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BY

B. OVERSBY & D. MCKENZIE

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Geology of Late Palaeozoic Ignimbrites and Associated Rocks in the Georgetown Region, northeastern Queensland

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ABSTRACT

During mid-Carboniferous time, previously cratonised crust in the Georgetown region was subjected to intense calc-alkaline magmatism. This activity is recorded mainly in widespread granitoid bodies of up to batholithic dimensions, and in comagmatic extrusive sequences, dominated by silicic ignimbrites and preserved in volcanic and volcano-tectonic cauldron structures. The silicic magmatism was preceded by accumulation of clastic sedimentary rocks during latest Devonian and Early Carboniferous time; it was succeeded in the latest Carboniferous to Early Permian by less intense mixed silicic and intermediate magmatism.

Meridional trends and elongation of Carboniferous cauldrons probably reflects an approximately east–west-oriented regional minimum principal stress. Roughly northwest-trending Carboniferous (and Permian) features may represent accommodation structures. Spacings of structures, extrusive remnants, and intrusive bodies suggest a late Palaeozoic crustal thickness of about 35 to 40 km, essentially the same as at present.

Stratigraphies of the main extrusive remnants indicate that cauldron structures, even those containing voluminous ignimbrites, never underwent wholesale catastrophic collapse. Surficial caldera forms were mostly subdued and basinal; some sequences might even have formed temporary constructional domes. Structural resurgence can be postulated tentatively in very few instances. Cauldron structures, with concentric (ring-) and other fracture/instrusion systems of increasing intricacy are postulated to form a continuum in space and time, reflecting initiation and modification in an aureole of complex regional extensional and local intrusive-extrusive strain interactions ahead of ascending magma chambers. Probably no cauldron was manifested at the palaeosurface until its associated magma chamber had reached an appropriately high crustal level.

Data presented in this report do not permit the tectonic setting of the Georgetown region during late Palaeozoic time to be evaluated rigorously. Neither the extensional stress regime inferred here nor the geochemical signatures of the magmatic products provide unequivocal evidence for or against a direct relationship between magmatism and subduction.

Introduction

Location and Setting

Geographically, the Georgetown region lies in the Cairns hinterland (Fig. 1), Georgetown itself being 411 km by road southwest of Cairns. For the purpose of this report, the region's extent is that represented by the Georgetown region 1:250 000-scale Geological Special map (hereafter "the map") of Bain & others (1985). Geologically, the region represented on the map covers the central Georgetown Inlier of previous workers. Ideally, the map should be consulted in conjunction with this text; the same rock unit codes are used.

During late Palaeozoic (mainly Carboniferous and Permian) time, the then cratonic Georgetown region, in common with much of the rest of northeastern Queensland, was the site of intense post tectonic or "transitional" (Geological Society of Australia, 1971; Rickard & Scheibner, 1975) igneous activity. This activity succeeded the climax of a compressional orogeny in the Hodgkinson sector of the Tasman mobile belt to the east; it was immediately preceded by accumulation of latest Devonian to earliest Carboniferous molasse like fluviatile sediments in the region. The intrusive and extrusive manifestations of late Palaeozoic activity in northeastern Queensland define the Coastal Ranges Igneous Province of Stephenson & Griffin (1976) which, in the extended sense of Henderson (1980), is equivalent to the "North Queensland volcanic and plutonic province" of Day & others (1983)*. Irrespective of the name used, the province is distinctive in that it overprints a large number of older tectonic entities over a very extensive area while retaining a high degree of uniformity in its basic characteristics. Molasse sediments that underlie considerable areas of the Late Carboniferous–Early Permian extrusive rocks may have been deposited as a result of the first stages of igneous activity, and therefore are included in this discussion.

Late Palaeozoic igneous activity in the Georgetown region took place in two main pulses, during about mid to late Carboniferous and early to mid Permian times, which were probably separated by an episode of widespread uplift and erosion. There are, thus, one non-volcanic and two volcanic tectonostratigraphic units (tectosomes) represented in the late Palaeozoic of the region.

Carboniferous igneous activity in the Georgetown region was characterised by the eruption of voluminous subaerial ignimbrites (ashflow tuffs) and intrusion of granitoids (granites and granodiorites). During Permian times, extrusive products were mixed, and included relatively more voluminous non-welded fragmental rocks and andesites. An approximately east-west tensional regime appears to have been active.

Previous Investigations

The first geological observations in the Georgetown region were recorded in 1856, during the North Australian Exploring Expedition, by Augustus Charles Gregory (*in* Gregory & Gregory, 1884 (1968), pp. 178–182). The expedition travelled southeast and east across the entire region, via "... a remarkable hill ... bare rock completely honeycombed", approximately 5 km southeast of Fish Hole (see Bain & others, 1976, Fig. 68). Gregory, in common with most later geologists (e.g. Queensland Legislative Assembly/Daintree, 1869; Jack & Etheridge, 1892; Cameron, 1900; Marks, 1911; Jensen, 1923; Reid, 1932; Hills, 1946; Denmead & Ridgeway, 1947), commented on the abundant and conspicuous late Palaeozoic "porphyries" and granitoids. However, the most comprehensive work on these particular rocks, before the present study, was undertaken in the 1960s by Colin Branch of the (then) Bureau of Mineral Resources (Branch, 1966).

Purpose and Scope of Study

Studies into the Coastal Ranges Igneous Province of the Georgetown region were mostly undertaken as an integral part of joint BMR–GSQ field investigations between 1972 and 1980. It was recognised at an early stage that the late Palaeozoic igneous rocks of the Newcastle Range could provide a model on which to base understanding of similar rocks elsewhere in northeastern Queensland, and study of them was extended into parts of the Galloway and Mount Surprise 1:100 000 Sheet areas, beyond the originally planned limits of systematic mapping. Studies more detailed than generally possible during systematic 1:100 000 scale mapping were undertaken in critical areas, e.g. Fig. 2; they demonstrate in particular the possible importance of extensional features, such as transfer structures and blocks rotated on listric normal faults, in the late Palaeozoic rocks of the region.

For convenience and simplicity of presentation, six-figure grid references to specific localities are preceded by a four-digit number which indicates the 1:100 000 Sheet area in which the locality occurs (from the west and north: 7461—Gilbert River; 7460—Esmeralda; 7561—Forest Home; 7560—North Head; 7662—Galloway; 7661—Georgetown; 7660—Forsayth; 7659—Gilberton; 7761—Mount Surprise; 7760—Einasleigh; 7759—Lyndhurst).

Terminology

In this report, the terms "granite" and "rhyolite" are extended to embrace "adamellite" and "rhyodacite" of earlier terminology, in accordance with recent IUGS recommendations (e.g. Streckeisen, 1967, 1978).

"Ignimbrite" (Marshall, 1935) is used in the same sense as "ash flow tuff" of Ross & Smith (1961). Because of the general lack of sufficiently detailed work, the numbers of flow units within most ignimbrite intervals mapped in the Georgetown region are not known. The intervals are discussed simply as "sheets"; most of them probably correspond to simple cooling units.

We differentiate between "crystals" and "phenocrysts" in descriptions of respectively, pyroclastic (including ignimbritic) and non-pyroclastic igneous rock types. Pyroclastic rock "crystals" have typically been corroded and broken into anhedral shapes before and during extrusion. Non-pyroclastic "phenocrysts" are most commonly subhedral to anhedral and unbroken.

* and the North Queensland Igneous Province of AGSO databases

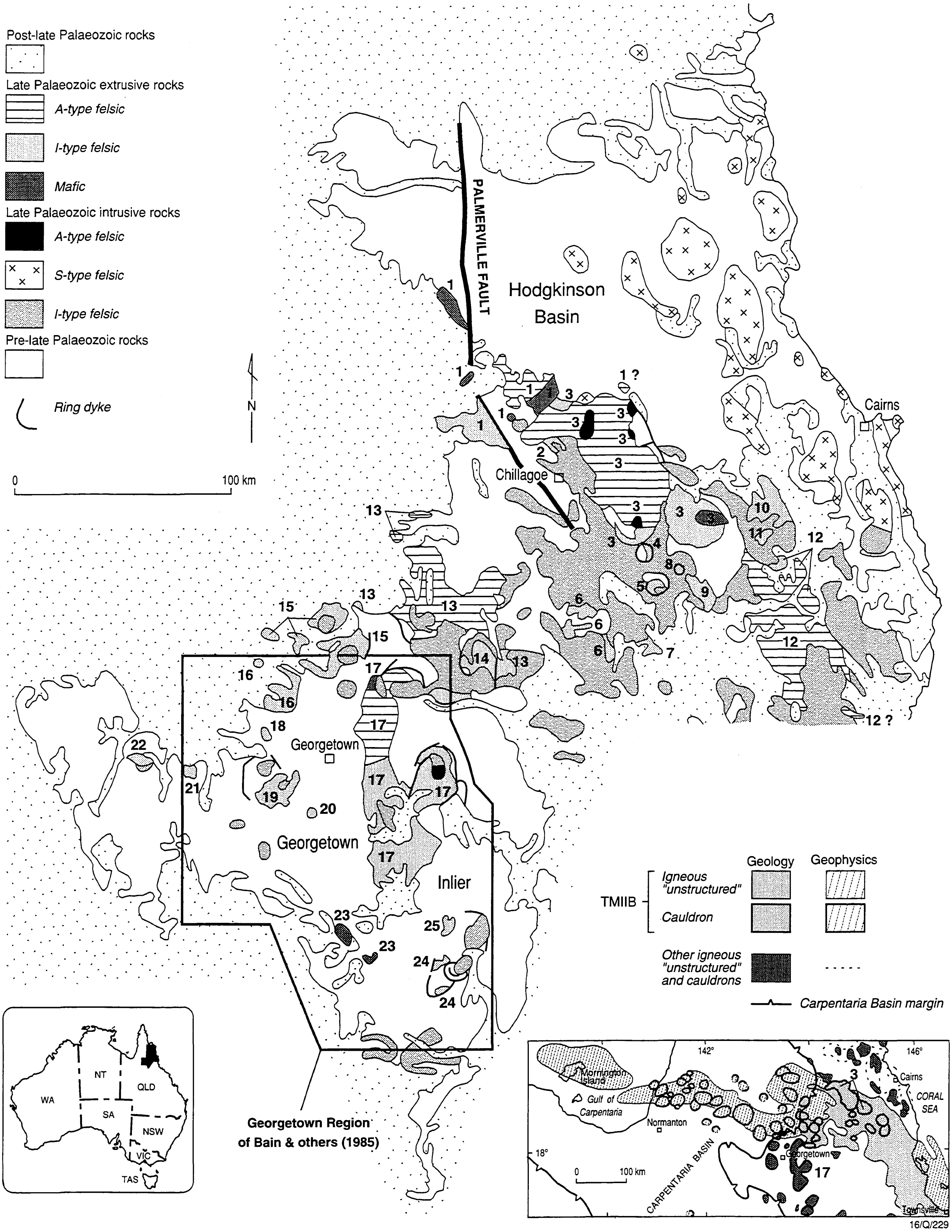

Fig. 1. Geographical location and geological setting of the Georgetown Region; modified from Oversby & others (1980) and Champion & Heinemann (1993). Inset: the Townsville–Mornington Island Igneous Belt (TMIIB); modified from Wellman & others (1994). 1=Nychum Volcanics; 2=Doolan Creek Rhyodacite; 3=Featherbed Volcanic Group; 4=Boxwood Volcanics; 5=Claret Creek Volcanics; 6=Gingerella Volcanics; 7=Kallon Volcanics; 8=Gurrumba Volcanics; 9=Nanyeta Volcanics; 10=Walsh Bluff Volcanics; 11=Slaughter Yard Creek Volcanics; 12=Glen Gordon Volcanics; 13=Scardons Volcanics; 14=Warby Volcanics; 15=Galloway Volcanics; 16=Maureen Volcanic Group; 17=Newcastle Range Volcanic Group; 18=Dismal Creek Dacite; 19=Cumberland Range Volcanic Group; 20=Marquis Rhyolite; 21=Bullseye Rhyolite; 22=Linley Rhyolite, McFarlanes Andesite, Little Pocket Dacite; 23=Agate Creek Volcanic Group; 24=Paddock Creek Formation; 25=Butlers Volcanic Group.

