner Creek junction area where a clast 40 m long and 15 m wide was measured, and large numbers of the other clasts are several metres long. Farther to the west along the Walsh River, blocks of andesite up to 15 m long were recorded in moderately lithics-rich to -poor ignimbrite that may represent either the stratigraphic top of an apparently concordant tabular apophysis(?) of Pwx or the basal part of the overlying Gavin Rhyolite (see **Relationships**).

The dominant clast lithology over most of the unit is sparsely porphyritic rhyolite, which is commonly flow-laminated and slightly less commonly brecciated. Other lithologies include moderately crystal-rich to crystal-rich rhyolitic ignimbrites, abundantly porphyritic rhyolite/microgranite, andesite, strongly porphyritic microgranite, meta-arenite and -siltstone, and biotite granite. In the most spectacular exposure of the unit, at the Walsh River-Dinner Creek junction (Fig. 7), moderately crystal-rich "rheomorphosed" rhyolitic ignimbrite (strongly resembling that in the Fisherman Rhyolite) forms the largest measured clast (40 x 15 m), and a substantial proportion of the smaller clasts, along with all the lithologies mentioned above. The andesite clasts at this locality are generally small (<30cm), sparsely porphyritic, and amygdaloidal. Ignimbrite cropping out near the margins of the tongue of Pwx that extends to the southwest along the Walsh River, and in parts of the body adjacent to the southwestern caldera margin and straddling the Walsh River, contains andesite blocks up to 15 m long. These blocks, or "blobs", commonly have highly irregular, scalloped margins, and some have gradational rather than sharp contacts: they show evidence of having been erupted, and possibly deposited, in a plastic state.

The matrix to the lithic clasts in most outcrops has the appearance of a typical crystal-rich ignimbrite: pumice ("eutaxitic") foliation is apparent in some outcrops, and "coarse-porphyritic" pumice *fiamme* (as opposed to clasts of non-vesiculated porphyritic microgranite which are also present in places) up to 30 cm long occur in places, particularly in the southwest, in the uppermost(?) parts of the unit. Crystals in the matrix are quartz, K-feldspar and plagioclase; ferromagnesian minerals are rarely apparent and in all cases completely altered. Garnet megacrysts up to 1.5 cm in diameter and variably altered and/or reacted are very rare.

Evidence of gas streaming through the matrix is abundant: at the Walsh River-Dinner Creek locality, it has produced an irregular, swirling pattern of grainsize sorting (Fig. 7B). Cross- laminated, bedded

Figure7.

A. General view of coarse volcanogenic rudite, or lithic-rich ignimbrite ("megabreccia", unnamed subunit Pwx, Wakara Volcanic Subgroup), showing a clast of rhyloitic ignimbrite which extends across the photograph (about 40m); it is about 15 m wide, and of unknown vertical extent. Walsh River-Dinner Creek junction (GR7764-174245).

B. Example of sorting by gas streaming, subunit Pwx: a graded, fines-enriched zone partly surrounds a core (above hammer) or fines-depleted material. Locality as for 7A.

C. Detail of outcrop at Walsh River-Dinner Creek locality, showing cross-section of a small "tuffisite" (fine ash deposited by gas streaming - lower right) and a clast of vesicular andesite (left of hammer).

rocks resembling base-surge deposits crop out at the southern extremity of the unit, near the southern caldera margin west of the Walsh River. At GR7764-220187, the horizon consists of thin (layers 1-2 cm thick), discontinuous and low-angle cross-laminated beds of pumice lapilli-rich, crystal-rich pyroclastic or possibly epiclastic material dipping to the north at 75°. At GR7764-216186, thin (~2.5 cm)-bedded, low-angle (10-15°) cross-bedded, variably crystal-rich and fines-depleted pyroclastic/epiclastic deposits dip northward at 45°. Some layers at this locality contain scattered pumice clasts up to 7-8 cm long, and some contain lithic clasts up to 2.5 cm across. At both localities, the bedded deposits overlie massive, lithics-poor, crystal-rich welded ignimbrite in a cross-cutting relationship.

Thickness of the main body of Pwx is unknown: if it is, as strongly suspected, largely intrusive, its thickness is indeterminable. The tabular, apparently concordant westward extension(?) of Pwx ranges from about 230 m to about 320 m thick.

Relationships. Most of the contact relationships of the main body of Pwx, especially in the southwestern extremity along the Walsh River, and the strip along Dinner Creek, are clearly cross-cutting. The southwestern and northeastern boundaries of the main body are concordant on a broad scale, but in detail are also cross-cutting. The most southerly of the small bodies appears to be mostly concordant, but cross-cutting in part at its southeastern end. The irregularly-shaped body to the east of the main mass also appears to be partly concordant, at least in the south, but its northern apophysis is almost certainly intrusive and the whole body may be so. The small body to the north of the main mass is partly cross-cutting and partly fault-bounded.

Rocks tentatively correlated with Pwx in the extreme southwest of the caldera, and the arcuate strip of similar rocks that connects that body with the southwestern extremity of the main mass, appear to be concordant with the overlying sheet of massive, welded ignimbrite (Gavin Rhyolite). It is not possible to define an unequivocal boundary between these rocks and the main body of Pwx in the Walsh River, and either:

(1) the main, cross-cutting body of Pwx merges imperceptibly with a concordant, lithics-rich ignimbrite sheet underlying Gavin Rhyolite, or

(2) the concordant lithics-rich rocks in the southwest are simply a lithics-enrichment zone at the base of Gavin Rhyolite and are unrelated to Pwx.

Pwx is at the same relative stratigraphic level as Pwd, and, apart from being generally coarser, is similar in lithology: they are probably correlatives. Pwx and Pwd are interpreted as mainly vent-fill and proximal lag deposits in and near a partial (semi-circular) cauldron margin-vent complex that partly outlines a subsidiary cauldron/caldera-collapse structure

Topography. Pwx is characterised by low, very subdued terrain with a medium to medium-sparse vegetation cover and slightly darker soil-vegetation tones relative to the topography of the surrounding rocks (predominantly welded crystal-rich ignimbrites). It is also characterised by numerous, extensive rock pavements and very low whalebacks, especially along and close to the Walsh River.

Age. The age of Pwx is between 289 ± 10 and 278 ± 3 Ma.

Gavin Rhyolite (Pwe_{1-3})

Derivation of name. The name Gavin is derived from the Parish of Gavin, County of Bolwarra, which includes part of the southwestern body of the unit.

Constituent units. Gavin Rhyolite comprises three unnamed Members: Pwe_1, Pwe_2, and Pwe_3.

Distribution. Gavin Rhyolite crops out extensively in the southwestern and southern parts of the Wakara Caldera. It is separated into two main masses by the body of Pwx that crops out along lower Dinner Creek and the Walsh River. The main mass extends in an arcuate belt averaging about 2 km wide from near Dimmer Creek on the northwestern caldera margin southeastward to within 300 m of the southern caldera margin, then northeastward to about the latitude of the Elizabeth Creek Fault Zone (GR7864-352268). Its total area is about 40 km^2. The southwestern mass, which extends from the northwestern caldera margin, across the Walsh River, and almost to the southern caldera margin, covers an area of about 22 km^2.

Type section. The type section, which includes two vitrophyre horizons up to several metres thick, is between GR7764-341212 and -329225, about 1 km west of Pandanus Creek. A supplementary section, with 100% outcrop including variably remobilised/brecciated ignimbrite, gas-streaming deposits ("tuffisites"), lithic clasts up to 40 m, and high-level intrusives, is along the Walsh River, just east of the Burke Developmental Road, between -140193 (caldera margin) and -170202 (faulted/intrusive contact with Pwx).

Lithology. Gavin Rhyolite consists of three ignimbrite subunits, Pwe_1, Pwe_2, and Pwe_3.

Pwe_1 crops out only along the eastern side of lower Dinner Creek and the Walsh River above the junction (the eastern side of the main body of Pwx), and near the southern caldera margin immediately west of the Walsh River. A small inlier (800 x 170 m) of Pwe_1 crops out near the southern margin, 4 km west of the Walsh River (around GR7764-189187). Some of the rocks that crop out in the strip of rocks straddling the Walsh River on the southwestern caldera margin may be correlatives of Pwe_1.

Pwe_2 forms the major part of the unit in both outcrop areas, while Pwe_3 forms only a small outlier (1 km x 500 m) in the east, 4.5 km west-northwest of the Doolan Creek-Stuarts Creek junction. Rocks similar to Pwe_3 crop out in the west (and at the top) of the main belt of Pwe_2, 6.5 km east-southeast of the Dinner Creek-Walsh River junction, but they are not sufficiently extensive to be mappable at 1:100 000 scale.

Pwe_1 consists of dark to medium grey, welded, lithics-poor or very lithics-poor to lithics-rich, crystal-rich, rhyolitic ignimbrite; fine pyroclastic ash is present at its base in places. The most lithics-rich rocks tend to be less intensely welded than the bulk of the subunit.

Content and size of lithics clasts is greatest at or near the base of the subunit, and decrease steadily upwards in both size and abundance; however, the subunit is noticeably more lithics-rich overall than the upper subunit. Lithic clasts range up to 15 cm (in the southernmost southeasternmost outcrops) or 20 cm (near lower Dinner Creek) at or near the base of the subunit. Clasts up to 60 cm across were recorded in rocks near the southwestern extremity of the caldera (straddling the Walsh River) that may be part of the subunit, but the distinctions between Pwx (its concordant "apophysis"), the basal lithics-concentration zone of Pwe_2, and the basal part of Pwe_1 are blurred and uncertain. In the bulk of the main part of the subunit, east of lower Dinner Creek-Walsh River, clast size is mostly $\leq$2 cm, with some reaching 5 cm. The dominant clast lithology is sparsely porphyritic rhyolite, commonly with contorted flow lamination; other lithologies include less common crystal-rich rhyolitic ignimbrite and andesite, rare metasediments (Hodgkinson Formation) and strongly porphyritic microgranite (which is in some cases difficult to distinguish from "coarse-porphyritic" pumice), and very rare dacitic ignimbrite. The andesite clasts include aphyric or glassy, as well as sparsely porphyritic lithologies, the former resembling rocks of the Nychum Volcanics.

Pumice fragments, mostly of the "coarse-porphyritic" variety, are apparent in most parts of the unit, especially near the base and the top, and range up to 10 cm long.

Crystal content ranges from 30% to 40%, tending to increase upward, and comprises quartz, sanidine/orthoclase and plagioclase (12-18%, 12-15%, 3-5%; all $\leq$3 mm), and up to 3% of, in order of decreasing abundance, clinopyroxene, orthopyroxene, Biotite, garnet, allanite, magnetite, zircon, and apatite. The garnet, which forms equant megacrysts/xenocrysts up to 1 cm in diameter, has mostly reacted to biotite-rich assemblage(s) or been altered to chlorite and opaque oxide(s). Pyroxenes are variably fringed or replaced by hornblende and/or biotite, or altered to chlorite.

The base of the subunit in the south (west of the Walsh River - GR7763-22181839) is marked by a thin (~2.5 cm) layer of pyroclastic ash or volcanogenic arenite. This layer consists of fine vitric ash with scattered lithic and pumice clasts up to 1 cm across, and is probably of base-surge origin. It is overlain by about 1 metre of lithics ($\leq$2.5 cm)-rich ignimbrite.