"Porphyritic" applies to "phenocrysts" only.

"Crystal-poor" denotes 1 to 5% by volume crystal content, and is equivalent to "sparsely porphyritic"; "very crystal-poor/sparsely porphyritic" indicates less than 1% crystals or phenocrysts. "Moderately crystal-rich" equates with 5–25% crystals, equivalent to "moderately porphyritic"; "crystal-rich" and "abundantly porphyritic" signify 25 to 50% crystals/phenocrysts, while the prefix "very" indicates an unusually high crystal/phenocryst content of more than 50%. Contents have been estimated by visual comparison of hand specimen and/or thin section material with the American Geological Institute's Data Sheet 15.1 (Dietrich & others 1982).

"Elvan" (Pryce, 1778) is an informal rock name used for a common and particularly distinctive type of intrusive microgranitoid with subequal quartz and feldspar phenocrysts in a notable combination of moderate to high abundance and large size (commonly one centimetre or more). Elvan-type rocks usually make up subvolcanic stocks and ring-dykes intimately associated with extrusive sequences. Although the term has rarely been applied outside its original Cornish mining context (e.g. Dines, 1956; Edmonds, & others, 1969), it was used occasionally by pioneer geologists in northeastern Queensland (e.g. Queensland Legislative Assembly/Daintree, 1869; Jack, 1887). It thus has some claim to historical legitimacy in the Georgetown region, in addition to its usefulness as a "shorthand" descriptor.

"Volcaniclastic" rocks consist predominantly of originally non-welded or poorly welded lithic, crystal, and/or vitric material. They commonly show some degree of stratification which gives them the superficial appearance of sedimentary rocks. Lack of detailed study makes specific origins uncertain. However, the rocks seem to be partly of primary pyroclastic origin, and to represent a variety of (mainly low-volume) flows and falls. Others probably accumulated in water, or underwent minimal sedimentary reworking and redeposition as they accumulated or afterwards. Some show definite evidence of reworking, although without incorporation of strictly epiclastic material from older and/or distant sources; these are probably alluvial fan and braided stream, and possibly "hyperconcentrated flood flow" (Smith, 1986), deposits.

A variety of origins commonly appear to be represented together in individual successions. The rocks are described by the standard grain-size qualifiers of "lutite", "siltite", "arenite" and "rudite". "Mudstone", "siltstone", "sandstone", and "conglomerate" are reserved for known epiclastic sedimentary rocks. "Lutite"/"mudstone" denote rocks composed of clay-size material, albeit not necessarily a mineralogical clay. The term "tuff" is avoided as being inappropriate for the coarser-grained volcaniclastic rocks, while "agglomerate" is equally unsuitable for the finer-grained ones. More importantly, both terms were open to misinterpretation before I.U.G.S. recommendations on the terminology of pyroclastic rocks (e.g. Le Maitre, 1989) became available. "Breccia" is unsuitable because the coarse-grained rocks mostly tend to contain some proportion, commonly a predominance, of milled (i.e. rounded by gas-streaming) clasts.

Following Smith & Bailey (1968, p. 616), we use the term cauldron as a general one for "... *all* volcanic subsidence structures *regardless* of shape or size, depth of erosion, or connection with surface volcanism" (our italics). Thus, the fault-bounded Kungaree "Trough", so-named to emphasise its elongate form, is conceptually as much a cauldron as more equidimensional and explicitly named associates, such as the Wirra Cauldron. Similarly, the partly subvolcanic to deeper Cumberland Range, Bagstowe, and Lochaber "Ring-Dyke Structures", as well as the Agate Creek "Basin" (probably), are also cauldrons. However, the terms "basin" and "trough" are primarily descriptive of the structural geometry of extrusive sequences; we do not assume any necessary direct correspondence between such geometry and calderas (below).

We regard calderas as making up an end-member subclass of cauldrons which have expression as "... large volcanic depressions, more or less circular or cirquelike in form, the diameters of which are many times greater than those of the included vent or vents, *no matter what* the steepness of the walls or form of the floor" (Williams, 1941, p. 242; our italics), i.e. topographic features.

"Centred igneous structure" is preferred as a general term for roughly equidimensional structures defined by intrusive or extrusive rocks, or both, in an approximately concentric or annular disposition. The term embraces "ring-dyke complex" and "cauldron subsidence area", as used previously in the Georgetown region (e.g. Branch, 1966). "Basins" and "calderas" are, respectively, the shallow-gentle sagged and deep-steep collapsed endmember surficial manifestations of cauldrons.

The stratigraphic nomenclature herein supersedes other systems used in preceeding BMR reports and maps, and in Bain & others (1978) and Oversby & others (1980).

Acknowledgements

Oversby has been primarily responsible for work in the main areas of Gilberton Formation, and in the Newcastle Range Volcanic Group and associated intrusive rocks. He also supervised investigation of the Bagstowe and Lochaber intrusive-extrusive sequences by Ray McLeod, Juliette Warnick, & Ian Withnall (Warnick and Withnall, 1985). Mackenzie has studied the Maureen and Cumberland Range Volcanic Groups, as well as the Gilberton Formation subjacent to them. Other important contributors have been John Bain and Max Baker, mainly in the Mount Turner area (Baker, 1978a, 1978b; Baker & Horton, 1982). The latter has also more recently (subsequent to his affiliation with G.S.Q. and participation in the Georgetown Project) enhanced understanding of the late Palaeozoic rocks and mineralisation at Kidston (Baker, 1987, 1988; Baker & Andrew, 1988); these new data have implications for mineral deposit potential throughout the Coastal Ranges Igneous Province, as well as in equivalent tectonic settings (Baker, 1984; Baker, & others, 1986).

Lance Black has been responsible for geochronological data; Richard Holmes has aided in evaluating these, and has made a semi-independent detailed study of the Yataga Granodiorite. Noreen Morris has commented on many of the plant macrofossils obtained, while Clinton Foster has identified polynomorph assemblages. Wadim Anfiloff undertook a detailed gravity traverse across the main outcrop area of the Agate Creek

Volcanic Group (Anfiloff, 1983). John Giddings and Mart Idnurm studied the palaeomagnetism of rocks in the southern and eastern lobes of the Newcastle Range.

Several exploration company geologists have also provided information, much of which cannot be used explicitly in this report, but which has been valuable in generating and checking ideas.

Information on the Galloway Volcanics comes in part from Smart & Bain (1977).

In addition to the contributing geologists listed above, this study has benefited from the assistance of all field staff, both permanent and temporary, involved in the Georgetown Project since its inception in 1972, and from the co-operation of local residents. Colin Branch has taken a constructive interest in the work at all stages.

Stratigraphy

Gilberton Formation (DC)

Introduction

The name Gilberton Formation (White, 1959a; Appendix) is now applied throughout the Georgetown region to all epiclastic sedimentary rocks, known or inferred to be of appropriate (late Devonian and/or early Carboniferous) age, on the basis of collective lithological similarity and commonality of tectonic significance.

Distribution

The most extensive outcrop area of Gilberton Formation is one of about 120 km^2 between the Percy River and Granite Creek, 5–15 km north of "Gilberton". Other major occurrences are: south of the Gilbert River opposite the homestead; adjacent to the southwestern Newcastle Range (and beneath Newcastle Range Volcanic Group) 20–30 km southeast of Forsayth; near Marquis Hill 5 km west northwest of Forsayth; at Mount Tabletop (and beneath Marquis Rhyolite) 15–20 km west-northwest of Forsayth; in the Dismal Creek area (and beneath Dismal Creek Dacite) 30–35 km west-northwest of Georgetown; and in the Maureen prospect area (beneath Maureen Volcanic Group) 35 km north-northwest of Georgetown.

Scattered, and relatively minor in contrast to the above occurrences, representatives of Gilberton Formation crop out: peripheral to other parts of the Newcastle Range, beneath Newcastle Range Volcanic Group; peripheral to the Cumberland Range, beneath Cumberland Range Volcanic Group; between the Maureen prospect area and the Etheridge River, beneath Maureen Volcanic Group; and adjacent to the southwestern part of the Galloway Volcanics.

There is no Gilberton Formation associated with the Paddock Creek Formation or Butlers Volcanic Group of the Bagstowe and Lochaber centred igneous structures.

The *Mamberra (DCm)* and *Spyglass (DCs) Andesite Members* (Appendix) of the formation occur, respectively, at the southeastern edge of the Newcastle Range, and in the Dismal Creek area.

Relationships to overlying extrusive units

Relationships between Gilberton Formation and overlying units vary, apparently unsystematically, from concordant and gradational to discordant (probably unconformable and/or structurally disrupted).

Rock types and stratigraphy

Immature and poorly sorted epiclastic sedimentary rocks, mainly clayey and pebbly quartz sandstone grading to arkose, and polymictic conglomerate, characterise the Gilberton Formation. Mudstone and siltstone are subordinate. Carbonaceous rocks are scarce. Limestone is rare, although many of the rocks have a carbonate cement. The few limestones known tend to be nodular, and may be pedogenic. Trough and planar cross-bedding is common, and the rocks are mostly some shade of brown or purple.

Most of the clastic material in the Gilberton Formation has come from immediately subjacent or nearby basement sources. An important exception is the population of graphite-bearing ignimbrite clasts which occurs in conglomerates of the lectostratotype area (between the Percy River and Granite Creek, Appendix 1). These clasts are believed to have been derived from the Croydon Volcanic Group, now cropping out about 80 km to the northwest (Withnall & others, 1980). In contrast, no clasts of nearby Einasleigh Metamorphics occur in the formation to the south of the Gilbert River opposite "Gilberton" and adjacent to the Gilberton Fault.

Quartzose rocks appear to be more common in the upper Gilberton Formation relative to the lower part in the lectostratotype section, and in the Maureen and Dismal Creek areas. Minor volcaniclastic material occurs locally, particularly in the Maureen prospect area.

Transport directions of Gilberton Formation clastic material appear to have been locally quite variable in space and time. However, available palaeocurrent data are too few and scattered to give a meaningful indication of the main long-term drainage trend(s).

Thickness

The thickest sequences of Gilberton Formation occur, in the lectostratotype area between the Percy River and Granite Creek, adjacent to the southwestern edge of the Newcastle Range, in the Maureen prospect area, at Mount Tabletop and in the Dismal Creek area.

The thickness of the formation in its lectostratotype section is uncertain because of possible structural complications; it could be as much as 875 m if such complications are nonexistant or minor. However, a thickness in the order of 300 m to 500 m seems more likely on a basis of areal distribution and by analogy with other main areas of preservation. Thicknesses adjacent to the southwestern Newcastle Range, and in the Maureen prospect and Mount Tabletop areas, are 200–300 m. The sedimentary component in the structurally complex Dismal Creek area is of unknown thickness. However, up to 200–300 m of *Spyglass Andesite Member* are developed as two lenses in the northeastern and southeastern parts of the Dismal Creek section. Both lenses expand to the extent of making up the whole of the Gilberton formation very locally, and both of them (most obviously the southeastern one) appear to be convex-upwards. This geometry suggests that the andesite lenses had positive palaeotopographic expression, which may be indicative of a partly intrusive nature. The *Mamberra Andesite Member*, which is also exposed as two lenses, crops out at the northeastern and southeastern edges of the southern lobe of the Newcastle Range. The southeastern lens at least is elongate, and concordant with respect to enclosing Gilberton Formation sedimentary rocks, consistent with a lava flow origin. In this southeastern lens, the Mamberra andesite is up to 50 m thick along an exposed south-southwest to north-northeast strike length of 2.8 km; it is underlain by 0 (south) to 50 m (north), and overlain by 60 m, of epiclastic sedimentary rocks.