Pwe_1 appears to be a single flow and cooling unit: there are no obvious breaks in the sequence, internal lithic-concentration zones, or abrupt changes in lithics, pumice, or crystal contents.

Pwe_2 is a dark to very dark grey, medium-grey, or, rarely, pale grey, very lithics-poor to lithics-poor, rarely lithics-rich, crystal-rich to very crystal-rich rhyolitic ignimbrite. It is characterised by generally prominent pale grey "coarse-porphyritic" microgranite clasts and/or pumice *fiamme* and relatively abundant garnet megacrysts. Vitrophyre/glassy ignimbrite is present at the base in two areas: overlying the eastern "lobe" of Pld, and overlying the eastern end of Ple. Welding is generally intense, but some of the most lithics-rich rocks are moderately to poorly welded.

Near the western margin of the Wakara Caldera, along the Walsh River, the lower part of Pwe_2 (possibly including part of Pwe_1) have been extensively disrupted and rewelded to give a breccia-like appearance (Fig. 8B). Individual clasts have well-developed pumice foliation, and, because of clast rotation, the orientation of the foliation is for the most part completely random. In places where disruption has been less severe and some coherence remains, average orientation of the foliation is sub-parallel to the caldera margin and near-vertical. These observations are consistent with deposition in an eruptive vent. The disrupted rocks, and undisrupted but otherwise similar rocks farther east (overlying[?]) are extensively cut by dyke-like, tabular bodies, up to 50 cm wide, of base-surge- like material which ranges in grainsize from fine to very coarse sand and is mostly cross-laminated (Fig. 8C).

The main variable in the subunit is abundance and size of lithic clasts. Lithic clast content at the base ranges up to 50%, and clast size to about 1 metre, notably where it overlies rhyolite domes/lavas (Pla, Plc, Pld, Ple/Plf). Where it overlies (or is intruded by?) Pwx, clasts are less abundant (up to 20-25%), but range up to 2 m. Clast abundance decreases to about 5% or less, and clast size to less than 10 cm - generally less than 5 cm - within 50 m of the base; lithic clasts less than ~2 cm across make up 2% (by volume) or less of the majority of the subunit. The dominant clast lithology is sparsely porphyritic, commonly flow-laminated, rhyolite; andesite, including an aphyric, glassy variety similar to that in the Nychum Volcanics (below), is moderately common, particularly in outcrops along the Walsh River adjacent to Pwx. Clasts of brecciated dacite up to 1 metre across occur in the base of the subunit where it overlies Plc. Clasts of strongly porphyritic biotite microgranite, resembling the ring dyke (Pmg) or Yokas Microgranite, up to 15 cm long were noted in a few outcrops, and clasts of medium-fine biotite granite were noted at one locality in the Walsh River.

Pumice fragments, commonly ellipsoidal or lenticular in shape, with rounded rather than pointed or "feathered" terminations, and composed of strongly porphyritic microgranite similar to Pmg or Yokas Microgranite, are common. They are most abundant near the base, where they range up to 30 cm long; higher in the subunit, abundance deceases slightly, and size decreases to 15 cm or less. In a number of outcrops, it was difficult to determine with confidence whether the strongly porphyritic "pods" or "lenses" were originally pumice (*i.e.*, vesiculated) or incompletely crystallised microgranite magma when erupted.

Crystal content of Pwe_2 ranges mainly between 30% and 45% (increasing upward), with some rocks at the base containing only 20-25% crystals and some near the top 50% or more. Quartz (10-20%), sanidine/orthoclase (10-20%) and plagioclase (2-4%) are the main crystalline phases, and range up to 4 or 5 mm long (average is about 3 mm). Other minerals, in approximate order of decreasing abundance, are orthopyroxene, garnet, clinopyroxene, fayalite, biotite, allanite, zircon, magnetite, and apatite. As in most other ignimbrites in the Featherbed Cauldron, pyroxenes are small (generally <1 mm) and variably reacted to hornblende and/or biotite or altered to chlorite and opaque oxide(s), or both; fayalite is extensively altered to iddingsite. Garnet, which forms equant megacrysts up to 1-1.5 cm in diameter, is less extensively altered/reacted than in most other units; this is a characteristic feature of Gavin Rhyolite.

Rounded "pellets" of fine-grained graphite up to 4 mm in diameter were found in one outcrop, at the northwestern extremity of the unit near Dinner Creek.

Pwe_2 appears to be a composite of at least two flow units which, in the west (*e.g.*, at GR7764-189202), are clearly separated by a lithics-concentration zone, and which cooled as a single unit.

Pwe_3 consists of a basal welded vitrophyre zone up to 10 m thick overlain by devitrified welded ignimbrite. Both are moderately lithics-poor to moderately lithics-rich and crystal-rich to very crystal-rich, with lithic clasts up to 5 cm long. Clast lithologies and crystal/crystal fragment mineralogy are similar to those of Pwe_2.

Alteration. Gavin Rhyolite is mostly very slightly altered (ferromagnesian minerals partly chloritised, feldspars slightly sericitised). More intense alteration is present in a few areas, generally

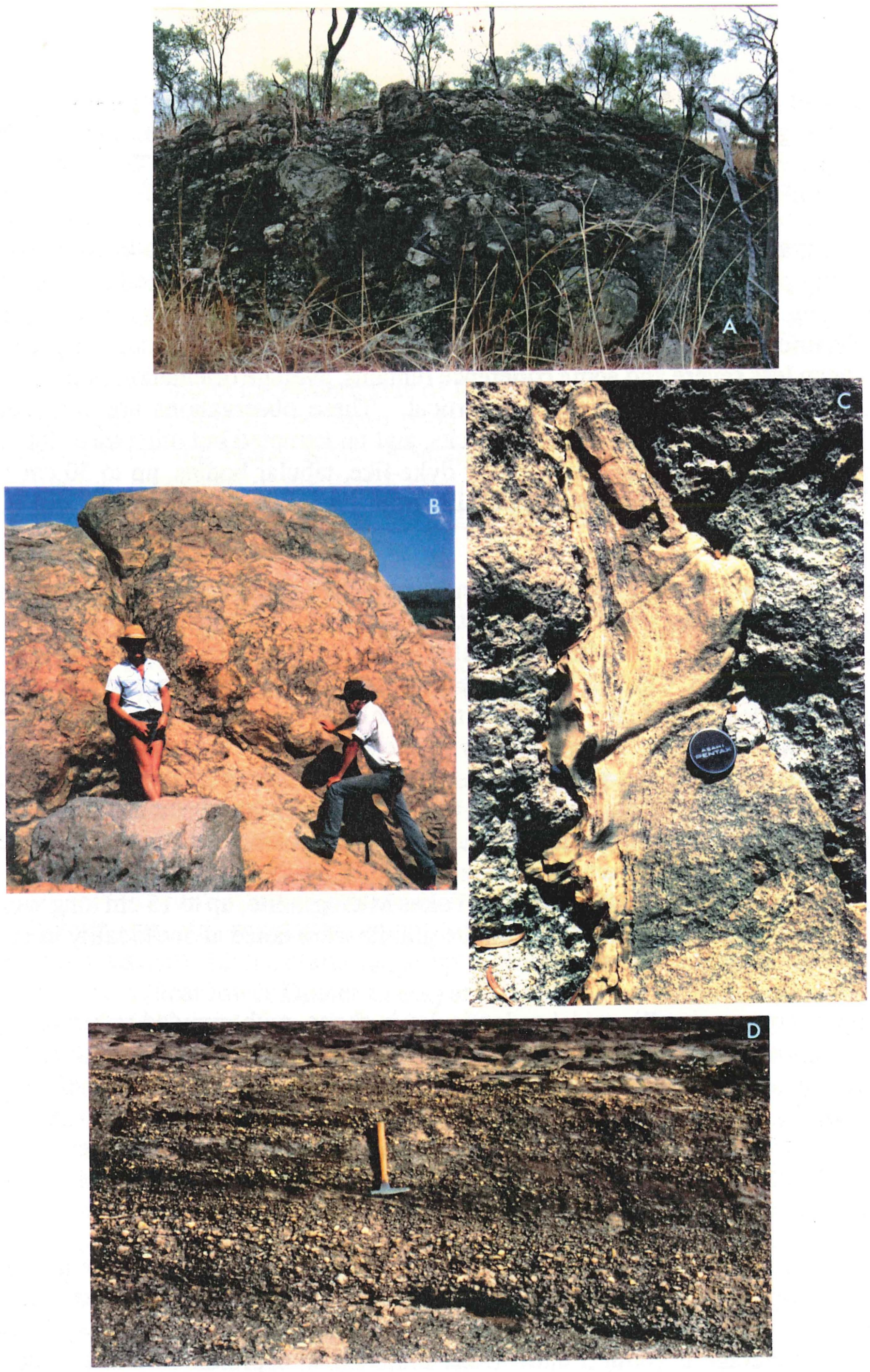

Figure 8.

A. Typical outcrop of lithic-rich ignimbrite, or volcanogenic rudite, unnamed subunit Pwd, Wakara Volcanic Subgroup. This lithology is concordant in places and cross-suts adjacent units in others. Head of Bustlem Creek (GR7864-386265).

B. Brecciated ignimbrite (Wollenden Rhyolite, Wakara Volcanic Subgroup)western margin of Wakara Caldera, Walsh River, near Gulf Developmental Road. (GR7764-143192).

C. "Tuffisite" (gas-escape deposit) dyke intruding Wollenden Rhyolite, Walsh River, near western margin of Wakara Caldera (GR7764-144192). Note the fine layering and grading; cross lamination is also apparent in places.

D. Pumice and lithic clast concentration zone at the base of an ignimbrite sheet, Rackarock Rhyolite, 2.5km southeast of "Nychum" homestead (GR7764-266345).

at or near the base, in relatively poorly welded, lithics-rich rocks: in the extreme northwest near the caldera margin, in the southwestern end of the caldera (in the lithics-rich horizon), near the southern caldera margin 3.5 km west of the Walsh River, overlying the western end of Ple, and in the extreme southeast.

Thickness. Pwe_1 varies widely in thickness, although it is doubtful that its original full thickness is preserved anywhere. Maximum remaining thickness east of Dinner Creek is about 100-150 m; in the south, it may reach 240 m thick. Pwe_2 varies enormously in thickness: in the southwest, it is probably at least 1800 m thick, and possibly considerably thicker, but the top is not preserved; in the main belt of outcrop, thickness varies from about 100 m to zero near Dinner Creek, increasing gradually eastward to a maximum of about 500 m in the central area, then decreasing farther east to about 80-100 m beneath Pwe_3 before disappearing or wedging out to the north.

Eruptive source(s). The combination of increasing thickness, increasing abundance and size of lithic and pumice clasts, and the close association with the very proximal Pwx indicate that Gavin Rhyolite was erupted from the area between lower Dinner Creek and the southwestern extremity of the Wakara Caldera.

Relationships. In the south, Pwe_1 unconformably overlies Plb and appears to be overlain unconformably by Pwx; however, the relationship with Pwx may be intrusive. In the southeast Pwe_1 is draped over and around Pld, and has a complex, probably mainly intrusive, relationship with Pwx. Pwe_1 partly overlies (paraconformably or unconformably?) and is partly intruded by Pwx in the main outcrop area east of Dinner Creek-Walsh River. In the southwestern extremity of the caldera, rocks tentatively correlated with Pwe_1 are intruded and/or underlain by Pwx, and overlain, apparently conformably, by Pwe_2.