Age

The lower Gilberton Formation in its lectostratotype area and south of the Gilbert River has yielded a macroflora dominated by *Leptophloeum australe* (White, 1965; Withnall & others, 1980), and associated with fish fragments (Hills, 1935). These fossils suggest a Famennian (Late Devonian) age. Such an age assignment is supported by a microflora from low in the formation in the lectostratotype area, which is characterised by the late Famennian to early Tournaisian (Early Carboniferous) palynomorph *Retispora lepidophyta* (C.B. Foster, personal communication, 1981). Lepidodendroid fragments from the uppermost part of the Gilberton Formation are of Visean aspect, while a *Granulatisporites frustulentus* microflora indicative of a late Visean age has also been recovered from high in the sequence.

Gilberton Formation rocks at Mount Tabletop and in the Cumberland Range area contain Visean microfloras, not yet examined in detail. Unidentified, but possibly Visean, lepidodendroid and fish fragments also occur at Mount Tabletop (I.W. Withnall, personal communication, 1980).

Discussion

As the only definite record in the Georgetown Region of conditions in the period between the end of the Siluro–Devonian Warunu Orogeny and the first major pulses of late Palaeozoic ignimbrite- generating magmatism to reach the surface, the Gilberton Formation represents a distinct tectonic-stratigraphic entity (tectosome) in its own right.

The molasse-like nature of the sequence presumably reflects regional uplift consequent on crustal thickening and/or thermal inflation during the compressional(?) Warunu Orogeny. The formation was probably deposited in a plexus of coalesced alluvial fans and proximal braided streams. A primarily lacustrine environment of accumulation (White, 1965) is not considered likely.

The regional or subregional drainage direction into the Georgetown region, during at least part of the time that the Gilberton Formation accumulated, presumably must have been from the northwest for clasts of Croydon Volcanics to have made an appearance. However, probable Gilberton Formation near "The Lynd", in the Lyndhurst 1:100 000 Sheet (7759) area to the east of the southern part of the Georgetown region, contains clastic material apparently derived from the south and southwest, as do penecontemporaneous parts of the Bundock Creek Group (Lang, in Withnall & others, 1988) in the nearby depocentre (and site of sporadic marine sedimentation) of the Bundock Basin (Withnall, & others, 1988). This indicates that the long-term, regional drainage was not influenced by the location and orientation of a palaeotopographically negative Bundock Basin as represented by its thickest remaining sedimentary infill. The late Devonian- early Carboniferous depocentre(s) may have been more extensive, and more gradational with the adjacent fans and fluvial sheets and/or channels of the Gilberton Formation, than the structurally bounded core area of the "basin" now preserved. This core area was apparently transverse to a major, if not the principal, drainage direction (Withnall, & others, 1988) and palaeotopographic low(s).

Irrespective of the details of drainage directions and provenances of clastic material, accumulation of the Gilberton Formation probably took place on an irregular and locally rugged topographic surface, similar to that developed on older rocks of the Georgetown Region at present. Interconnection of at least a series of fluvial ribbons of Gilberton Formation was presumably essentially continuous throughout the region.

The absence of Gilberton Formation in or immediately adjacent to the Bagstowe and Lochaber centred igneous structures (below), even as remnants preserved beneath the extrusive sequences of the Paddock Creek Formation and Butlers Volcanic Group, suggests the possibility of uplift with stripping off of the formation before the emplacement of magmas at the present level of exposure in both structures. Some degree of uplift ("inflation"), reflecting the early ascent of magma at depth, is commonly (although not invariably, cf. Rytuba & McKee, 1984) inferred to precede voluminous ignimbrite eruptions and formation of calderas, or equivalent structures (e.g. Smith & Bailey, 1968).

In other parts of the Georgetown Region, however, exposed representatives of the Gilberton Formation do not provide wholly unambiguous evidence for any systematic pattern, either of premonitory uplift or subsidence at sites where ignimbrite activity was to be subsequently concentrated, even though there are indications that high-angle faults were locally active. On one hand, the thick representatives of Gilberton Formation in the lectostratotype area, at Mount Tabletop, and in the Dismal Creek area, lie outside areas of major ignimbrite-dominated sequences; this suggests that premonitory uplift might have taken place in areas of major ignimbrite extrusion. On the other hand, comparable thicknesses of the formation directly subjacent to parts of the Wirra Volcanic Subgroup of the Newcastle Range Volcanic Group, and to the eastern Maureen Volcanic Group, suggest that at least local downwarping and/or faulting, with preferential accumulation and/or redeposition of clastic sedimentary rocks, occurred at (marginal to?) some centres of subsequent ignimbrite extrusion.

There is a tendency for the Gilberton Formation to be more common, as well as consistently thicker, beneath the marginal Wirra, Namarrong, and Eveleigh Volcanic Subgroups than it is at the edge of the Kungaree subgroup. This again suggests subsidence prior to accumulation of the first three sequences. However, the distribution of Gilberton Formation beneath the main parts of such extrusive sequences is unknown; it could be substantially different from that of exposed peripheral occurrences. Additionally, the influence of pre-extrusive palaeotopography on the Gilberton Formation's distribution and thickness variations, irrespective of any uplift or subsidence effects, is impossible to evaluate from available information.

Intuitively, it seems likely that at least transient inflations of local extent would have preceded magmatism in the subsequent core areas of ignimbrite effusion, if nowhere else.

Ignimbrite-dominated volcanism in many regions has commonly also been preceded by the construction of clustered stratovolcanoes of mainly intermediate, or mixed acid and intermediate, composition (e.g. Smith & Bailey, 1968; Cobbing & Pitcher, 1972; Steven & Lipman, 1976). As far as the Georgetown Region is concerned, however, the maximum extrusive component of the Gilberton Formation, represented by the Mamberra and Spyglass members, can in no way be compared with this stratovolcano build up.

Wyatt & Jell (1980) have suggested that the incoming of abundant clastic quartz in lowest Carboniferous rocks of northeastern Queensland, as in the upper Gilberton Formation at least locally, might reflect a change in climate as Gondwanaland moved towards high southern latitudes.

Newcastle Range Volcanic Group

Introduction

The Newcastle Range Volcanic Group (Appendix) represents the most extensive remnant of a Carboniferous ignimbrite-dominated extrusive sequence in the Georgetown region; it is exceeded in extent and thickness in northeastern Queensland probably only by the Featherbed volcanics near Chillagoe (e.g. Branch, 1966; Mackenzie, 1993; Mackenzie & others, 1993). The Newcastle Range volcanics sequence occupies an area of 2500 km^2 in all but the extreme southern end of the Newcastle Range. This range extends as a topographic entity from the southwestern side of the Einasleigh River, about 55 km north-northeast of Georgetown, slightly east of south for 150 km to the headwaters of the Percy River, about 50 km south-southwest of Forsayth.

Topographically, that part of the Newcastle Range occupied by the volcanic group is made up of southern (750 km^2), northern (150 km^2), and eastern (500 km^2) lobes; an 1100 km^2 central isthmus connects the first two features. Rocks assigned to the Newcastle Range Volcanic Group also occupy an area of about 25 km^2 to the east of the northern Newcastle Range proper (about 10 km^2 of this area lie to the east of the edge of the Georgetown region map).

Rocks of the Newcastle Range group either have locally variable relationships to underlying Gilberton Formation, or lie with major angular unconformity directly on Proterozoic and Siluro–Devonian basement. Relationships with the Gilberton Formation are concordant and apparently gradational, through concordant but sharp (disconformable?), to sharp and discordant (angularly unconformable and/or structurally disrupted). The Newcastle Range Volcanic Group is overlain unconformably by Mesozoic and Cainozoic rocks, particularly in the southern Newcastle Range.

The Newcastle Range Volcanic Group contains fifteen formations, which make up the Wirra (two formations), Namarrong (three definite and one tentative formations), Eveleigh (five formations), and Kungaree (four formations) subgroups (Appendix 1). These subgroups occur mainly or entirely in the southern, northern, and eastern lobes, and in the central isthmus, of the Newcastle Range, respectively. Many of the formations contain subunits of member status, not all of which have been named.

All but three of the formations, currently defined as making up the Newcastle Range Volcanic Group (Routh Dacite, Canyon Dacite, and Corkscrew Rhyolite—see below), are characterised and dominated by sheets of welded ignimbrite. The three exceptions contain significant proportions of lava. Overall, rock compositions are mainly rhyolitic, while dacites are subordinate; andesites are scarce and basalts extremely rare, if not entirely absent (below).

The maximum preserved thickness of the Newcastle Range Volcanic Group is in the order of 8 000 to 10 000 m. This thickness is cumulative; it is not attained in any one area, because there is none in which all units overlie each other in simple vertical succession. The thickest preserved single sequences are 1450 m in the southern lobe of the Newcastle Range, up to nearly 2000 m in the central isthmus and northern lobe, and nearly 2500 m in the eastern lobe.

Each lobe of the Newcastle Range coincides with a centred igneous structure defined by a basinal Newcastle Range Volcanic Group sequence and subsidiary intrusive bodies, including variably developed ring-dykes. The central isthmus is equivalent, but of trough-like structure. A subsidiary and rather poorly defined basin also occurs to the east of the northern Newcastle Range.

On a basis of three total-rock Rb-Sr analyses, Richards & others (1966) interpreted the age of the Newcastle Range Volcanic Group to lie between 370 and 350 Ma (Late Devonian to Early Carboniferous). Subsequently, Rb-Sr studies by Black (1973, 1974, 1978) suggested an appreciably younger age of about 310 Ma (Late Carboniferous) for the group. Re-evaluation of these, and additional, data (L.P. Black & R.D. Holmes, personal communications) suggest that the bulk of the group accumulated during a short span of time about 327 Ma ago, during the late Early Carboniferous.

A single loose fragment tentatively identified as *Lepidodendropsis pacifica* by N. Morris (pers. comm.) has been obtained from volcanogenic clastic rocks making up the lowermost Bousey Rhyolite (below) in the southern lobe of the Newcastle Range, about 20 km southeast of Forsayth. Its occurrence is consistent with the isotopic age.

Wirra Volcanic Subgroup

Introduction

The Wirra Volcanic Subgroup (Appendix) makes up much of the southern lobe of the Newcastle Range; it is also believed to extend into the southern third of the central isthmus.

The lowermost, and most extensive, formation making up the subgroup is the Bousey Rhyolite. This is overlain by Jinker Creek Rhyolite in the north-central part of the southern lobe.

Bousey Rhyolite (Cp)

Bousey Rhyolite (Appendix 1) crops out in an area of about 380 km^2 in all but the north-central part of the southern lobe of the Newcastle Range. It is believed to extend north beneath Mesozoic–Cainozoic rocks to reappear in the southern part of the central isthmus, where it crops out or lies beneath a thin veneer of cover rocks in an area of 200 km^2 before before cutting out beneath and against Routh Dacite (Kungaree Volcanic Subgroup) to the south of the Gulf highway.

The formation is moderately heterogeneous; it is dominated by brown to purple welded rhyolitic ignimbrite (Cp). Rhyolitic lavas (Cp_2) and volcanogenic clastic rocks (Cp_l) are sporadic and localised. There are three main ignimbrite sheets (probably separate cooling units) in the main area of Bousey Rhyolite. Of these, only the middle one is recognised in the central isthmus of the Newcastle Range.

Ignimbrites and lavas in the Bousey Rhyolite are all moderately crystal-rich, and have both quartz and feldspar. Lavas, and the lower and upper ignimbrite sheets, most commonly contain 10 to 25% phenocrysts/crystals averaging 2 mm in maximum dimension. The middle ignimbrite sheet contains a similar proportion of slightly larger crystals; their average maximum dimension is 3 mm. This middle sheet is further characterised by up to 5% irregular chlorite-epidote aggregates, possibly after hornblende.

The lower and upper ignimbrites locally contain up to 10% volcanic lithic clasts with maximum dimensions of 10 cm or less. The lowermost part of the middle sheet also has a variety of such clasts, particularly in the central isthmus area; an unusually coarse lag-fall or ground-lag (Wright & Walker, 1977; Froggatt, 1981) concentration of autolithic and basement-derived clasts up to 0.9 m in maximum dimension occurs on the western side of the isthmus, 9 km south of the debouchement of the Etheridge River from the Newcastle Range.

Volcaniclastic rocks in the Bousey Rhyolite are mostly arenites; lutites, siltites, and rudites occur sporadically. The volcaniclastic interval separating Gilberton Formation from the lower ignimbrite sheet near Fish Hole, about 20 km southeast of Forsayth, contains lenses of arenaceous limestone. This lowermost interval has also yielded the only fossil (above) so far found in the Newcastle Range Volcanic Group.

The lower, middle, and upper ignimbrite sheets of the Bousey Rhyolite in its holostratotype area (Appendix) are 120 m, 420 m, and 80 m thick, respectively. Lava in the lower part of the formation is up to 200 m thick, although of very restricted lateral extent. Volcaniclastic rocks, which account for up to a total of 120 m of the formation's thickness, occur between the lower ignimbrite and the Gilberton Formation, and sporadically between the three ignimbrite sheets themselves. The Bousey Rhyolite in the central isthmus of the Newcastle Range is probably 150 m thick, as preserved. Assuming that the lower, middle, and upper ignimbrite sheets originally maintained approximately constant thicknesses throughout the area of the southern lobe of the Newcastle Range, their respective volumes would have been 90, 315, and 60 km^3; an additional 30 km^3 of material assigned to the middle sheet are preserved in the central isthmus of the range.

Jinker Creek Rhyolite (Co)

Jinker Creek Rhyolite crops out in an area of about 70 km^2 restricted to the north-central part of the southern lobe of the Newcastle Range to the south of the main belt of Mesozoic–Cainozoic cover.

Jinker Creek Rhyolite (Appendix) is a strikingly homogeneous formation which superficially resembles an intrusive microgranitoid. It consists of a single sheet of mid brownish or pinkish-grey welded rhyolitic ignimbrite. The rock is crystal-rich verging on very crystal-rich, and contains ubiquitous biotite with subsidiary hornblende, in addition to quartz and feldspar. The formation has 40% to slightly more than 50% quartz and feldspar crystals up to an average of about 5 mm in maximum dimension. About 2% to 5% biotite, which tends to increase upwards in the sheet, occurs in crystals up to 3 mm long. Hornblende is a sporadic constituent. Groundmass shard pseudomorphs are preserved only in the lower third of the sheet; higher up they have been destroyed by micro-equigranular recrystallisation. Microgranitoid fragments are moderately common in the upper 200 m of the sheet.

The Jinker Creek Rhyolite has a preserved thickness of 550 m in the area of its holostratotype section, with a probable volume of nearly 40 km^2. If the formation originally occurred uniformly throughout the southern lobe of the Newcastle Range, it would have had a volume of at least about 400 km^3.

Kungaree Volcanic Subgroup

Introduction

The Kungaree Volcanic Subgroup (Appendix) occupies about two thirds of the trough-like structure making up the central isthmus of the Newcastle Range. Formations in the subgroup are (in ascending stratigraphic order) Shamrock Rhyolite, Routh Dacite, Corkscrew Rhyolite, and Kitchen Creek Rhyolite. Of these, the most extensive is the Corkscrew Rhyolite, which occurs in the central and northern parts of the central isthmus and extends into the northern lobe locally.

Shamrock Rhyolite (Cn)

Rocks assigned to the Shamrock Rhyolite (Appendix) crop out mainly on the western and eastern sides of the Newcastle Range to the north of the Gulf Developmental Road, about 15 km and 25 km, respectively, northeast of Georgetown. They apparently cut out before the highway is reached. A tongue of the formation extends into the northern lobe of the range. The outcrop areas of the formation total 15 km^2.

The Shamrock Rhyolite is moderately heterogeneous and dominated by up to two sheets of mid to dark-grey grading to mid purple or dark-brown welded rhyolitic ignimbrite (Cn). These ignimbrites are moderately crystal-rich and typically contain 10 to 25% quartz and feldspar crystals averaging 2 mm in maximum dimension. Fiamme are locally well developed. Volcanic lithic clasts up to about 10 cm in maximum dimension occur locally.

Volcaniclastic rocks (Cn_l) in the Shamrock Rhyolite are most commonly arenites; lutites, siltites and rudites are subsidiary.

The exposed thickness of Shamrock Rhyolite in its holostratotype section, making due allowance for repetition across known faults, is 250 m. This total is made up of 50 m of volcaniclastic rocks, whose base is not exposed, overlain by a 50 m lower and 150 m upper ignimbrite sheets. In the parastratotype section of the Shamrock Rhyolite, the formation consists of a lower 30 m of volcaniclastic rocks, and an upper 120 m of ignimbrite. The tongue of Shamrock Rhyolite in the northern lobe of the Newcastle Range contains up to 30 m of volcaniclastic rocks, overlain by 120 m of ignimbrite. Assuming an average thickness of 100 m for exposed and concealed/eroded Shamrock Rhyolite ignimbrite in an area of 350 km^2, a total volume in the order of 35 km^3 is suggested as an original minimum.

Routh Dacite (Cm)

Rocks assigned to the Routh Dacite (Appendix) crop out in an area of about 50 km^2 in the central part of the Newcastle Range isthmus. The formation partly abuts against a high-angle fault zone and partly ascends to above the level of erosion in the south, and cuts out below Corkscrew Rhyolite in the north.

The Routh Dacite consists mainly of moderately homogeneous greenish-mid grey or brown to orangey-dark brown dacitic lava (Cm) with subsidiary welded ignimbrite (included in Cm), and scarce volcaniclastic rocks (Cm_1). These may be intimately intermixed with undifferentiated, very high-level intrusive dacite which, with the lava, has contributed to the evidently original irregular top of the formation. The rocks are characterised by 10 to 50% feldspar phenocrysts and crystals (in lava and ignimbrite, respectively) mostly to 3 mm in maximum dimension (averaging 1 mm), but up to 1 cm locally. The feldspar is accompanied by up to 1% quartz phenocrysts/ crystals, mostly up to 1 mm in maximum dimension. The rocks are also characterised by up to 15% irregular chlorite-epidote aggregates up to 1 cm (but mostly 1 mm) in maximum dimension. These are mostly in the groundmass, although also commonly intergrown with single and multiple feldspar phenocrysts/crystals. Remnant biotite is associated with the chlorite locally.

Rocks of intermediate or mixed appearance (at hand specimen to outcrop scale) between Routh Dacite and Corkscrew Rhyolite, occur sporadically. The assignment of such rocks to one or other of the formations is subjective, mainly guided by the abundance of chlorite and phenocryst/crystal contents. The distinction locally becomes arbitrary.

Volcaniclastic rocks (Cm_1) in the Routh Dacite range from arenite to rudite. The latter is conspicuous at Turtle Rock (7661–903735), adjacent to the Gulf Developmental Road, and probably represents a near-vent airfall accumulation.

In its holostratotype section, the Routh Dacite has a thickness in the order of 1000 m; this is probably a maximum for the formation. Neither the thickness nor volume of welded ignimbrite in the formation are known.

Corkscrew Rhyolite (Cl)

The Corkscrew Rhyolite (Appendix) crops out extensively (250 km^2) in the northern two-thirds of the central isthmus; its distribution is limited southwards by erosion, and by high-angle fault zones. A tongue extends into the northern lobe of the range, although most of the formation apparently cuts out against the Brodies Gap—Dagworth Bore Fault Zone. It also cuts out beneath Kitchen Creek Rhyolite locally near of the Gulf Highway.

The formation contains one named member *(Thornborough Andesite Member,* Clt) (Appendix) and four un-named subunits of member rank.

Overall, the Corkscrew Rhyolite is a heterogeneous formation. The dominant rock type is pale-brown to pale-purple rhyolitic lava (Cl) with 3 to 5% of mainly feldspar phenocrysts averaging 2 mm in maximum dimension. There may be an intrusive component mixed with the lava, judging from the very irregular nature of the formation's upper surface, but it cannot be differentiated. Welded rhyolitic ignimbrite (Cl_3) with locally well-developed fiamme in the Corkscrew Rhyolite is purplish-mid or dark grey to pale brown and contains 1 to 25% of mainly feldspar crystals between 1 mm and 3 mm in maximum dimension. Quartz crystals are of similar size, but occur only rarely. Corkscrew Rhyolite ignimbrite commonly contains a varied suite of lithic clasts. At and to the south of the western (lower) end of the holostratotype section, ignimbrite grades laterally into very crudely stratified polymictic volcanogenic rudite (Cl_2) which has clasts up to 0.9 m in maximum dimension. This rudite probably represents a lag-fall accumulation (Wright & Walker, 1977). Volcaniclastic rocks (Cl_1) elsewhere in the Corkscrew Rhyolite are mainly siltites and arenites, with subsidiary fine to medium rudites.

The *Thornborough Andesite Member* (Cl_t) consists of grey to greenish-grey, extensively altered, sparsely porphyritic, andesitic lava.

In its holostratotype section, the Corkscrew Rhyolite is 100 m thick. Of this total, welded rhyolitic ignimbrite in the lower part of the formation accounts for 50 m. Overlying the ignimbrite are 10 m of volcaniclastic rocks, succeeded by 40 m of rhyolitic lava. The thickest lava section (760 m) lies on the western side of the central isthmus of the Newcastle Range, 8 km south of the Gulf Developmental Road.

The *Thornborough Andesite Member* of the Corkscrew Rhyolite is probably 30 m thick.

Assuming an average thickness of 50 m for exposed and concealed/eroded Corkscrew Rhyolite welded ignimbrite over 150 km^2 of the Newcastle Range, a volume in the order of 7.5 km^3 is suggested.

Kitchen Creek Rhyolite (Ck)

This Rhyolite (Appendix) is dominated by a single sheet of moderately crystal-rich welded rhyolitic ignimbrite (Ck) in which fiamme and columnar jointing are well-developed and conspicuous. The ignimbrite is mostly some shade of mid brown, commonly greyish or purplish. Crystal contents are typically in the range of 5 to 10%, with quartz and feldspar both present. Up to 20% crystals occur in the lower part of the sheet. Crystals are mostly about 1 mm in maximum dimension, although larger ones are present locally, particularly in the lower part of the sheet. Up to 3% chlorite aggregates up to 3 mm in maximum dimension (but mostly less than 1 mm) also are present in some parts of the sheet.

Volcaniclastic rocks in the lowermost Kitchen Creek Rhyolite (Ck_1) are mainly arenite to very coarse rudite. Stratified arenite in the holostratotype area is too thin and localised to show on the Georgetown region map. More significant developments of stratified arenite to coarse rudite have been discovered in the southern part of the main outcrop area since the map was compiled, and are shown in Fig. 2. Unstratified coarse to very coarse rudite, in an area shown as undivided Routh Dacite on the map, also occurs in Kitchen Creek Rhyolite to the southwest of the main outcrop area of welded ignimbrite.

The Kitchen Creek Rhyolite has a preserved thickness of 180 m in the area of its holostratotype section. Of this total, a lower 3 m is made up of volcaniclastic rocks, with the remainder being a single sheet of welded rhyolitic ignimbrite. Stratified volcaniclastic rocks in the south are 200 m thick. Unstratified coarse to very coarse rudite is markedly lenticular, but at least about 30 m thick locally. Slightly more than 7 km^3 of welded ignimbrite is preserved in the outcrop area of the formation.

Namarrong Volcanic Subgroup

Introduction

The Namarrong Volcanic Subgroup (Appendix) makes up most of the basinal sequence in the centred igneous structure of the Newcastle Range's northern lobe. It also extends southwards into the northern third of the central isthmus. An apparent outlier of the subgroup occurs in a subsidiary, poorly centred structure 7 km southeast of the northern lobe of the Newcastle Range.