Pwe_2 overlies Pwe_1 with apparent conformity to the east of Dinner Creek, but to the southwest is mostly separated from it by (intrusive?) Pwx (or by a coarse basal lithics-concentration zone similar to Pwx). It overlies unconformably a number of rhyolite/dacite domes and flows (Pla, Plc, Pld, Ple), apparently without any intervening Pwe_1, but it would be very difficult, or impossible, to distinguish between a thin veneer of basal Pwe_1 and the basal lithics concentration zone of Pwe_2. In the west of the main belt of outcrop (above Dinner Creek), Pwe_2 is overlain with probably unconformity by Pwg; farther east, it is overlain with apparent conformity (nonconformity?) by Pwf, and unconformably by Pwh. It is intruded by Pwx, and by dykes and irregular sills of porphyritic microgranite (Pmg: Fig. 1) that are either part of, or related to, the ring dyke.

Pwe_3 overlies Pwe_2 conformably, and is overlain with apparent conformity by Pwf.

Topography. Pwe_1 is characterised by low to moderate relief and ruggedness, abundant outcrop (relatively large boulders plus some rock pavements and whalebacks), medium-sparse to sparse cover of grass and short trees, and medium-pale to pale tones on airphotographs. The remainder of the unit is characterised by more rugged terrain with greater relief (up to 260 m), abundant outcrop (relatively small boulders), and very sparse to moderate (becoming denser to the east) cover of short trees and grass

Age. The Gavin Rhyolite is between 289±10 Ma (the age of the Arringunna Rhyolite) and 278±3 Ma (the age of the Ticklehim Rhyolite) old.

Synonymy. Branch (1966) and de Keyser & Lucas (1968) included Gavin Rhyolite in undivided "Featherbed Volcanics".

Unnamed unit Pwf

Distribution. Pwf extends in a belt averaging 1 km wide from 3.5 km northeast of the Dinner Creek-Walsh River junction 3 km to the southeast, then 10 km to Pandanus Creek in the east; its total outcrop area is about 11 km^2.

Type section. The type section of Pwf extends from GR7764-294218 (base) to -283231 (top), about 6 km northwest of the Doolan Creek-Walsh River junction.

Lithology. Pwf is a dark to very dark grey or black, intensely to moderately(?) welded, very to moderately lithics-poor, moderately crystal-rich to crystal-rich, rhyolitic ignimbrite. It has a well-developed vitrophyre horizon preserved at the base in two areas - the central, thickest part and the eastern end. A large proportion of the unit appears to be only slightly modified vitrophyre - *i.e.*, devitrified, very slightly recrystallised or unrecrystallised, and unaltered to very slightly altered - giving it its very dark colour. Columnar jointing is extensively developed.

As in the Gavin Rhyolite, the main variables are abundance and size of lithic clasts. Content of lithic clasts decreases from about 5% (up to 10% near the eastern end) at the base to less than 1% throughout the majority of the unit. Clast size also decreases slightly upwards, from up to 5 cm at the base to less than 2 cm for most of the unit. Clast lithologies include flow-banded, sparsely porphyritic rhyolite (predominant), sparsely porphyritic to aphyric andesite, glassy andesite, and porphyritic microgranite. Some of the andesite clasts have irregular, scalloped margins strongly suggesting that they were plastic (incompletely crystallised) when the ignimbrite was erupted, if not when it was deposited and compacted; the glassy andesite clasts resemble rocks in the Nychum Volcanics.

Crystal content is noticeably lower than in the Gavin Rhyolite, and increases slightly upwards from between 20% and 30% at the base to between 30% and 40% at the top. The crystal population is similar to that in the Gavin Rhyolite, although grainsize is perhaps slightly smaller, and includes relatively abundant orthopyroxene and minor (<1%) but ubiquitous, partly reacted/altered garnet up to ~1 cm.

Pwf is a single cooling unit, and appears to be a single flow unit: there are no obvious breaks such as poorly welded horizons or abrupt changes in lithic clast or pumice content.

Alteration. Pwf is unaltered to very slightly (deuterically?) altered to chlorite and sericite.

Thickness of Pwf ranges from about 130 m (in the west) up to about 380-400 m, and averages about 190-200 m.

Eruptive source(s). The location of the eruptive source(s) of Pwf is (are) unknown, but is probably in the east rather than the west, judging by the eastward increase in thickness and the relatively greater abundance and size of lithic clasts in the east.

Relationships. Pwf forms a sheet dipping at about 15^{o} to the northeast, north, or northwest. It overlies, with apparent conformity, Gavin Rhyolite, and is overlain by unnamed ignimbrite sheets Pwg and Pwh. The contact between Pwf and Pwg is grossly concordant, and probably either conformable or paraconformable; that between Pwf and Pwh is probably unconformable. Pwf is faulted against Gavin Rhyolite and Pwg at the western end of the sheet, where it also overlies(?) Pwx.

Topography. The topographic expression of Pwf is moderate to low relief (up to 200 m) and moderate ruggedness; vegetation cover comprises very sparse tree cover, concentrated along joints/fractures and on the steeper slopes developed on the lowermost, least welded parts of the unit, and a medium-light grass cover. Tones on airphotographs are slightly darker than those of most of the Gavin Rhyolite, due mainly to the very dark colour of the rocks: there is abundant outcrop in the from of tors, pavements, and low whalebacks.

Age of Pwf is between 289 ± 10 Ma and 278 ± 3 Ma - probably closer to the latter.

Unnamed unit Pwg

Distribution. Pwg crops out in the northwestern and central parts of the Wakara Caldera, extending from the northwestern margin near upper Dinner Creek south, then southeast for about 11 km, and covering a total area of about 12 km^2.

Type section. A complete section through Pwg is exposed between GR7764-254231 (base) and -257238 (top); a more accessible, also well-exposed section is along a tributary of Dinner Creek, between -214281 (faulted boundary) and -218277 (contact with Pwt/Plh).

Lithology. Pwg is a medium to dark grey, mostly intensely welded, very lithics-poor to lithics- rich, crystal-rich to very crystal-rich rhyolitic ignimbrite. It differs from adjacent units (Pwf, Pwh, Gavin Rhyolite, and Ticklehim Rhyolite) in containing generally more abundant, larger lithic clasts.

Lithic clast abundance and size are greatest at the base of the sheet, which contains between 5% and 20% angular clasts of andesite and flow-laminated rhyolite up to 15-20 cm (30 cm at one locality). Maximum clast size decreases upward to between 5 cm and <1cm throughout much of the unit; abundance decreases to between 5% and less than 1%. The general upward decreases in size and abundance are interrupted by at least two horizons where clast abundance rises to as much as 15% and maximum size to 8 cm. Maximum clast size, and probably abundance, also decrease towards the east.

Pumice fragments, ranging up to 25cm x 0.5 cm but generally between 3 x 1 cm and 7 x 1 cm, are common, especially towards the base and the top.

Crystal content varies irregularly between 30% and 45%, and comprises quartz, K-feldspar (sanidine variably inverted to orthoclase) and plagioclase, up to 3 mm, in the "usual" proportions (about 10:10:2-3), and various combinations and proportions of: clinopyroxene, fayalite, orthopyroxene, allanite, biotite, hornblende, zircon, magnetite, and apatite. Most or all of these minerals are present throughout most of the unit, generally in the above order of decreasing abundance; rare garnet was observed at two localities. The pyroxenes and fayalite are partly to completely altered in most rocks, and post-magmatic biotite and hornblende are common.

Pwg is probably a composite of at least three flow sheets, alike in lithology, that were emplaced in rapid succession and formed a single cooling unit.

Alteration. Most of the unit is slightly to very altered, mainly to propylitic assemblages (chlorite, sericite, and calcite), commonly with an overprint of clay(s) + hematite which may be partly due to weathering, but which is probably largely hydrothermal.

Thickness of Pwg averages between 170 and 250 m, ranging up to possibly 360 m in the northwest (Dinner Creek), and decreasing to a few metres at its eastern extremity. Dip of the sheet decreases from up to ~45° (eastward) in the northwest to 10-15° (northeastward) through most of its extent, and finally to very gently northward or subhorizontal at the eastern end.

Eruptive source. A westward/northwestward increase in thickness and in maximum size of lithic clasts suggest that the eruptive source of Pwg is probably in the west or northwest.

Relationships. Pwg overlies Pwf in a conformable or, more likely, paraconformable relationship, and is overlain unconformably by Ticklehim Rhyolite (Pwi). It is also overlain in the northwest by a thin tuff layer (Pwt) and a rhyolite lava unit (Plh), probably unconformably: the tuff layer appears to dip less steeply than the underlying ignimbrite. In the east, Pwg interfingers in part with Pwh and in part is paraconformably or unconformably overlain by it. Along its northwestern margin, Pwg is faulted against Pli, Plt, and Nychum Volcanics. It is cut by the porphyritic microgranite ring dyke (Pmg) and a dyke of similar microgranite orthogonal to the ring dyke, and appears to be intruded by a small body of Pwx. It is cut by one major north-south fault, on the eastern side of which dip is less and thickness greater(?) than on the western side.

Topography. Pwg is characterised by low to moderate relief and ruggedness, moderately abundant outcrop in the from of bouldery tors and rock pavements, a medium-sparse cover of trees and grasses, and a medium-brown (to green, in the wet season) tone on airphotographs. It is slightly darker in tone and less rugged than the underlying unit (Pwf), and slightly paler in tone and less rugged than the overlying unit (Pwi).

Age. Pwg is stratigraphically beneath, and therefore slightly younger than, Ticklehim Rhyolite, which has been isotopically dated at 278 $\pm$ 3 Ma.

Unnamed units Pwt and Plh

Pwt is the only known example in the Featherbed Cauldron of an airfall tuff within the eruptive sequence, and Plh is the only rhyolite lava flow of mappable dimensions intercalated well within the ignimbrite pile. Both crop out about 5 km north-northeast of the Dinner Creek-Walsh River junction.

Pwt crops out in a belt 1.5 km long and up to 60 m wide. It consists of massive to subtly laminated, dark purple to buff or white, crystal-poor, fine vitric airfall(?) tuff with thin (a few centimetres) lithic clast-rich zones, containing angular rhyolite clasts up to 3 or 4 cm (mostly < 1 cm), and extending only a few tens of metres, in one locality. Thickness of Pwt reaches almost 20 m in places, but is mostly about 10-15 m. The upper and lower boundaries are broadly concordant with the regional trends, but irregular in detail; the tuff is clearly unconformable on Pwg, and paraconformably or unconformably overlain by Plh.

Plh crops out over an area of about 1.3 km^2. It consists of mainly pale brown, sparsely porphyritic rhyolite lava, most of which is flow-banded/laminated; it is up to about 140 m thick. The lava is extensively brecciated around the margins, particularly at the top, where the breccia zone is several metres wide and contains clasts up to 1 m in diameter. It overlies Pwg unconformably, overlies Pwt either unconformably or paraconformably, and is overlain paraconformably by Ticklehim Rhyolite. Pwt forms very subdued terrain and Plh is characterised by a very rough surface with abundant outcrop in the form of pavements, bluffs, whalebacks, and tors; both are very sparsely vegetated, and show very pale tones on airphotographs.

Both Pwt and Plh are slightly older than Ticklehim Rhyolite (278 ± 3 Ma).

Unnamed unit Pwh

Distribution. Pwh crops out over an area 11 km long and up to 2.5 km wide (about 15 km^2) in the central part of the Wakara Caldera, extending from 8 km east of the Dinner Creek-Walsh River junction to the headwaters of Native Cat Creek.