Formations in the Namarrong Volcanic Subgroup are (in ascending stratigraphic order) Twin Dams Andesite, Dagworth Andesite, Brodies Gap Rhyolite, and Cumbana Rhyolite; the last two may be lateral equivalents of each other.

Twin Dams Andesite (Cj)

Twin Dams Andesite (Appendix) crops out only in the western part of the northern lobe of the Newcastle Range, in outcrop areas totalling 4.5 km^2. It abuts against the Brodies Gap–Dagworth Bore Fault Zone, and cuts out against a high-angle fault beneath Shamrock Rhyolite 1.2 km north of Twin Dams.

The Twin Dams Andesite consist of an unknown number of flows of moderately uniform mid to dark-greyish green clinopyroxene-bearing andesitic lava which is characteristically aphyric. Groundmass grain sizes and textures grade locally from andesitic to microdioritic in diffuse patches and bands, but there is no evidence of any intrusive component in the formation.

The greatest thickness of Twin Dams Andesite occurs 1.5 km south of the holostratotype section (Appendix), and is 300 m.

Dagworth Andesite (Ci)

Rocks assigned to the Dagworth Andesite (Appendix) crop out in an area of slightly more than 10 km^2 in the western part of the northern lobe of the Newcastle Range. They occur in discontinuous and irregular areas totalling less than 5 km^2 around the remainder of the periphery of the northern lobe, and extend south on the western side of the central isthmus as tongues intercalated with lower Kungaree subgroup rocks at least as far as 10 km north of the Gulf Developmental Road. Minor occurrences of andesite on the eastern side of the central isthmus at 7661–966906 and 7661- 929708 probably belong to the formation. Dagworth Andesite also occurs as roof pendants in Elizabeth Creek Granite.

The lower interval of the Dagworth Andesite contains flows of moderately to abundantly porphyritic dark greyish to purplish-green andesitic lava. This porphyritic andesite contains 20 to 30% feldspar phenocrysts and aggregates from 3 mm to 20 mm (mostly up to about 10 mm) in maximum dimension. The feldspar phenocrysts are accompanied by 5% clinopyroxene (mainly pigeonite with subordinate augite) crystals up to 1 mm in maximum dimension. Small (1 mm or less) quartz xenocrysts occur rarely. Chlorite aggregates, probably after biotite, are sporadic. The rocks locally have abundant amygdales of carbonate and silica (agate), and sporadic minor chalcopyrite. Andesite in the upper interval is aphyric to moderately phenocryst-rich. Feldspar phenocryst contents range up to about 20%; the phenocrysts are mostly up to about 4 mm, and rarely 10 mm, in maximum dimension. Quartz xenocrysts are again rare.

Sporadic lenses of inter-flow volcaniclastic rocks in the Dagworth Andesite sequence are mostly arenites, and commonly pebbly. Occurrences are too limited in strike length and thickness to portray at the scale of the Georgetown Region map.

In its holostratotype section (Appendix), the Dagworth Andesite has an estimated thickness of 380 m. This consists of the un-named lower and upper andesitic lava intervals, 120 m and 260 m thick respectively, separated by up to 3 m of volcaniclastic rocks. Volcaniclastic lenses up to about 3 m thick also occur locally between the lower lava interval and underlying Shamrock Rhyolite.

There is a marked decrease in the thickness of Dagworth Andesite south across the Brodies Gap–Dagworth Bore Fault Zone.

Brodies Gap Rhyolite (Ch)

This unit (Appendix), the most extensive of the preserved formations in the Namarrong subgroup, dominates the centred igneous structure of the northern lobe of the Newcastle Range. It also extends south into the northern third of the range's central isthmus; its distribution is limited southwards by the level of erosion. The formation crops out in a total area of about 240 km^2. The Brodies Gap Rhyolite contains several un-named subunits of member rank.

The Brodies Gap Rhyolite is dominated by crystal-rich welded rhyolitic ignimbrite (Ch). Ignimbrite in the lower part of the formation south of Brodies Gap is mid to dark greyish to brownish-purple, and mostly contains 30 to 40% quartz and feldspar crystals up to 4 mm in maximum dimension. The rocks also locally have up to 3% biotite flakes about 1 mm in maximum dimension. Ignimbrite in the upper part of the formation south of Brodies Gap is dark grey to reddish-brown and has 20 to 30% quartz and feldspar crystals 0.5 to 1 mm in maximum dimension. Ignimbrites in upper Brodies Gap Rhyolite to the north of Brodies Gap are mostly similar to those in the lower part of the formation to the south of the gap. Biotite becomes characteristic at higher stratigraphic levels.

Volcaniclastic rocks (Ch_1,Ch_2) are characteristic of the Brodies Gap Rhyolite to the north of Brodies Gap. They occur sporadically to the south of the gap, where intervals contain a diverse assemblage of rocks, with arenites being the most common. North of Brodies Gap, autolithic rudite (Ch_2) is more common. This rudite is massive to crudely stratified, clasts are subangular to rounded, and the maximum known clast size is 5 m; it grades laterally and vertically into welded ignimbrite, and is interpreted as a lag-fall deposit (Wright & Walker, 1977). About 4.6 m of laminated to medium-bedded silty and arenaceous limestone occurs with volcaniclastic arenite locally in the northern lobe of the Newcastle Range. Coarse autolithic volcaniclastic rudite in the lowermost part of the ignimbrite interval to the south of Brodies Gap is interpreted as another ground-lag deposit

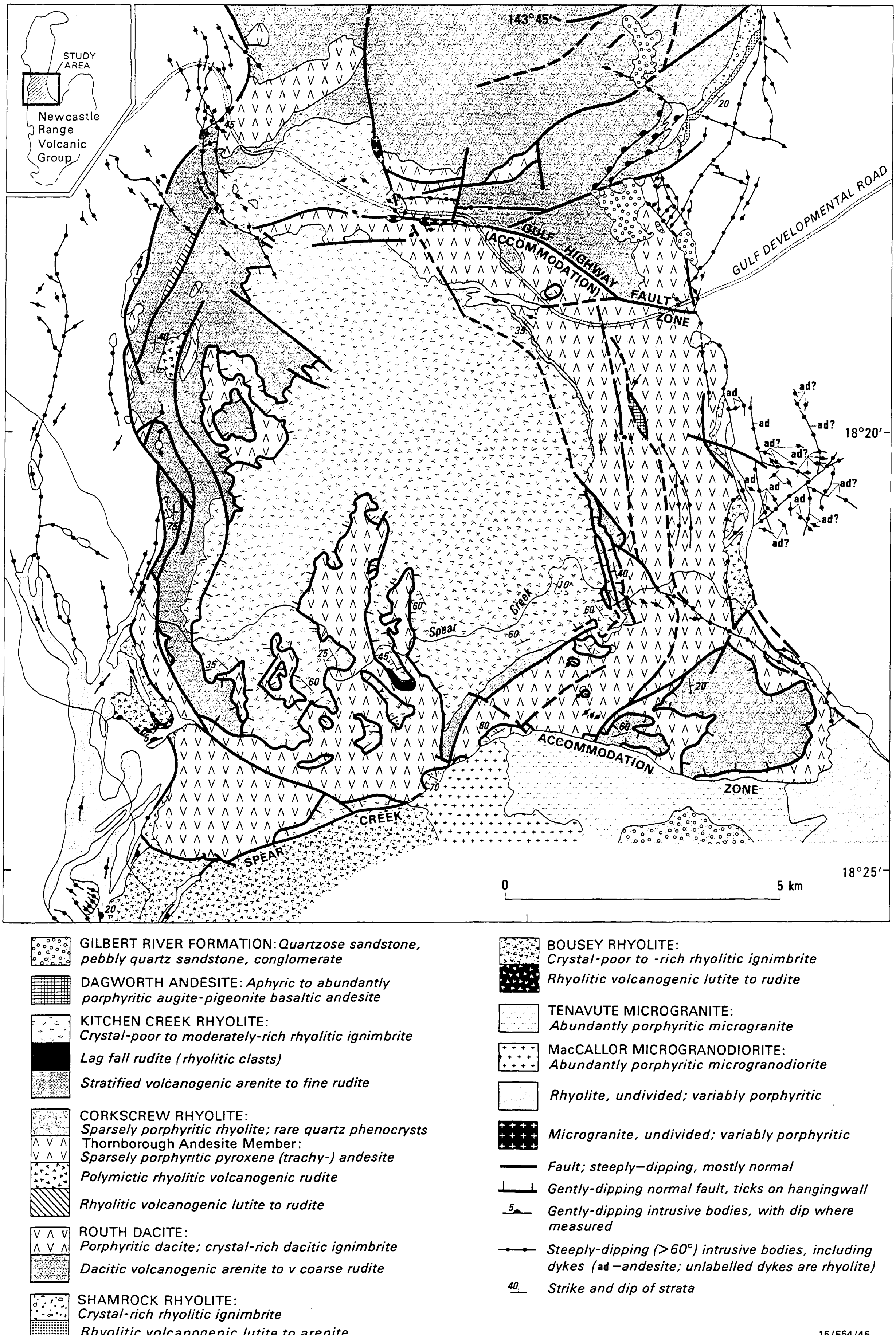

Fig. 2. Revised geology of the central Kungaree Trough. Modified from & others (1985) on the basis of additional field research in 1983 and 1984 by B.S. Oversby. Note particularly the postulated extensional structures (gently-dipping normal faults and accommodation zones with juxtaposed stratigraphic contrasts).

(Walker & others, 1981).

The Brodies Gap Rhyolite is estimated to have a preserved thickness of about 1600 m in its holostratotype area (Appendix). Of this total, ignimbrites in the lower part of the formation make up 1010 m, while those in the upper part are 550 m thick. Volcaniclastic rocks in the lowermost part of the formation account for about 30 m. This clastic interval probably thickens to about 100 m 0.5 km north of the holostratotype area. A volcaniclastic interval between ignimbrite sheets in the lower and upper parts of the formation south of Brodies Gap is about 10 m thick. In its parastratotype area (Appendix), the formation is estimated to be about 1250 m thick, with predominantly volcaniclastic rocks in the lower part of the sequence accounting for about 920 m. The sheet of biotite-bearing ignimbrite in the upper part of the unit is about 330 m thick. The top of the Brodies Gap Rhyolite is not preserved. Slightly more than 90 km^3 of material probably occurs in the lower ignimbrite sheet south of Brodies Gap. Assuming that the upper sheet originally maintained at least its present thickness over the same outcrop area as the lower sheet, a minimum volume of nearly 50 km^3 would have been present. North of Brodies Gap, the lower part of the sequence would have had a volume of nearly 140 km^3, if it had originally occurred uniformly throughout the area of the northern lobe of the Newcastle Range. On the same basis, the sheet of biotite-bearing welded ignimbrite in the upper part of the formation would have had a minimum volume of about 50 km^3.

Cumbana Rhyolite (Cf)

Cumbana Rhyolite (Appendix) occurs in a subsidiary and incomplete basinal structure 7 km southeast of the northern lobe of the Newcastle Range. The formation also lies 14 km south-southwest of rocks assigned to the Warby Volcanics (Branch, 1966). Cumbana Rhyolite crops out in an area of about 13.5 km^2 in the Georgetown 1:250 000 Sheet area. The formation extends for 7 km farther east, and occupies an additional 10 km^2 or so beyond the map area.

Cumbana Rhyolite has been included in the Namarrong Volcanic Subgroup of the Newcastle Range Volcanic Group partly for nomenclatural simplicity and convenience of treatment. Geographical proximity of Cumbana and northeastern Brodies Gap Rhyolites, and the quite close similarities between some ignimbrites in both, support a broad correlation. It is not supported by the occurrence of Cumbana Rhyolite outside the structural Namarrong Cauldron. Three chemical analyses have revealed that Brodies Gap Rhyolite ignimbrite is A-type (Champion & Heinemann, 1993, 1994). Unfortunately, no analyses of comparable Cumbana Rhyolite are available, even though the unit is currently represented tentatively as an I-type. If such I-type nature is confirmed by additional study of Cumbana Rhyolite, the unit should be removed from the Namarrong subgroup.