Type section. The type section extends from GR7764-302233 to -307262.

Lithology. The unit consists of medium to dark grey or greenish-grey, welded, very to moderately lithics-rich, crystal-rich to moderately crystal-rich rhyolitic ignimbrite. Lithic clasts comprise about between 1% and 5% by volume at the base, and throughout most of the sequence, but reach 20-25% in several intervals, including one about 70-80 m above the base, and several near the top: this strongly suggests that several flow sheets are involved. Clast abundance and possibly size tend to increase towards the southwest.

The lithic clasts are angular, generally less than 2-3 cm across, and are composed dominantly of either very fine, aphyric to very sparsely porphyritic andesite or sparsely porphyritic rhyolite. Pumice fragments with the typical "coarse-porphyritic" texture, and ranging up to 15 cm long, are common throughout the unit, but tend to increase in size and abundance upward.

Crystal content varies erratically from about 20-25% to about 30%, and comprises quartz, K-feldspar and plagioclase (all ≤3 mm; 90% of the total, in the approximate proportions 5:5:1), and up to 2-3% of, in general order of decreasing abundance, orthopyroxene, biotite, clinopyroxene, garnet, fayalite(?), zircon, allanite, magnetite, and apatite; clinopyroxene, fayalite, and allanite were not found in all samples. Garnet is mostly altered to chlorite and opaque oxide(s) and/or reacted to biotite, feldspar, and pyroxene. Pyroxene grains are extensively altered to chlorite + opaque oxide(s) ± calcite, and most fayalite(?) is altered to iddingsite or chlorite.

Thickness of Pwh ranges between 190 and 260 m over most of its extent, but thins abruptly at its western end against Pwg.

Eruptive source. Location of the eruptive source of Pwh is unknown: variation in abundance and size of lithic clasts points to the west or southwest, but thickness variation is inconclusive or equivocal.

Relationships. To the west of upper Pandanus Creek, Pwh overlies Pwf in a relationship that is grossly concordant but in detail paraconformable. Farther to the northeast, Pwh overlaps Pwf unconformably to rest directly on Gavin Rhyolite. At its western end GR7764-265235), Pwh partly interfingers with Pwg, and partly overlies it paraconformably or unconformably. Pwh is apparently intruded in the east by Pwd, and is overlain and overlapped, paraconformably to the west of the fault at the head of Pandanus Creek (Figure 1), and unconformably to the northeast, by Ticklehim Rhyolite.

Topography. The topographic expression of Pwh is similar to that described for Pwg and the uppermost subunit of Stuarts Rhyolite (Pwc_2).

Age of Pwh is slightly greater than that of the Ticklehim Rhyolite, which is dated at 278 ± 3 Ma (L.P. Black, pers. comm., 1991).

Ticklehim Rhyolite (Pwi) (new name)

Derivation of name. Ticklehim Creek is a tributary of Elizabeth Creek (junction at GR7764-230369); it intersects the unit at GR7764-252339, and its headwaters drain the northernmost parts of the outcrop area.

Distribution. Ticklehim Rhyolite is by far the most extensive unit of the Wakara Volcanic Subgroup; it crops out over an area of about 85 km^2 in the northern part of the caldera, extending from Native Cat Creek northwestward to the caldera margin a few kilometres south of "Nychum" homestead, and westward almost to the caldera margin near Dinner Creek.

Type section. The type section extends from GR7764-223267 (base) to -237273, then -242283, and from there to -266285; the top is not preserved.

Lithology. Ticklehim Rhyolite is composed of mostly dark to very dark grey, very lithics-poor to moderately lithics-poor/rich(?), crystal-rich rhyolitic ignimbrite; colour ranges to almost black, medium or pale grey, greenish-grey or brownish-grey in places. The base of the unit is marked in several areas, particularly where it overlies Plh and Pwg, by one or more vitrophyre horizons, or by relatively lithics-rich rocks, or both. Closely-spaced (~1 cm), subhorizontal jointing characterises large areas of outcrop of the ignimbrite, especially in its upper parts and/or in the north and northwest.

Lithic clast content decreases generally upward from the base, where it reaches 15-20% in places, notably where it overlies Plh, and at the southernmost margin; most of the unit contains less than 5% by volume lithic clasts, and much of the uppermost part contains less than 1% clasts. Clast size varies sympathetically with clast abundance, ranging from up to a metre at the base in the east (*e.g.*, overlying Plh and Plm) to less than 2-3 cm through most of the unit, and less than 1 cm in its highest parts. Lithologies represented in the clast population include sparsely porphyritic rhyolite (dominant), sparsely to moderately porphyritic dacite, sparsely porphyritic to aphyric andesite, and very rare biotite granite. *Fiamme* of strongly porphyritic (feldspars up to 1 cm; quartz up to 7 mm, very rare garnet) - "coarse-porphyritic" pumice, commonly up to 15 cm long, and up to 40 cm in one locality (60 m above the base in the type section), are relatively abundant. In some exposures it is difficult to discriminate between oblique or basal sections through pumice *fiamme*, or *fiamme* with a high aspect ratio, and unexpanded/nonvesicular clasts of strongly porphyritic microgranite which may be present in very small numbers.

Crystal content ranges between 25% and 35% (rarely up to 40%); it increases upward overall, but varies irregularly in detail, especially near the base. Proportion of major mineral species among the crystals/crystal fragments is similar to that in the Gavin Rhyolite, and crystal/crystal fragment size averages between 2 mm and 3 mm. Minor mineral species include, in approximate order of decreasing abundance, orthopyroxene, biotite, and garnet, scarce clinopyroxene and fayalite, and accessory allanite, zircon, magnetite, and apatite; monazite was detected in two samples. The pyroxenes and fayalite are extensively chloritised, and most garnet, which occurs as megacrysts/xenocrysts? up to 1 cm in diameter, is partly reacted to biotite-rich aggregates or to chlorite, or both.

The ignimbrite appears to be a single cooling unit, and the lack of any clear evidence of abrupt changes in the abundance of lithic clasts, crystals, or pumice suggests that it may be a single flow sheet.

Alteration. Most of the unit is slightly propylitised (chlorite + sericite ± calcite), but within about 1 km of the rhyolite body Plm, and overlying Plh, alteration is much more intense. Superimposed upon the propylitic alteration in some areas, notably near Plm, is a clay(s)-hematite assemblage which may be due to subsequent lower-temperature hydrothermal alteration and/or weathering; montmorillonite was identified in one sample.

Thickness. Although the top of the Ticklehim Rhyolite is preserved in the north, beneath Rackarock Rhyolite, there is no continuous, complete section: total thickness is at least 160 m, probably about 600 m, and possibly 700 m or more.

Eruptive source. The relative size and abundance of lithic clasts in the west to southwest of the unit strongly suggest a vent located in the west or southwest - possibly in the general area now occupied by Pwx, or along the northwestern margin of the caldera.

Relationships. Ticklehim Rhyolite overlies Pwg and Plh paraconformably, and overlies Pwg paraconformably in the west but unconformably in the east. It is faulted against Pwd along Native Cat Creek, and probably also overlies it unconformably farther to the southwest, but this relationship is uncertain due to the poor outcrop in the area. Ticklehim Rhyolite also overlies Plm unconformably, and is overlain paraconformably by Rackarock Rhyolite. In the northeast, it is faulted against Nightflower Dacite and a small body of granite/granodiorite (part of the Bilch Creek Granodiorite) which intrudes Nightflower Dacite. In the north and northeast, Ticklehim Rhyolite is extensively intruded by Yokas Microgranite.

Topography. The Ticklehim Rhyolite is characterised by moderate to low relief (up to 190 m) and ruggedness, with mainly rounded hills, some steep-sided, linear, fracture-controlled valleys, and numerous, conspicuous, mainly northeast- and northwest-trending, fault and joint lineations. Vegetation cover is moderate to sparse, and comprises short (up to ~5 m) to moderate-height (up to 15-20 m) trees, mainly ironbark, and a moderate to dense cover of "speargrass". Vegetation is strongly controlled by faults and joints, which have produced narrow belts of relatively dense vegetation, and by aspect, with denser tree growth in the east and on south-facing slopes. Ticklehim Rhyolite has greater relief, and is slightly darker in tone on airphotographs, than the units underlying it, and is darker in tone than Rackarock Rhyolite.

Age. Ticklehim Rhyolite has been dated by the Rb-Sr isotopic method at 278 ± 3 Ma, or mid Early Permian (L.P. Black pers. comm., 1991). It is the youngest dated extrusive unit in the Featherbed Volcanic Group.

Synonymy. Branch (1966) and de Keyser & Lucas (1968) included Ticklehim Rhyolite in undivided "Featherbed Volcanics".

4.1.3.3(m) **Rackarock Rhyolite (Pwj, Pwk, Pwm)** (new name)

Derivation of name. The name is derived from Rackarock Creek, which joins Elizabeth Creek at GR7864-281352, and cuts across the unit between -282346 and -286339.

Distribution. Rackarock Rhyolite is the uppermost and most northerly preserved unit of the Wakara Volcanic Subgroup. It crops out over an area of about 3.5 km^2 near Elizabeth Creek, 3 km south of "Nychum" homestead.

Type section. The type section is between 7764-26553453 (base) and 26333400.

Lithology. Rackarock Rhyolite consists of a series of rhyolitic ignimbrite sheets which range widely in composition (abundance of lithic and pumice clasts in particular) both vertically and laterally (over a few metres in the most lithic-and pumice-rich horizons) and degree of welding. The type section, which is only 550 m long and rises 80 m, contains well-exposed examples of most of the classic features of ignimbrites, or "ash-flow tuffs" (*e.g.*, Smith, 1960b; 1979), and is unique in this resect in the Featherbed Cauldron.

Pwj consists of at least three poorly to moderately welded ignimbrite flow sheets. The base of the subunit is marked by a lithics-concentration zone, about 1 m thick, composed of angular clasts of (mainly) flow-banded rhyolite between 2 cm and 10 cm across set in a medium-fine, crystal-rich matrix. The clast-rich layer is overlain by about 3 metres of dark grey to green-grey (at the base), moderately lithics-poor to -rich, crystal-rich (up to 35%) ignimbrite; pumice clasts in this sheet range up to 7 x 1 cm, but most are smaller and highly flattened, resulting in a well-defined foliation.

This ignimbrite sheet is overlain by 2-3 m of flow-banded rhyolite lava breccia containing in the type section a ~1 m block of breccia composed of angular clasts of amygdaloidal andesite up to 5 cm long. Overlying the lava breccia is a dark-grey, moderately lithics-rich, crystal-rich to moderately crystal-rich rhyolitic ignimbrite sheet about 5 m thick which contains angular clasts of flow-banded, moderately porphyritic rhyolite ranging in size from ≤60 cm at the base to ≤3 cm at the top.

The second ignimbrite sheet is overlain by a thin (< 1 m) horizon rich in angular to subangular clasts of rhyolite (≤20 cm) resembling a talus or flow-front/margin breccia. The breccia is overlain in turn by about 5 m of medium-grey, welded, lithics-poor, crystal-rich rhyolitic ignimbrite containing 1-2% small (≤2; mostly ≤1 cm) clasts of aphanitic to sparsely porphyritic rhyolite and abundant pumice *fiamme* up to 10 x 1.5 cm.

Pwk. The base of Pwk is marked by an horizon about 2-3 m thick of clast-supported breccia made up of subangular to angular clasts of flow-laminated to massive rhyolite up to 80 cm in diameter set in a coarse "sandy", crystal-rich matrix; it is probably a proximal ground-lag deposit. This layer is overlain by a series of medium greenish-grey, rhyolitic ignimbrite sheets (Fig 8C): (1) A basal crystal-rich layer (m) containing scattered large (≤15 cm) lithic clasts;

(2a) a layer a few centimetres thick rich in small (≤2 cm) lithic clasts;

(2b) a crystal-rich horizon about 2 m thick containing abundant, conspicuous, "coarse-porphyritic" pumice clasts up to 30 cm long and 8 cm thick;

(3a) a fine, crystal-rich, base-surge(?) layer a few centimetres thick;

(3b) about 5 metres of massive, moderately lithics-poor, crystal-rich ignimbrite with clasts of rhyolite mostly -3 cm, rarely up to 7-8 cm;

(4) several sheets, each between 20 and 50 cm thick, displaying spectacular, rhythmically repeated basal lithics-enrichment zones (rhyolite clasts up to 2-5 cm long) and pumice-enriched upper zones (Figure 5) which show pronounced lateral compositional variation;

(5) about 3 metres of massive, fine, lithics-rich, crystal-rich ignimbrite containing subangular clasts of rhyolite and dacite or andesite up to 1-2 cm long; and, above a sharp, subhorizontal contact with the lithics-rich horizon,

(6) several thin sheets of poorly welded or unwelded, lithics-poor, crystal-rich ignimbrite characterised by cavernous weathering due to the preferential etching out of unwelded pumice in several pumice-enrichment zones.

Pwk is moderately to strongly altered to propylitic assemblages of chlorite + sericite + calcite ± hematite. Alteration has destroyed most grains of non-felsic minerals, but orthopyroxene and traces of garnet (which originally formed rare megacrysts up to 1 cm in diameter) survive in places.

Pwm consists of dark to medium-grey, crystal-rich rhyolitic ignimbrite which ranges from lithics-rich to lithics-poor, overlying a very coarse greenish to purplish-grey volcanogenic rudite (or breccia). The rudite consists of subangular to angular blocks of dark-grey, aphanitic, commonly vesicular andesite (predominant) and flow-banded, sparsely porphyritic rhyolite up to a metre long set in a greenish to purplish sandy-textured, crystal-rich matrix; it may be a proximal ground-lag deposit. Overlying the rudite is a massive ignimbrite sequence, which ranges between 30 and 80 m thick (as preserved), consisting of the following components.

(1) Massive, unwelded, lithics-rich ignimbrite, with clasts of rhyolite, rhyolite breccia and and andesite up to 30 cm long and pumice clasts up to 20 x 2 cm at the base. Size and abundance of both lithic and pumice clasts decrease gradually and regularly upward over about 20-25 m to a relatively fine and lithics-poor (1-2% clasts ≤2-3 cm) flow-unit top.

(2) A second lithics-rich horizon (lithics-concentration zone) containing angular clasts, mainly of rhyolite, up to 60 cm long, and overlain by:

(3) Moderately lithics-rich ignimbrite containing rhyolite clasts up to 2-3 cm long;

(4) Lithics-rich ignimbrite containing angular rhyolite clasts up to 7-8 cm long;

(5) Lithics-poor ignimbrite containing 1-2% angular clasts of sparsely porphyritic rhyolite.

As in Pwk, moderate to intense propylitic alteration (to chlorite + sericite + calcite ± hematite) has destroyed most non-felsic minerals, but traces of orthopyroxene and, in the uppermost part of the sequence, garnet, remain.

Thickness. The remaining thickness of Rackarock Rhyolite is at least 80 m, and probably between 130 and 200 m; an unknown thickness has been eroded from the top of the unit.

Eruptive source. The thin, vertically and laterally variable (in terms of lithic and pumice clast size and abundance) nature of the flow sheets, the general abundance and size of lithic clasts, the presence of very coarse, very lithic-rich horizons, and the generally low intensity of welding suggest low-volume eruptions from a local source. The vent may be at or near the northern (faulted) margin of the unit.

Relationships. Rackarock Rhyolite paraconformably overlies Ticklehim Rhyolite, and is intruded by Yokas Microgranite and by a related microgranite dyke.

Structure. Rackarock Rhyolite is folded into a "boat-shaped" syncline, with dips of about 20-25° on the northern limb, 15° on the southern limb, and about 5° at the western end. It is cut by two faults, one of which is a major fracture that appears to be an extension of the Upper Doolan Fault Zone.

Topography. Compared to the surrounding terrain (underlain by Ticklehim Rhyolite and Yokas Microgranite to the south, Nightflower Dacite to the east, and Hodgkinson Formation and Nychum Volcanics to the north), Rackarock Rhyolite has greater (moderate rather than low) relief, sparse vegetation cover, and pale to very pale tones on airphotographs; density of tree cover conspicuously greater in gullies and on steeper slopes (*e.g.* on unwelded ignimbrite). Outcrop is extensive, mainly in the form of large rock pavements and bluffs; these are particularly well developed on Pwk and Pwm.

Age. Rackarock Rhyolite is younger than Ticklehim Rhyolite, which has been dated at 278 ± 3 Ma, but indistinguishable (by Rb-Sr isotopic means) in age from it because it is also older than Yokas Microgranite and the microgranite ring dyke which are probably equivalent in age to Bustlem (280 ± 4 Ma) and Lags Microgranites (280 ± 2 Ma).

Synonymy. Branch (1966) and de Keyser & Lucas (1968) included Rackarock Rhyolite in undivided "Featherbed Volcanics".

PRATT VOLCANICS

The Pratt Volcanics are not part of the Featherbed Volcanic Group; they were regarded as correlatives of the Nychum Volcanics by Morgan (1961; 1964; 1974), Best (1962), Amos & de Keyser (1964) and de Keyser & Lucas (1968), but were recognised as being distinctly different in character to the volcanics in the "Nychum" homestead region, and were assigned to a new rock unit, by Bultitude & Domagala (1988).

According to Bultitude & Domagala (1988), the Pratt Volcanics consist of massive, welded, crystal-rich rhyolitic ignimbrite, minor dacite lava, and rare rhyolite lava, rhyolitic airfall tuff, and andesite lava. The eruptive sequence overlies a thin (few metres) layer of quartzose sandstone and conglomerate containing rounded cobbles and pebbles derived from either the Hodgkinson and Chillagoe Formations, or from felsic volcanic rocks.

The Pratt Volcanics occupy a basin-like subsidence structure, comparable in style to the Boonmoo Cauldron, with inward dips of between 25° and 40° around most of its periphery. Dips steepen to about 75° adjacent to the Palmerville Fault, which cuts the volcanics. The sequence has a total thickness of no more than 250 m (Bultitude & Domagala, 1988).

Bultitude & Domagala (1988) argue that the Pratt Volcanics are of I-type character, based on their oxidised compositions and the common presence of hornblende. They more closely resemble some of the Late Carboniferous rocks of the Featherbed Volcanic Group than either the Nychum Volcanics or the Early Permian rocks of the Featherbed Volcanic Group, and are intruded by the Almac Granodiorite (Bultitude & Domagala, 1988), which is similar to the Late Carboniferous Ruddygore and Almaden Granodiorites. A Late Carboniferous age is therefore likely, but the presence of clasts of felsic volcanic rocks in parts of the basal sedimentary layer indicates that the Pratt Volcanics probably postdate at least some of the other Late Carboniferous volcanic rocks of the region.

NYCHUM VOLANICS

The Nychum Volcanics have been studied by Morgan (1961; 1964; 1974), who named the unit, and by Bailey & others (1982), who addressed their chemical composition and petrogenesis. More recently, the volcanic stratigraphy was mapped and described in detail by Bultiude & Domagala (1988). They described a sequence of thin lava flows, mainly of rhyolitic composition, but including relatively minor volumes of basalt, andesite, and dacite, less voluminous rhyolitic ignimbrites, and minor airfall pyroclastic deposits mainly of rhyolitic composition. Maximum thickness of the sequence is about 150 m (Morgan, 1974). The eruptive rocks are intruded or accompanied by a small number of plugs of andesite and dacite, and cut by numerous dykes of rhyolite.

Isotopic and plant-fossil dating indicate an Éarly to Middle Permian age (*ca.* 270 Ma) for the Nychum Volcanics (Black & others, 1972; Bailey & others, 1982). There is some evidence, however, that at least some of the rocks are older than this. Clasts of andesitic to basaltic composition resembling lithologies present in the Nychum Volcanics are common in the Rackarock Rhyolite, and are also found in other units of the Wakara sequence (Pwf, Pwg?). This suggests that the Nychum Volcanics, or, at least, the mafic lowermost components, predate some of the Wakara Volcanic Subgroup. The ring fault-dyke system that bounds the Wakara Caldera, and which may be inferred to be about 280 Ma old, also clearly truncates the Nychum Volcanics. It is therefore likely that the Nychum Volcanics - or at least those rocks closest to the Wakara Caldera, and the more mafic rocks in particular - overlap in age the youngest rocks of the Featherbed Volcanic Group.

However, the Nychum Volcanics differ in several important respects from the Featherbed Volcanic Group. In contrast with the Featherbed Volcanic Group, there is no evidence of subsidence structure(s) (although there is some evidence to suggest that [some of] the numerous dykes cutting the volcanics may occupy eruptive vents, at least in the case of the rhyolites), and the Nychum sequence is very thin relative to the Featherbed sequence but laterally very extensive. Lavas are much more volumetrically important relative to the pyroclastic rocks than in the Featherbed Volcanic Group, the rhyolitic lavas are much more laterally extensive than those in the Featherbed Volcanic Group (especially relative to their thickness), and glassy lavas are common: these features indicate high eruption temperatures, relatively low viscosities, and low volatile (particularly water) contents. As discussed in a later section, there are also significant differences between the Featherbed Volcanic Group and the Nychum Volcanics in chemical composition and probable nature of the source rocks.

CAINOZOIC

TERTIARY

Unnamed Basalt (Tb)

Two plugs of picritic olivine basalt, which are probably Tertiary in age (30-40 Ma?), intrude the Tennyson Volcanic Subgroup adjacent to the southeasterm margin of the Featherbed Caldera (Fig. 1). The more northerly of the two, about 8 km northwest of Petford, is elliptical in plan, and about 300 m long and 150 m wide. The other, about 10 km west-northwest of Petford, is "dumb-bell"-shaped, about 500 m long, and up to 250 m wide. In both plugs, the basalt is sparsely porphyritic, with scattered phenocrysts up to 5-7 mm across of olivine and calcic plagioclase. Small (100-200 m in diameter) plugs of similar basalt intrude granites on the southwestern margin of the Tennyson Ring Dyke, about 5 km southwest of Koorboora (Fig. 1). An elliptical, plug-like body, about 450 m long and 250 m wide, intruding Ruddygore Granodiorite about 7 km north-northeast of Chillagoe also comprises picritic olivine basalt, and is also probably Tertiary in age.

Unnamed Ferruginised Talus (Czt)

Deposits on the northern slopes of Reynolds Blue Mountain comprise angular clasts of ignimbrite and granite ranging from a few millimetres to 50 cm across set in a ferruginous (hematite?-rich) cement. This material was probably formed as a result of debris avalanches or mudslides.