The lower part of the Cumbana Rhyolite is heterogeneous, although it is dominated by mid purplish-grey crystal-rich rhyolitic ignimbrite (Cf) similar to that in Brodies Gap Rhyolite. Ignimbrite in this lower part of the formation is crystal-rich, with quartz and feldspar contents of mostly 30 to 40% and sizes of up to about 3 mm in maximum dimension. Biotite occurs locally as sparse (up to 3%) crystals averaging about 3 mm in maximum dimension. The upper part of the formation is more homogeneous and massive, and locally resembles an intrusive microgranitoid. It consists of an apparent single sheet of brown to grey crystal-rich ignimbrite with an average of about 40% crystals up to 4 mm in maximum dimension, and ubiquitous (up to 1%) biotite, which increases to 3% upwards in the sheet.

Volcaniclastic rocks (Cf_1) in the Cumbana Rhyolite are mainly coarse siltites to fine rudites. Very coarse rudite of uncertain origin is locally interstratified with finer varieties. Andesite (Cf_2) in the lower Cumbana Rhyolite is dark greenish-grey and aphyric.

In the vicinity of its lectostratotype section, the lower Cumbana Rhyolite has an estimated exposed thickness of about 450 m, ignoring the probable fault at 7661–124018, whose effect is not known. Of this thickness, volcaniclastic rocks occupy the interval from 280 to 310 m, and andesitic lava occurs between 350 m and 380 m. Ignimbrite makes up the remainder. The apparently single ignimbrite sheet in the upper part of the Cumbana Rhyolite is about 470 m thick as preserved. The original top of the Cumbana Rhyolite has been eroded away. The base of the formation is not exposed, althought it presumably lies unconformably on Einasleigh Metamorphics. Assuming originally constant thickness throughout the whole outcrop area, the main part of the lower welded ignimbrite in the Cumbana Rhyolite is about 9 km^3 of material. As preserved, the upper sheet has a volume of about 7 km^3.

Eveleigh Volcanic Subgroup

Introduction

The Eveleigh Volcanic Subgroup (Appendix), along with intrusive rocks, makes up the centred igneous structure in the eastern lobe of the Newcastle Range. In ascending stratigraphic order, formations in the subgroup are Yellow Jacket Rhyolite (which includes the Pint Pot Andesite Member), Beril Peak Rhyolite, Mosaic Gully Rhyolite, Canyon Dacite, and Shrimp Creek Rhyolite. Of these, the most extensive are the Mosaic Gully and Shrimp Creek rhyolites. None of the formations can be identified unambiguously in any other parts of the Newcastle Range.

Yellow Jacket Rhyolite (Ce)

The Yellow Jacket Rhyolite (Appendix) is exposed in an area of 45 km^2 around the eastern and northern to northwestern periphery of the eastern lobe of the Newcastle Range. The formation has one named member (Pint Pot Andesite Member), and several un-named ones.

The Yellow Jacket Rhyolite is a moderately heterogeneous formation dominated by brown and purple welded rhyolitic ignimbrite (Ce) with up to five sporadic impersistant intervals of volcaniclastic rocks (Ce_1) and scarce andesitic lava. Ignimbrites are moderately crystal-rich to to crystal-rich, with 5 to 30% quartz and feldspar crystals up to an average of 2 mm in maximum dimension. Volcaniclastic rocks in the Yellow Jacket Rhyolite range from lutite through dominant arenite to rudite with cobble-sized clasts.

The *Pint Pot Andesite Member* (Appendix) consists of greenish-grey sparsely porphyritic andesitic lava. It is associated with the uppermost volcaniclastic interval in the formation.

About 10 m of altered olivine dolerite occur locally in the middle part of the Yellow Jacket Rhyolite in the Pint Pot Creek area. The rock was included in the "middle composite member" by Branch (1966), but it probably occurs in a concordant intrusive sheet. Its age could be significantly younger than that of the Yellow Jacket Rhyolite, perhaps even Tertiary or Quaternary, in view of the fact that the basalt of Stockmans Hill near Einasleigh is intrusive, and of probable Oligocene age (I.W. Withnall & B.S. Oversby, unpublished data).

The Yellow Jacket Rhyolite has a thickness of 560 m in its holostratotype area (Appendix). Of this, 440 m consist of welded rhyolitic ignimbrite in at least four sheets. The remaining thickness is taken up by up to six (but more commonly two or three exposed) volcaniclastic rock intervals up to 120 m (but mostly about 30 m) thick underlying and intercalated with the ignimbrites. Approximately the same total thickness of Yellow Jacket Rhyolite is maintained throughout the outcrop area of the formation. The Pint Pot Andesite Member is about 10 m thick in the Pint Pot Creek Section, and up to about 150 m in the northwestern part of the eastern lobe of the Newcastle Range. Six sheets of welded ignimbrite are separated by volcaniclastic intervals in the Yellow Jacket Rhyolite along Miner Creek. Assuming that all six sheets were originally present throughout the eastern lobe of the Newcastle Range, though evidently not everywhere separated by volcaniclastic rocks, and that they maintained essentially constant thicknesses, volumes of (from lower to upper) 25 km^3, 37.5 km^3, 50 km^3, 25 km^3, 30 km^3 and 40 km^3 would be represented.

Beril Peak Rhyolite (Cd)

Beril Peak Rhyolite (Appendix) crops out in an area of 20 km^2 around the eastern and northern to northwestern periphery of the eastern lobe of the Newcastle Range. The formation consists of a single markedly homogeneous sheet of what was probably originally intensely welded ignimbrite; none of its characteristics, particularly the homogeneity and gradual nature of thickness variations in an extensive outcrop belt, are consistent with a rhyolitic lava or intrusive origin.

The rock of the Beril Peak Rhyolite is essentially crystal-free, and characteristically shows good development of columnar joints. Very attenuated small fiamme like structures are common, although they are more coarsely and irregularly microcrystalline than the average groundmass and may represent streaky concentrations of vapour-phase minerals rather than original pumice fragments. In overall aspect, Beril Peak Rhyolite is some shade, commonly slightly pink or orange, of mid brown grading to grey.

The Beril Peak Rhyolite has a thickness of 250 m in its holostratotype section (Appendix). It is possibly about 360 m thick in Pint Pot Creek. South of the holostratotype section area, the formation thins progressively to an estimated 120 m at the southeastern corner of the eastern lobe of the Newcastle Range. North of Pint Pot Creek, the formation evidently maintains a constant thickness of 200 to 300 m before apparently cutting out beneath Mosaic Gully Rhyolite on the western side of the range.

Assuming that Beril Peak Rhyolite originally had an average thickness of 250 m throughout 200 km^2 of the eastern lobe of the Newcastle Range, a volume in the order of 50 km^3 is suggested.

Mosaic Gully Rhyolite (Cc)

Mosaic Gully Rhyolite (Appendix) crops out in a large area (100 km^2) mainly in the north-central and eastern parts of the eastern lobe of the Newcastle Range.

The Mosaic Gully Rhyolite is a moderately homogeneous formation. It consists of a single sheet of orangey-brown crystal-rich welded rhyolitic ignimbrite with 40 to 50% quartz and feldspar crystals 1 to 4 mm in maximum dimension. Irregular chlorite-epidote aggregates reach 3% locally, and are mostly 1 to 2 mm across.

The Mosaic Gully Rhyolite has a thickness of about 1000 m in the area of its holostratotype section (Appendix). If this thickness was originally present throughout the eastern lobe of the Newcastle Range, a volume of 500 km^3 would have been present in the Mosaic Gully Rhyolite.

Canyon Dacite (Cb)

The Canyon Dacite (Appendix), which consists of two un-named members, crops out only in an area of slightly less than 10 km^2 in the southwestern part of the eastern lobe of the Newcastle Range.

The lower member of the Canyon Dacite (Cb_1) is a sequence of interbedded volcaniclastic arenite and subordinate siltite, with sporadic rudite in its upper part. The rudite contains clasts up to 1.2 m in maximum dimension, and may be a proximal fall deposit. The upper member of the formation (Cb) consists of purple, moderately crystal-rich to crystal-rich dacitic lava and welded ignimbrite with 5 to 30% quartz and feldspar crystals averaging 1 mm to 2.5 mm in maximum dimension. Epidote pseudomorphing hornblende(?) occurs sporadically. The respective thicknesses and distributions of lava and ignimbrite in the upper Canyon Dacite overall are not known.

The lower member of the Canyon Dacite in the formation's holostratotype area (Appendix) has an estimated thickness of 120 m. The upper member is about 550 m thick. Both members disappear beneath the unconformably superjacent Shrimp Creek Rhyolite.

Shrimp Creek Rhyolite (Ca)

Shrimp Creek Rhyolite (Appendix) crops out, or is obscured by thin cover, in an area of 165 km^2 in the central and southern parts of the eastern lobe of the Newcastle Range. The original top of the formation is not preserved.

The Shrimp Creek Rhyolite is a markedly homogeneous formation which characteristically resembles an intrusive microgranitoid. It consists of grey to pale orangey-red welded rhyolitic ignimbrite. The rock is moderately crystal-rich to very crystal-rich, and contains ubiquitous biotite and hornblende. The lower part of the sheet has about 25%, increasing upwards to about 50%, quartz and feldspar crystals up to about 3 mm in maximum dimension. Sporadic sparse (less than 1%) partly altered (chloritised) hornblende crystals up to about 1 mm long also occur in this part of the sheet.

The middle and upper parts of the ignimbrite sheet have 40% to slightly more than 50% quartz and feldspar crystals, and up to 10% (but mostly about 3%) biotite and/or hornblende in single crystals and aggregate up to 1.5 mm and 5 mm in maximum dimension respectively.

Preserved thicknesses of Shrimp Creek Rhyolite in its holostratotype and hypostratotype areas (Appendix) are estimated at 500 m and 560 m, respectively; the volume of material present is about 80 to 90 km^3. Assuming that the formation originally occurred uniformly throughout the whole area of the eastern lobe of the Newcastle Range, it would have had a minimum volume of about 250 km^3.

Discussion

Correlation of Newcastle Range Volcanic Group Units

Available isotopic data do not give sufficient resolution for detailed correlations within the Newcastle Range Volcanic Group. However, correlations between sequences in the southern lobe, central isthmus, and northern lobe of the range are moderately good to good because of overlapping and interfingering relationships in an essentially continuous outcrop belt. Particularly important relationships are Bousey Rhyolite beneath Routh Dacite, and Brodies Gap Rhyolite above Corkscrew Rhyolite.

In contrast, correlations between the structurally juxtaposed southern and eastern lobes of the Newcastle Range are uncertain because no units are recognised as being shared. The Gilberton Formation beneath the extrusive sequences of both lobes suggests that they were at comparable elevations at the onset of extrusive activity. This implies that at least the product(s) of initial activity in one of the lobes should have had some representation in the other lobe's sequence. The distinctive Beril Peak Rhyolite of the eastern lobe can be ruled out as a unit shared with the southern lobe sequence as currently known. However, there are general similarities between the collectively heterogeneous Yellow Jacket plus Mosaic Gully rhyolites (eastern lobe) and the Bousey Rhyolite (southern lobe), and it may be that unrecognisable (on the basis of current data) interfingering relationships are present in these parts of the sequences.

Similarities of Jinker Creek Rhyolite to Shrimp Creek Rhyolite are believed to be outweighed by differences between them. The two formations are not now directly correlated, as they were previously (e.g. Oversby, & others, 1980).

The Canyon and Routh dacites may broadly represent a single magmatic event, although they cannot be regarded as the same lithostratigraphic entity.

Preliminary magnetostratigraphic data (J. Giddings & M. Idnurm, personal communications) indicate that Gilberton Formation remnants in the southern and eastern lobes of the Newcastle Range have normal polarity. The lower, middle, and upper parts of both Bousey and Yellow Jacket rhyolites show a pattern of reverse-normal-reverse polarity. These data support the otherwise tenuous case for some degree of interfingering between the extrusive sequences in the southern and eastern lobes (see above).