Unnamed Ferruginised Valley Fill and Ferricrete (Td)

Deposits mapped as Td (*e.g.*, 7 km northwest of Dimbulah; Solanum area) are mostly immature to highly immature fluviatile sediments, including fanglomerates and slope wash, and talus, cemented and lithified by hematite-rich material. Finer-grained, highly ferruginised and/or ferruginous-cemented regolith material, or ferricrete, and nodular/pisolitic ferricrete were observed in only a few, very restricted areas in the areas near Dimbulah mentioned above.

TERTIARY TO QUATERNARY

Unnamed Alluvium and Talus (Valley Fill) (TQr)

TQr comprises essentially partially lithified/cemented alluvium (both coarser channel material and finer overbank deposits), fanglomerate, minor talus, and rare soil. It reaches several tens of metres in thickness in the Dimbulah area, where it has acted as valley fill, "drowning" the pre-existing, originally more rugged, topography. The cement in these deposits is a variable mixture of clay(s) and ferruginous (mainly limonite/goethite?) material. Their cohesiveness is such that erosion by the present drainage system has formed very steep-sided gullies and ravines up to 15 m deep. It is distinguished on airphotos from TQa by its slightly greater elevation and relief/degree of dissection, and in generally being more distal from present drainage channels.

Unnamed Alluvium (TQa)

TQa comprises variably (partially) lithified/indurated channel alluvium, including sand, gravel, and silt, some overbank or floodplain alluvium (mainly silt and sand), and minor soil. Along the Walsh River within the Featherbed Caldera (Featherbed Range), it also includes extensive coarse (cobble to boulder) fanglomerates shed from the walls of the gorge. TQa is slightly to moderately dissected in places, mainly near larger present drainage channels, and in general probably postdates most TQr.

Unnamed Alluvium, Residual Material, and Soil (TQs)

TQs includes undivided TQr and TQa, as well as extensive areas of residual sand (*e.g.*, areas around Dimbulah and southeast of Chillagoe), gravel (over volcanics), and soil.

QUATERNARY

Overbank Alluvium (Qa)

Qa comprises overbank and floodplain alluvium (sand, silt, rare gravel) deposited by the present drainage system, together with modern soils developed on them; there is little or no evidence of lithification. While there is abundant evidence of these deposits being augmented (thickened) periodically, and, in places, there is also some erosion, they are relatively static in comparison to Qha (below).

Active Channel Alluvium (Qha)

Sand, gravel, silt and mud within channels of the present drainage system are designated Qha: in general, these materials are transitory or ephemeral in terms of the geological time scale. Pebble to boulder gravels are concentrated within the areas of volcanic rocks, particularly in the Featherbed, Djungan and Wakara Calderas: quartz-rich sands predominate in areas of granite, and pebble gravels and lithic clast-rich sands predominate in areas of Chillagoe and Hodgkinson Formations.

SPRINGS IN AND NEAR THE FEATHERBED CAULDRON

There are several areas in the western part of the Featherbed Cauldron where active spring activity is evident. The best known are in the Fisherman Waterhole area, and on lower Hot Springs Creek, but there are also several springs on Doolan Creek, just within the Wakara Caldera, and in the outcrop area of Ruddygore Granodiorite, between the Walsh River and Doolan Creek.

There are two springs in the Fisherman Waterhole area. The more northerly is located on a small travertine mound at the northern end of a 100 x 150 m pond at GR7863-465128. It was emitting (in July 1983) warm (about 30°C), clear water at the rate of a few litres per second; deposits of white, powdery material around the vent gave scintillometer total count readings of up to 1800 cps. The other spring is located near the centre of a low, broad (80 m diameter), travertine mound at GR7863-469122. It was emitting clear, cold, water at a few litres per minute, and depositing pale greenish-blue (520 cps) and white (no response from scintillometer) encrustations around a 1 m-diameter pool. Both springs produced occasional gas bubbles (mainly $SO_2 \pm H_2S$); hand-held total-count scintillometer readings taken over the more northerly vent were mostly off-scale, presumably due to the presence of radon. Flow rates of both springs are commonly higher, judging from the relative positions of recent deposits and water levels at that time (a particularly dry season).

One spring in lower Hot Springs Creek (GR7863-548120) was examined: it was emitting slightly turbid, highly gas-charged ($H_2S \pm SO_2$) water with a temperature estimated at about 60°C, but there was little evidence of active deposition at the surface.

One large, composite spring and two smaller springs were observed in Doolan Creek. The largest, at GR7864-368198, is marked by an area of sinter and/or travertine terraces about 90 m long, up to 40 m wide, and up to 2 m high on the western bank of the creek. In July 1983 cool to cold, clear water with abundant gas bubbles (mainly $H_2S \pm SO_2$) was being emitted from numerous vents on the terraces, and both in the creek and on the opposite bank to the east and southeast. Other, much smaller springs are located at GR7864-36901965 and -369207. Flow rates are generally low (a few litres per minute), but there is active deposition of sinter and/or travertine, ranging in colour from off-white to brown, at all vents.

Evidence of spring activity was observed on airphotographs, and from the air during helicopter-supported work, at several localities to the west of the Featherbed Cauldron; the clearest evidence was at a site west of Election Mountain (GR7863-40351205), where a sinter/travertine mound, about 25 m in diameter, with an apical vent was evident; three smaller probable springs are present in the same general area (GR7863-403123, -39901245, and -398126).

EVOLUTION OF THE FEATHERBED CAULDRON

Tectonomagmatic activity in the Featherbed Cauldron complex took place in six main stages, over a period of about 30 Ma. The results of these stages - six overlapping subsidence structures and associated volcanic fields - are illustrated in Figure 6 and Table 3.

Table 3. Tectonomagmatic stages of the Featherbed Cauldron Complex.

STAGE	STRUCTURE	LOCATION	AGE
1	southern Boonmoo Sag	extreme southeast	ca 311 Ma
2	main Boonmoo Sag	far southeast	306-308 Ma
3	Eight Mile Cauldron;	southeast;	ca 300 Ma
	Jamtin Rhyolite,	southwest	
	Redcap Dacite;	west	
	Wolfram Cauldron?	east	(Pratt Volcanics?)
4	Mulligan Caldera	northeast	290-300 Ma?
5	Featherbed Caldera	south-central	290 Ma
	(Nychum Volcanics?)		
6	Djungan Caldera	north	280 Ma
7	Wakara Caldera	northwest	280 Ma

Stage 1 began with small to medium-volume ash-flow eruption in the southern(?) Boonmoo Sag (Boonmoo Cauldron), the southeasternmost part of the composite Featherbed Cauldron. The oldest known rocks (*ca* 311 Ma) of the Featherbed Volcanic Group are in the southeast of the Boonmoo Sag, extending along its southern margin. While these ignimbrites are not proximal facies, they were probably erupted within the Sag: they share petrological and geochemical characteristics with other units of the Boonmoo Cauldron, and crop out nowhere else.

Isotopic age data and field observations indicate that **Stage 2** of eruptive activity was divided between the Boonmoo Sag (Bluewater Rhyolite [306±3 Ma] and, probably, Eureka Rhyolite) and the Nightflower area (Nightflower Dacite [308±4 Ma]) 80 km to the northwest, in the north of the Featherbed Cauldron. No isotopic age data are available for the Doolan Creek Rhyolite, but it bears close petrological and geochemical similarities to some rocks of the Nightflower Dacite, and may therefore be coeval and/or genetically related.

The Boonmoo Sag is a basin-shaped structure, without any well-defined or persistent ring fault(s) evident at, near, or circumscribing its margins (Figure 2). However, the Emuford Fault, which appears to have a predominantly north-side-down movement sense, may be part of an "outboard" ring-fault system. Similarly, the smooth, curved boundary between Atlanta Granite and Hodgkinson Formation on the northeastern side of the Sag may represent a partial ring fault, although there is no evidence of faulting preserved. It is therefore possible that the Boonmoo Sag is the sagged (inner) floor of a deeply-eroded, partly fault-bounded, cauldron about 30 km in diameter; it is also possible that this cauldron was trapdoor-like, with a hinge on its east-southeastern side (Figure 2).

The tectonomagmatic setting of the Nightflower Dacite is uncertain. It appears, judging from its lithic clast content and presence of proximal, lithic clast-rich facies, to have a local source, and its northern margin has the characteristics of a ring fault/dyke system. However, the size and configuration of the (probable) caldera are unknown: it probably extended southward over several tens of square kilometres before being overprinted by the Djungan and Wakara Calderas.

The Doolan Creek Rhyolite and associated intrusive rocks occupy a possible cauldron subsidence structure (Doolan Creek Cauldron; Fig.), and, as discussed above, petrological and geochemical similarities with the Nightflower Dacite suggest that it may have been erupted at about the same time. It is also possible that some rocks in the Doolan Creek Cauldron were erupted from the Nightflower area, and *vice versa*.

Stage 3, to this point by far most voluminous and extensive, stage in the tectonomagmatic evolution of the Featherbed Cauldron took place about 300 Ma ago, when several eruptive sequences, widely distributed over the southern two-thirds of the region, were emplaced. These are the Eight Mile Cauldron sequence, the "Wallaroo" rhyolite, Beapeo Rhyolite, Jamtin Rhyolite, Redcap Dacite and Doolan Creek Rhyolite, the Tennyson Caldera sequence, and probably the Boxwood Volcanics (Figures 6,1).

The **Eight Mile Cauldron** is bounded by a ring fault (Blue Mountain Fault) in the east and southeast, where it clearly overprints the Boonmoo Sag. However, its western side is cut by a number of later faults, and truncated by the Featherbed Caldera; its northern margin has been engulfed by the Atlanta and James Creek Granites; and its southern margin engulfed by the Petford Granite. Nevertheless it is likely, considering the distribution and thickness of constituent units, that the Eight Mile Cauldron was in fact a caldera, about 17-20 km in diameter.

The **Jamtin Rhyolite**, on the western side of the Featherbed Caldera, is probably a relict part of outflow sheets comprising equivalents of units in the Boonmoo Volcanic Subgroup (Eight Mile Cauldron). The more mafic constituents of the Jamtin Rhyolite (Cjd, $Cjr_{3,4}$) are petrographically and chemically similar to Adder Dacite and Muirson Rhyolite, and the most felsic component (Cjr_1) is petrographically similar to, and chemically indistinguishable from, Rock Hole Rhyolite. The isotopic age of the Jamtin Rhyolite is indistinguishable from that deduced for the Eight Mile sequence, although the former may have been reset by intrusion of the Almaden Granodiorite (302 ± 5 Ma).