Implications of inability to correlate juxtaposed sequences

On the other hand, there really may be no temporal correspondence between the southern and eastern lobe sequences, as the lack of ability to clearly recognise any shared units despite their juxtaposition most strongly suggests. This implies that each somehow acted as an independent depocentre. In turn this might be taken to indicate that the sequences represent the infillings of autonomous negative topographic features, such as steep-walled calderas. This is thought not to be the case because of the lack of coarse clastic rocks representing talus and alluvial fans formed by the degradation of caldera walls. Also, there is a notable scarcity of basement material in clastic intervals, even low in the sequences; formation of calderas, particularly by catastrophic collapse, would presumably have initially exposed mainly basement rocks around the margins.

The existance of palaeotopographically positive extrusive features (below) is in no way ruled out by available data.

Extrusive palaeotopography

An alternative scenario permitted by available data envisages each sequence as having been preceded by some degree of uplift in its source area; this uplift was succeeded and progressively emphasised by the construction of a broad ignimbrite dome (cf. Baker, 1981) during main phase (ignimbritic) extrusive activity. Most, or all, pyroclastic flows from external sources were diverted around the uplift, rather than being deposited on it. The basinal centred igneous forms seen now would be later (and deeper) superimposed structural features (below). Periodic and transient episodes of neutral or basinal palaeotopography would not affect the overall tendency for accumulation of extrusive material, and need not significantly affect the construction of a domal palaeotopography.

The slightly thinnner development of Brodies Gap Rhyolite in the northern lobe of the Newcastle Range relative to that in the central isthmus is consistent with the lobe having been a positive feature during extrusion and accumulation of the unit.

The apparent extension of only the middle ignimbrite sheet of the Bousey Rhyolite into the southern part of the central isthmus of the Newcastle Range suggests that the Wirra Cauldron was at least locally and temporarily negative and capable of restricting outflow of the lower Bousey Rhyolite, however.

None of the other Carboniferous and presumed Carboniferous ignimbrite-dominated sequences in the Georgetown Region can be confidently correlated directly with any part of the Newcastle Range Volcanic Group. This problem of inability to identify common denominators, even in juxtaposed and closely adjacent extrusive sequences which appear to be of essentially the same age, is additional support for the concept that constructional palaeo-land forms were widespread during ignimbrite volcanism. The resultant problem of correlation will be addressed further below; it has become significant and an ever present one.

Extrusive trends

In general terms, the Newcastle Range Volcanic Group represents a series of overlapping cycles which reflect an overall pattern of decreasing variability of extrusive processes coupled with eruption of increasingly voluminous pyroclastic flows through time. The pattern is most marked in the Wirra and Eveleigh subgroups, where there are respectively, (a) lower associations of thin (less than 100 m) to moderately thick (100 to 500 m) ignimbrite sheets with volcaniclastic intervals and compositionally variable lavas, and (b) upper intervals of the massive, crystal-rich, and mafic-bearing Jinker Creek and Shrimp Creek rhyolites. In detail, the pattern in the Eveligh Volcanic Subgroup is perturbed by thin dacitic lavas and ignimbrites with volcaniclastic rocks (Canyon Dacite) between thick Mosaic Gully and Shrimp Creek ignimbrite sheets.

The Namarrong Volcanic Subgroup also shows some development of the pattern, particularly in the Cumbana Rhyolite. However, the Kungaree subgroup as preserved has not progressed beyond the stage of maximum heterogeneity of its extrusive assemblage, with only minor ignimbrite sheets relative to other Newcastle Range Volcanic Group sequences.

Superimposed on the upwardly increasing homogeneity in the Wirra and Eveleigh subgroups is a tendency for crystals in ignimbrites to attain maximum content and size at stratigraphically high levels. Also, biotite and/or hornblende become ubiquitous only at such levels. This zonation is also evident within some single thick ignimbrite sheets, notably the Shrimp Creek Rhyolite. A conspicuous reversal of the tendency is seen in the essentially crystal-free Beril Peak Rhyolite, lying between crystal-bearing ignimbrites in the Yellow Jacket and Mosaic Gully rhyolites. Similar zonation occurs in the Namarrong subgroup, but is not apparent in the Kungaree sequence as preserved.

Other Carboniferous ignimbrite-dominated sequences in the Georgetown region (discussed further below) are heterogeneous, with only thin to moderately thick ignimbrite sheets. Systematic primary zoning is not apparent either at the scale of single ignimbrite sheets, or of whole sequences as preserved.

Primary zonation features in ignimbrites of the kinds described above, particularly when developed in single voluminous sheets, are routinely interpreted as inverted representations of pre-eruptive vertical zonation in source magma chambers (e.g. Smith & Bailey, 1966; Lipman, & others, 1966; Wright & Walker, 1977; Smith, 1979; Hildreth, 1979, 1981). Marked perturbations in zoning could be caused by a variety of factors, including tapping of different magma chambers, and withdrawal from different levels within the one chamber. Equivalent zonations spread through entire stratigraphic sequences (representing broader evolutionary progressions), as in the Newcastle Range Volcanic Group, would presumably reflect longer-term developments of the entire magmatic system. Pyroclastic flows would become more voluminous as increasing quantities of melt became available for tapping at any one time. As the quantities of melt concentrated into single magma chambers increased, so would the tendency for those portions drawn off by extrusion to be increasingly homogeneous.

The combination of features shown collectively by the subgroups in the Newcastle Range Volcanic Group is consistent with an overall long-term evolutionary progression from an early phase of "immature" extrusive activity emanating from small and/or scattered and/or deep magma chambers, to later "mature" activity in which magma was withdrawn in greater volumes from larger and/or shallower single sources. This progression would be a reflection of the ascent and coalescence of magma into batholith-scale chambers. The stage reached by the progression in any one area must have been a function of many interacting variables. The observation that ignimbrite-dominated activity in the Georgetown Region, other than in those parts of the Newcastle Range discussed above, did not progress beyond a relatively "immature" stage of development implies that upper crustal batholith emplacement was less advanced in most parts of the Region than it was beneath the site of the Newcastle Range.

It is suggested that the heterogeneous lower parts of sequences are made up of the products of relatively small, scattered, and perhaps deep, magma chambers. Ascent(?) and eventual coalescence of these resulted in a crude zonation, and in production of the upper ignimbrites. A similar pattern of magma chamber ascent and growth through time has been inferred semi-independently from ignimbrite geochemistry in the Featherbed Volcanic Group of the Chillagoe district (Mackenzie, 1987b,1988).

A feature of the Maureen and Cumberland Range volcanic groups, as well as of Dismal Creek Dacite and Paddock Creek Formation (below) is that dacitic ignimbrites are appreciably more common than in any of the Newcastle Range Group's sequences, to the extent of being characteristic of the units.

Ignimbrite volumes

Making the reasonable assumption that Mosaic Gully Rhyolite, which appears to be a single cooling unit, was originally present as a sheet of uniform thickness at least throughout the entire area of the eastern lobe of the Newcastle Range, its volume of 500 km^3 or (probably) more would be well within the range of Caldera-forming eruptions (Smith, 1960). The Shrimp Creek and Jinker Creek rhyolites were almost certainly originally appreciably more voluminous than the Mosaic Gully Rhyolite. Reconciliation of this observation with ones that suggest absence of calderas requires some important differences between the site of the Newcastle Range and areas of "classical" caldera-generating activity.

The presently known Newcastle Range Volcanic Group rocks (and the other ignimbrite-dominated units in the Georgetown Region) apparently contain most, if not all, coeval extrusive centres. The occurrences are consequently believed to essentially coincide with the areas of original maximum development of sequences. These areas, in turn, presumably coincide with sites of maximum syn-extrusive extension and subsidence. This postulate involves no presumption as to whether or not the areas were necessarily also sites of collapse calderas.

Intrusive Rocks associated with the Newcastle Range Volcanic Group

Introduction

Intrusive rocks associated spatially, and probably broadly genetically, with the Newcastle Range Volcanic Group occur as dykes, plugs, stocks and sheets within and/or adjacent to the outcrop area of extrusive rocks; many form irregular external swarms which follow the overall northerly to north-northeasterly trend of the Newcastle Range, or partly mimic the form of one of its lobes. Rocks within the miscellaneous acid suite (CPr-below), present in swarms with a more nearly linear northwesterly trend, are believed to be of Permian age, and so are excluded from this discussion. Elizabeth Creek Granite is also excluded because, although it is intimately associated with the northern lobe of the Newcastle Range, it is probably not closely related to the extrusive rocks preserved there.

Tenavute Microgranite (Cgh)

By definition (Appendix), the Tenavute Microgranite is associated only with the centred igneous structure (Wirra Cauldron) making up the southern lobe of the Newcastle Range. It appears to cut mainly MacCallor Microgranodiorite, and is faulted against Bousey Rhyolite in the zone between the southern lobe and central isthmus of the range.

The principal occurrence of Tenavute Microgranite is in an outcrop area of 40 km^2. Sporadic minor representatives of rocks assigned to the unit are also present in dykes and plugs in and around the southern lobe of the Newcastle Range. Branch (1966) did not differentiate Tenavute Microgranite as a distinct unit.

Tenavute Microgranite is a moderately homogeneous elvan-type microgranite. Most rocks assigned to the unit are pale to mid orangey-grey or brown. They are abundantly and conspicuously porphyritic, and contain 30 to 40% quartz and feldspar phenocrysts. Quartz phenocrysts average 2 to 4 mm in maximum dimension; feldspar phenocrysts are mostly in the range 3 to 7 mm. Up to 5% chlorite aggregates occur as discrete specks and diffuse patches up to several millimetres in maximum dimension, in both feldspar crystals and groundmass. At least some of this chlorite has probably replaced biotite.

As currently exposed, Tenavute Microgranite intrudes up to the level of Jinker Creek Rhyolite (Wirra subgroup). The microgranite is assumed to be of only slightly younger Carboniferous age than that formation.

Mount Departure Microgranite (Cgi)

By definition (Appendix), the Mount Departure Microgranite is associated mainly with the northern lobe of the Newcastle Range. The unit occurs in high-angle discordant plugs and dykes mainly cutting Proterozoic basement rocks, Brodies Gap Rhyolite, and unassigned intrusive rhyolites and microgranites marginal to and up to 2 km beyond the northeastern and northern peripheries of the outcrop of extrusive rocks, Gilberton Formation, and unassigned rhyolites and microgranites. It passes westwards into the extrusive sequence (and concordant rhyolite-microgranite sheets), where it becomes gently inclined and concordant with the enclosing rocks.

Microgranite in a high-angle discordant body at the southern edge of the Cumbana Rhyolite is also assigned to Mount Departure Microgranite.

The Mount Departure Microgranite is an elvan-type rock, lithologically identical to Tenavute (above) and Caterpillar (below) microgranites in all essential respects.

As currently exposed, rocks assigned to the Mount Departure Microgranite intrude up to the level of the middle part of the Brodies Gap and Cumbana Rhyolites. The unit is assumed to be of only slightly younger Carboniferous age than those formations.

Talaroo Microgranite (Cgj)

Talaroo Microgranite (Appendix) occurs only in two north-northwest-elongated plugs 20 km northeast of Georgetown. The plugs cut mainly welded ignimbrites of the Corkscrew and Brodies Gap rhyolites. The larger (eastern) of the two bodies has a surface area of nearly 5 km^2. The smaller western body crops out in an area of 0.5 km^2.

The Talaroo Microgranite is a moderately homogeneous grey to dark reddish-brown elvan. Rocks assigned to the unit are abundantly porphyritic, and contain 40 to 50% quartz and feldspar phenocrysts mostly up to 5 mm in maximum dimension. The rocks locally have up to 5% hornblende and subsidiary biotite crystals up to 3 mm in maximum dimension. Rare fine-grained equigranular hornblende-feldspar aggregates are up to about 4 mm in maximum dimension. Angular to subrounded xenoliths of coarse-grained hornblende-bearing granitoid occur locally. Similar granitoid also cuts the Talaroo Microgranite as minor veins.