Similarly, the **Redcap Dacite**, which occupies a triangular-shaped, steeply tilted outlier northwest of Chillagoe (14 km west of the margin of the Featherbed Caldera and 9 km south of the Wakara Caldera), may comprise outflow equivalents of the Muirson Rhyolite, Hopscotch Rhyolite, Adder

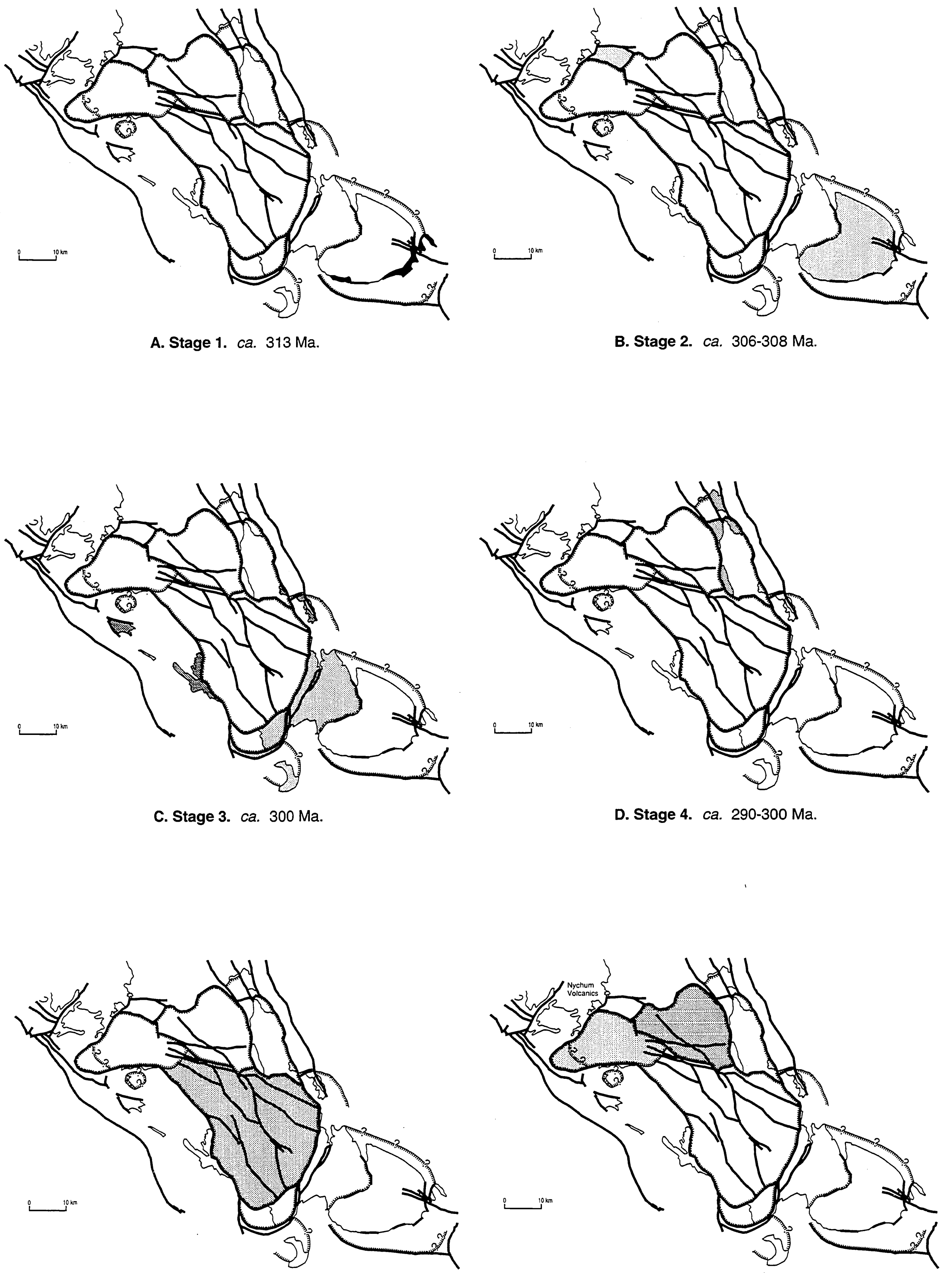

Figure 9. Evolution of the Featherbed cauldron complex.

Dacite and Verdure Andesite. Crv_1 and Crv_2 bear strong petrological and geochemical similarities to the Muirson Rhyolite and Hopscotch Rhyolite, Crv_3 is similar to Adder Dacite, and Crv_4 is similar to Verdure Andesite. Redcap Dacite has not been dated isotopically, but, like the Jamtin Rhyolite, it is intruded by Ruddygore Granodiorite and Belgravia Granodiorite, which are probably the same age as the Almaden Granodiorite.

The **Pratt Volcanics**, to the west of the Palmerville Fault, have been preserved in a separate, basin-shaped depression (Bultitude & Domagala, 1988) which, by analogy with the Boonmoo, Doolan Creek, and Nightflower structures, probably formed in the Late Carboniferous (between 308 and 300 Ma).

Black (1978) considered the Tennyson ring dyke to be about 300 Ma old. This is in accord with known geological relationships, and with dating of the Rock Hole Rhyolite in the adjacent Eight Mile Cauldron (304 4 Ma: L.P.Black, pers. comm., 1990). Therfore, it is probable that the Tennyson Caldera also formed during Stage 3.

As argued above (page 42), it is probable that the Boxwood Volcanics ara also about 300 Ma old, and it is therefore likely that the Boxwood Cauldron also formed during Stage 3.

The outliers of **Beapeo Rhyolite** and **Wallaroo rhyolite**, to the northwest of the Boonmoo Cauldron, are spatially associated with an elliptical structure - the Wolfram Cauldron (Figure 2). The northern and eastern margins of the Cauldron are defined by the outer contacts of the Worcester Granite; it is truncated in the west by the Featherbed Caldera and cut in the south by the Atlanta and James Creek Granites. The outliers may have a local source, but there is no evidence of proximal facies, and there are sufficient petrological and geochemical similarities between these rocks and units of the Eight Mile sequence (Beapeo Rhyolite *cf* Muirson Rhyolite/Hopscotch Rhyolite and Adder Dacite; Wallaroo rhyolite *cf* Rock Hole Rhyolite) to suggest that the outliers are outflow from the Eight Mile Cauldron. It is also possible that the Wolfram Cauldron is part of an irregularly-shaped or composite Eight Mile Cauldron.

Stage 4. The timing of the formation of the Mulligan Caldera relative to the Late Carboniferous calderas/cauldrons discussed above is uncertain; no isotopic dating has been carried out Timber Top Volcanic Subgroup. However, the A-type geochemical signature of both the intrusive and extrusive rocks, and the structural relationships with the Djungan and Featherbed Calderas indicate an Early Permian or possibly latest Carboniferous age. Its formation certainly marks a dramatic switch from I-type to A-type magmatism, and a more subtle change in volcanotectonic style. The change in style is from basin-like sag structures with variably, generally poorly, defined peripheral ring faults, or lacking ring faults, to clearly defined, apparently vertical-walled, "classical" calderas with continuous ring fractures and (semi)continuous ring dykes.

Stage 5 in the evolution of the Featherbed Cauldron Complex was the development of its most impressive and important feature, in terms of both physiographic and volcanological dimensions - the Featherbed Caldera. This caldera covers an area of about 1100 km^2, and probably contains a minimum of 1000-1500 cubic kilometres of eruptive rocks. As described above, its southern portion has a partial sub-circular outline, as in a classic caldera; this merges to the north-northwest with a graben-like structure. Together, the two appear to comprise a trapdoor-style collapse structure, with maximum subsidence at its south-southeastern end. The Featherbed Caldera cuts across all adjacent volcano-tectonic subsidence structures (Boonmoo Sag/Eight Mile Cauldron, Tennyson Caldera, Wolfram Cauldron), and across the Jamtin Rhyolite outlier. Rb-Sr isotopic age of the Featherbed Caldera (average of three samples) is 289 $\pm$6 Ma.

Apart from the change in volcano-tectonic style, the advent of the Featherbed Caldera (and possibly the Mulligan Caldera) marked a profound change in the types and volumes of eruptive rocks. Rather than the relatively low-volume eruptions of highly varied (basalt/andesite to rhyolite) that characterise the Late Carboniferous, the Early Permian saw large-volume, high-temperature (as evidenced by the abundance of rheoignimbrites and vitrophyres) eruptions with a very restricted compositional range. It also saw the production of very large-volume, crystal-rich ignimbrites - the result of late, paroxysmal eruptions - that characterise many other caldera-related volcanic sequences (*e.g.*, Lipman, 1984), but appear to be poorly developed or lacking in the Late Carboniferous of the Featherbed Volcanic Group.

Stage 6 was the development of the Djungan and Wakara Calderas, in the north of the Featherbed Cauldron. Rocks from each caldera have been dated isotopically at 280 Ma, but field relationships indicate that the Djungan Caldera formed first, closely followed and partly overlapped by the Wakara Caldera. The Djungan Caldera has truncated the Mulligan Caldera and the Nightflower Dacite as well as the Featherbed Caldera; the peripheral ring dyke(s) and faults of the Wakara Caldera cut the Featherbed Caldera, Doolan Creek Cauldron, Nightflower Dacite, and Nychum Volcanics. As discussed earlier, both the Djungan Caldera and the Wakara Caldera appear to have collapsed asymmetrically, with hinge zones in the south and southwest, respectively, and maximum subsidence in the northwest and north.

The Wakara Caldera developed in at least two stages. Eruptive activity and maximum subsidence appear to have been focussed initially in the western end of the structure. Ash flows erupted from this area moved mainly eastward, towards the northern end of the Featherbed Caldera, which was apparently still a topographic depression at that time. Eruptive activity later switched to the northwestern side of the Wakara Caldera, where subsidence beneath the present outcrop area of Rackarock Rhyolite may have been as much as the total thickness of the remaining Wakara sequence in that area (up to 2500 m). Distribution patterns of the units between Pwf and Ticklehim Rhyolite (Pwi) on airphotographs and enhanced Landsat TM images (bands 5, 6, and 7) suggest that this episode of subsidence has affected a crudely circular area about 15 km in diameter (Fig. 6F).

The place of the **Nychum Volcanics** in the proposed evolutionary scheme is uncertain: The only dating presently available (Black & others, 1972; Bailey & others, 1982) suggests an Early to Middle Permian age, apparently younger than the Wakara Volcanic Subgroup.

As mentioned above (REGIONAL GEOLOGICAL AND STRUCTURAL SETTING), there is evidence that the tectonics of the western margin of the Hodgkinson Basin has played a major role in the development of the Featherbed cauldron complex.

This evidence may be summarised as follows:

(1) Part of the western margin of the Featherbed Caldera is straight, and subparallel to the Palmerville Fault;

(2) The Retina Fault, which extends many kilometres north of the Featherbed cauldron complex (Halfpenny & others, 1987), forms part of the eastern margins of the Djungan and Featherbed Calderas;

(3) The Featherbed cauldron complex is located adjacent to an inflexion in the Palmerville Fault at a postion consistent the presence with strain-release structures;

(4) The cauldron complex has an overall lozenge, or "Z"-shaped geometry, reminiscent of the shape of a tension gash;

(5) The oldest rocks of the Featherbed Volcanic Group are in the extreme southeast (Bedlog and Orient Rhyolites. Ages of the remaining rocks decrease northwestward (noting that the Jamtin Rhyolite and Redcap Dacite, which appear to be anomalous, are probably outflow remnants derived from the Eight Mile Cauldron).

These lines of evidence suggest that the Featherbed cauldron complex may have evolved in response to stress related to movement on the Palmerville and associated fault systems, perhaps in a manner akin to opening of a tension gash. This proposition will be examined further in a subsequent publication.

GEOCHEMISTRY

Details of the geochemistry and petrogenesis of the Featherbed Volcanic Group and associated rocks will be presented in a separate report. In summary, the Late Carboniferous rocks (Boonmoo Volcanic Subgroup, Tennyson Volcanic Subgroup, Beapeo Rhyolite, Wallaroo rhyolite, Jamtin Rhyolite, Redcap Dacite, Doolan Creek Rhyolite, and Nightflower Dacite) are of I-type character, characterised by relatively high Na/K and Fe^{3+}/Fe^{2+} ratios, high siderophile and transition element contents, and relatively low contents of Ba, Ga, "incompatible" elements, and large, highly-charged cations (e.g. Zr). They commonly contain minerals such as hornblende, magnetite and titanite.

The I-type rocks may be divided into four geochemical groups:

(1) the southern and eastern Boonmoo Cauldron (Bedlog, Orient, Bluewater, and Eureka Rhyolite);

(2) the Nightflower Dacite and Doolan Creek Rhyolite;

(3) the Eight Mile Cauldron sequence, Jamtin Rhyolite, Beapeo Rhyolite, Wallaroo rhyolite, and Redcap Dacite; and

(4) the Tennyson Volcanic Subgroup.

Each group shows clearly defined curvilinear trends on Harker plots, indicating fractional crystallisation, and it is apparent that this mechanism is the principal cause of geochemical variation in each suite.

In contrast, the Early Permian rocks of the Featherbed (Yongala Volcanic Subgroup), Djungan, Wakara, and Timber Top calderas are of A-type character, with high $Al_2O_3/(Ca+Na+K)$ (most rocks are mildly peraluminous), high K_2O, K/Na, Ba, Zr, Nb, Ga, and, in particular, Zr contents relative to the I-types. They lack hornblende and titanite, but contain abundant allanite, and commonly contain pyroxene (mainly ortho-, but also clinopyroxene) and small amounts of garnet.

The A-types form a strongly cohesive geochemical group, although there is some suggestion that the Timber Top Volcanic Subgroup may differ slightly from the others. All form tight, linear trends on Harker plots and most other variation diagrams, which, along with the mineralogical evidence of restite components, is strong evidence of restite-controlled differentiation.

MINERALISATION

Surrounding the Featherbed cauldron complex is one of the most intensely mineralised regions of northeastern Queensland (Fig. 2): it is flanked, and partly overlapped, to the southeast and south by the extensive Herberton-Emuford tinfield, and to the west by the Chillagoe-Calcifer-Fluorspar base metal-gold-fluorite province, and flanked to the east by the Hodgkinson goldfield (*e.g.*, de Keyser & Wolff, 1964; Blake, 1972; Pollard & Taylor, 1983; Black & others, 1978; Johnston & Black, 1986). It is also overprinted by the Wolfram Camp-Eight Mile-Bamford Hill-Sunnymount belt of W, Mo, and Sn mineralisation (de Keyser & Wolff, 1964; Plimer, 1974; Blevin, 1990). In addition, there is minor base-metal mineralisation in the Reynolds Blue Mountain and lower Eureka Creek areas, minor uranium mineralisation at Pinchgut Pinnacle and in the Fisherman Waterhole area, and base-metal-W mineralisation in the Nightflower mine area.

It is not proposed to describe or discuss individual deposits or occurrences in detail here: such information may be obtained from the BRS/AGSO MINLOC and MINDEP databases, the MINOCC database operated by the Queensland Department of Minerals and Energy, and numerous publications and open-file exploration company reports dealing with the area. Distribution of the major mines (most now closed) is shown on the map (Figure 1: Mackenzie & others, 1993); a complete listing of mineral occurrences, including mines, for the map area is available in digital form.

Ewers & others (in press) present oxygen-isotope data for the Featherbed Volcanic Group, and show that, while there is an area of ^{18}O depletion coinciding approximately with the Wolfram Camp-Eight Mile-Bamford belt of mineralisation, most of the cauldron complex has normal igneous oxygen-isotope signatures. A comprehensive report dealing with the relationships of mineralisation to alteration types, structure, and pattern of oxygen isotope depletion is planned.

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GEOLOGY OF THE FEATHERBED CAULDRON COMPLEX
QUEENSLAND

Geology 1973–1974 by A.D. Lawrence, LaTrobe University (Boonmoo Cauldron); T.H. Reddicliffe, University of Queensland (western Tennyson Ring Dyke)
Detailed geology and complete revision of earlier work
1981–1987 by D.E. Mackenzie, AGSO
1982–1986 by R.J. Bultitude, GSQ
1982–1983 by P.J.T. Donchak, GSQ
1983 by L.J. Hutton, GSQ
1984–1985 by R.W. Halfpenny, GSQ
1985–1986 by I.P. Rienks, GSQ
1986 by S.R. Law, GSQ
1986–1987 by B.S. Oversby, AGSO

Compiled 1985–1987 by D.E. Mackenzie, AGSO
(based on numerous traverses and airphoto interpretation)

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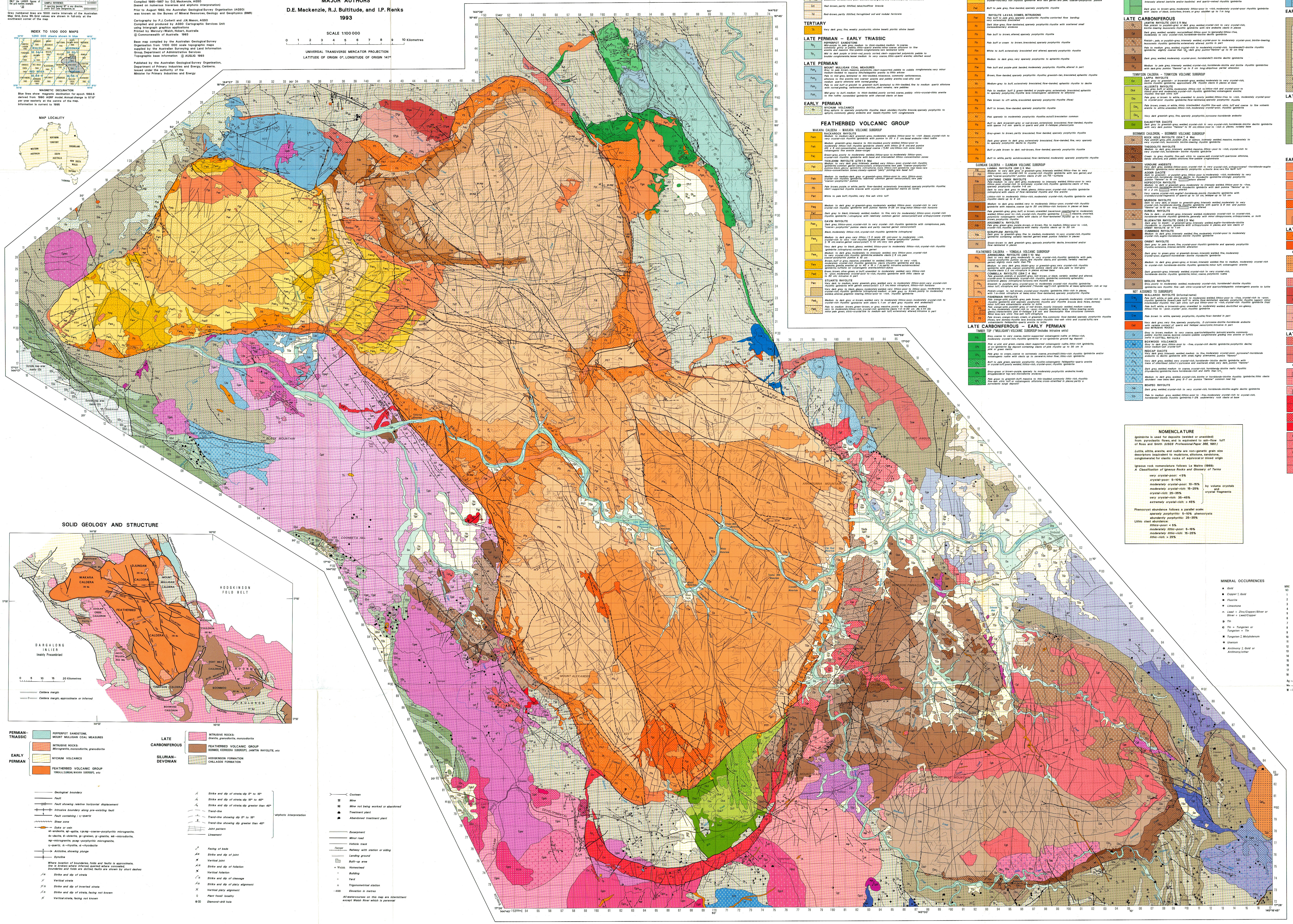
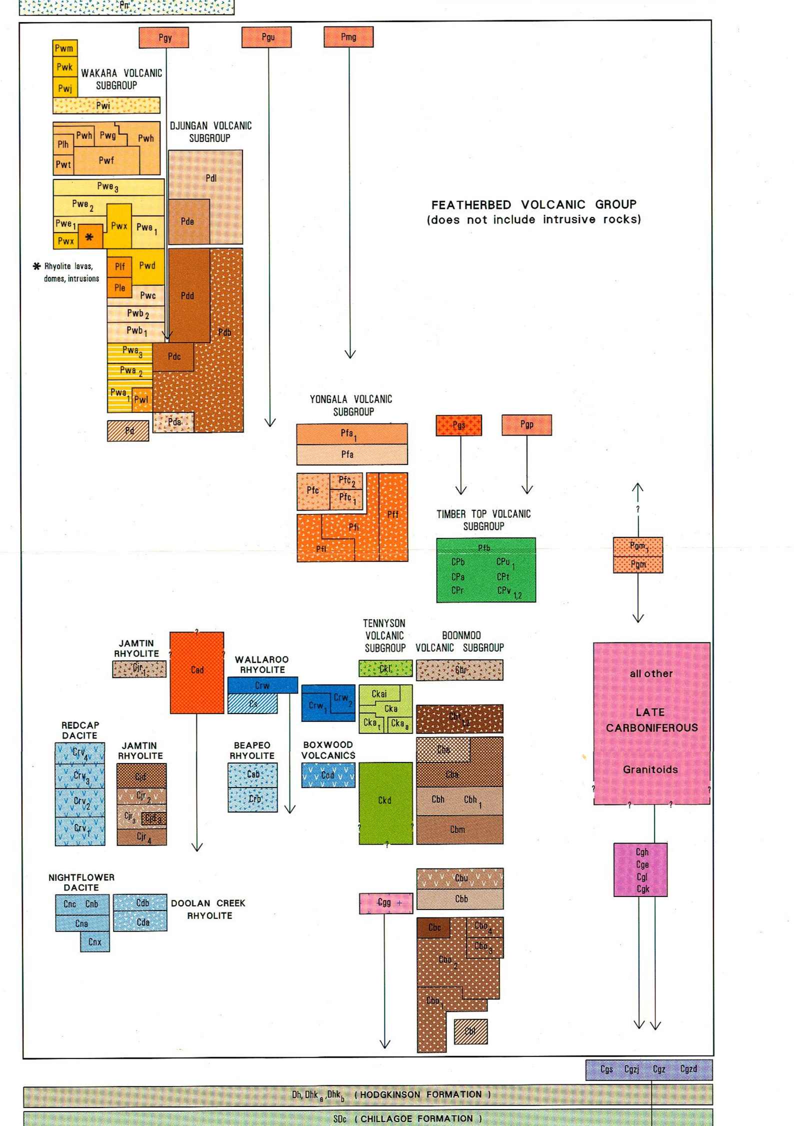
1993

SCALE 1:100 000

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
LATITUDE OF ORIGIN 0°, LONGITUDE OF ORIGIN 147°



SOLID GEOLOGY AND STRUCTURE



DIGITAL DATA

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It is recommended that this map be referred to as:
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