The hornblende and biotite content distinguishes Talaroo Microgranite from superficially similar Tenavute, Mount Departure, and Caterpillar microgranites.

As currently exposed, rocks assigned to the Talaroo Microgranite intrude up to the level of the lower sheet of Brodies Gap Rhyolite ignimbrite. The unit is assumed to be of only slightly younger Carboniferous age than the Brodies Gap Rhyolite.

Caterpillar Microgranite (Cgk)

By definition (Appendix), Caterpillar Microgranite is associated with the eastern lobe of the Newcastle Range. It is extensively developed in dykes, plugs, stocks, and concordant (relative to enclosing extrusive rocks) sheets outside, around, and within the lobe. The most widespread occurrence of the unit is in a 16 km^2 area in the north-central part of the lobe. A smaller (5 km^2) area is at the lobe's northeastern corner.

Caterpillar Microgranite is a moderately homogeneous elvan, lithologically identical to Tenavute and Mount Departure microgranites in all essential respects.

As currently exposed, rocks assigned to the Caterpillar Microgranite intrude up to the level of the lower part of the Shrimp Creek Rhyolite. The unit is assumed to be of only slightly younger age.

MacCallor Microgranodiorite (Cgl)

The MacCallor Microgranodiorite (Appendix) cuts mainly Bousey Rhyolite in the southern lobe and southern third of the central isthmus of the Newcastle Range.

The unit occurs in five, rather irregular but mostly north-northwest-elongated, discordant stock-like bodies. The most extensive of these, in the western part of the southern lobe of the range, occupies an area of 12 km^2. The two main bodies of the microgranodiorite in the southern lobe of the Newcastle Range may, with associated faults, mark the site of a partial internal ring-dyke structure. Cumulatively, outcrop areas of MacCallor Microgranodiorite total slightly more than 30 km^2.

MacCallor Microgranodiorite is homogeneous unit of broadly elvan type. It is typically pale to mid orangey to greenish-brown, and moderately to abundantly porphyritic, with 20 to 40% mainly feldspar phenocrysts 2 to 6 mm (but locally up to 1.5 cm) in maximum dimension. Quartz phenocrysts constitute only up to about 1% of the rock; they average 1 mm in maximum dimension, with a few reaching 4 mm. MacCallor Microgranodiorite is further characterised by 5 to 20% groundmass chlorite and chlorite-feldspar aggregates, locally up to more than 2 cm across.

MacCallor Microgranodiorite as currently exposed intrudes up to the level of the middle Bousey Rhyolite welded ignimbrite sheet. The unit is assumed to be of only slightly younger age than the ignimbrite.

Mopata Microgranite (Cgd)

Rocks assigned to Mopata Microgranite (Appendix) cut the Wirra Volcanic Subgroup. The unit crops out as small (up to 0.5 km^2 in outcrop area) plug-like bodies in the east-central part of the southern lobe of the Newcastle Range, 30 km east-southeast of Forsayth.

The Mopata Microgranite is a moderately homogeneous elvan, with many similarities to the Eva Creek Microgranite (below) of the latter's main outcrop area. The rock is pinkish to greenish-grey to brown, and moderately to abundantly porphyritic. It contains up to 40% quartz and feldspar phenocrysts, with quartz markedly subsidiary. The largest phenocrysts are commonly about 1 cm across. About 2% biotite and hornblende occur in single crystals and aggregates up to 10 mm in maximum dimension.

Rocks assigned to the Mopata Microgranite intrude up to the level of Jinker Creek Rhyolite. The unit is assumed to be of approximately the same age as the Eva Creek Microgranite (below).

Eva Creek Microgranite (Cgf)

Rocks assigned to this unit (Withnall & others, 1976) cut Einasleigh Metamorphics, Eveleigh Volcanic Subgroup formations, and Caterpillar Microgranite. The main body of Eva Creek Microgranite crops out in an area of 8 km^2 in the northern part of the eastern lobe of the Newcastle Range, 45 km east of Georgetown. A subsidiary body of slightly less than 1 km^2 outcrop area occurs 2 km southwest of the main one. A shallowly-dipping concordant sheet of Eva Creek Microgranite, probably connected to the main body at shallow depth (or originally connected at a level slightly above the current erosion surface) is exposed at the northern edge of the the eastern lobe of the range. Plug to dyke-like bodies with rocks assigned to the unit cut Einasleigh Metamorphics outside the eastern lobe, 7 km west-southwest of "Eveleigh", and at Mount "Alder" (believed to be a misprint for Adler—the surname of a manager at the Einasleigh Mine in about 1910–Marks, 1911), at the northern end of the Caterpillar Hills dyke system 10 km north of Einasleigh.

As currently defined, Eva Creek Microgranite is a moderately homogeneous unit. In its principal and subsidiary outcrop areas, it consists of mainly grey, abundantly porphyritic, biotite microgranite to fine-grained granite. The rock typically has 25 to 50% quartz and feldspar phenocrysts mostly up to 1 cm in maximum dimension; quartz is characteristically subordinate to feldspar. Up to 10% biotite occurs as single crystals and aggregates up to 2 mm in maximum dimension. Groundmass textures are microequigranular to locally fine (macro-)equigranular.

Rocks assigned to the Eva Creek Microgranite in the concordant sheet at the northern edge of the eastern lobe of the Newcastle Range, and at Mount "Alder", are pale green to pale brown, and contain 30 to 40% quartz and feldspar phenocrysts up to 5 mm (quartz) and 2 cm (feldspar) in maximum dimension. Up to 10% variably chloritised biotite crystals and aggregates up to 4 mm in maximum dimension also occur. Groundmass textures are mostly micrographic (granophyric) to locally microequigranular. The isolated plug 7 km west-southwest of "Eveleigh" consists of a very pale brown vughy and altered porphyritic granophyre with 20% quartz phenocrysts up to 4 mm in maximum dimension, and 20% extensively chloritised biotite.

As currently exposed, rocks assigned to the Eva Creek Microgranite intrude up to the level of Mosaic Gully Rhyolite; they also appear to intrude Caterpillar Microgranite. Whole-rock and biotite Rb-Sr isotopic data indicate ages of 320 Ma and 317 Ma (early Late Carboniferous), respectively, for the Eva Creek Microgranite. This is statistically younger than the pooled age of about 327 Ma for extrusive rocks of the Newcastle Range Volcanic Group.

Lubrina Granite (Cge)

Lubrina Granite (Appendix) crops out in a single, nearly rectangular, area of about 3 km^2 at the northwestern corner of the northern lobe of the Newcastle Range, 40 km north-northeast of Georgetown. The unit cuts Robertson River Subgroup (Lane Creek Formation) and Cobbold Metadolerite, and also appears to cut Mount Departure Microgranite.

Lubrina Granite is an homogeneous lecucocratic pinkish grey, fine-grained, sparsely to abundantly porphyritic biotite granite. The rock contains up to 30% quartz and feldspar phenocrysts up to about 1 cm in maximum dimension. Quartz is markedly subsidiary to feldspar; up to 5% biotite crystals and aggregates, mostly about 2 mm in maximum dimension, also occur. The groundmass of the rock is finely macroequigranular.

Lubrina Granite is assumed to be of approximately the same early Late Carboniferous age as Eva Creek Microgranite (see above), even though two isotopic Rb-Sr whole-rock analyses from the unit define an age of 331 Ma. This relatively old age may be an artefact of inadequate sampling.

Elizabeth Creek Granite sensu stricto (Cgg)

The name Elizabeth Creek Granite has been widely, but rather uncritically, applied throughout northeastern

Queensland in the past to virtually any late Palaeozoic intrusive assemblage dominated by coarse, generally pink, biotite leucogranite. It is now clear that many of these identifications have been of Elizabeth Creek-type granite(s), or "Elizabeth Creek Granite" *sensu lato*; these rocks evidently differ widely from area to area in age and affiliations to other intrusive and extrusive units.

The 1:2500 000 Georgetown Sheet area is notable in that it contains Elizabeth Creek Granite, *sensu stricto* (Appendix); this crops out in a total area of 250 km^2, which includes the nominated type locality. The region is thus critical to characterisation and understanding of the unit. The Georgetown region's outcrop area makes up the westernmost extremity of an extensive pluton ("Cumbana Batholith" of Richards, 1980, but in view of the formal stratigraphic pre-emption of the geographic name here referred to as the "Fulford Batholith", after a major creek which drains it and joins the Lynd River at 7762–077418). The pluton extends from the northernmost end of the Newcastle Range to the eastern edge of the Georgetown region sheet area, and continues for another 70 km farther east.

In the Georgetown Sheet area, Elizabeth Creek Granite mostly makes up a western, roughly rectangular, stock ("Mount Noble Stock", after the hill opposite the confluence of White Springs Creek and the Einasleigh River at 7661–058049) of 150 km^2 outcrop area. This Mount Noble Stock is connected to the main part of the Fulford Batholith by a narrow (1 km minimum) neck. A small plug of rocks assigned to Elizabeth Creek Granite 1 km west of the edge of the Mount Noble Stock probably represents an apophyse protruding from the upper surface of a shallowly buried extension of the stock.

Grey to pink and leucocratic, medium to coarse-grained equigranular, biotite granite dominates the Elizabeth Creek Granite. The rocks have 1 to 5% biotite crystals up to 1 mm long. Aplitic veins and patches are moderately common; pegmatites occur in a number of places. The rocks are sporadically greisenised. With decreasing grain size, particularly marginally, this equigranular granite grades locally through an inequigranular medium-grained variety into abundantly porphyritic fine-grained granite and micrographic microgranite. The latter is close to elvan; it contains up to 40% subequal quartz and feldspar phenocrysts up to 4 mm in maxiumum dimension.

In some parts of the eastern Mount Noble Stock, and possibly elsewhere in the Fulford Batholith, leucocratic biotite granite cuts mainly mid-grey, fine-grained equigranular and variably porphyritic, biotite granite with up to 20% subequal quartz and feldspar phenocrysts up to 1 cm (quartz) and 5 cm (feldspar) in maximum dimension, and 10 to 15% biotite crystals up to 1 mm long. This rock commonly occurs as irregular to subspherical, subrounded to rounded, xenoliths up to 1 m across in the leucocratic granite.

Two roof pendants made up mainly of Dagworth Andesite occur in the west-central part of the Mount Noble Stock.

Elizabeth Creek Granite is surrounded by a moderately conspicuous contact metamorphic aureole within which Proterozoic and older late Palaeozoic rocks have been recrystallised. The true width of the aureole is about 200 m, although a much greater width is apparent locally where the granite contact dips gently.

As currently exposed, Elizabeth Creek Granite *sensu stricto* cuts Brodies Gap and Cumbana rhyolites (upper Namarrong Subgroup, Newcastle Range Volcanic Group). Richards, & others (1966) obtained a K-Ar biotite age from Elizabeth Creek Granite in the holostratotype area (Appendix) of 306.4 Ma (recalculated). A biotite/whole-rock pair from the same area has indicated a probable maximum Rb-Sr isotopic age of 318 Ma.

Miscellaneous acid intrusive rocks (part of CPr)

Most of those miscellaneous acid intrusive rocks (CPr) associated with the Newcastle Range Volcanic Group occur as steep dykes, although concordant (with respect to extrusive hosts) sheets are present in the northern, eastern, and probably southern lobes of the Newcastle Range, as well as on the western side of the central isthmus of the range. Commonly, individual intrusive bodies and swarms, which are high-angle dykes where they cut basement rocks, are reoriented into concordance where they pass upwards into the Gilberton Formation and Newcastle Range Volcanic Group rocks. This is most conspicuously the case in the northern lobe of the range.

The acid intrusive rocks form a moderately heterogeneous assemblage, consisting of various aphyric to abundantly porphyritic rhyolites and microgranites. Where present, both quartz and feldspar phenocrysts range in maximum dimension from less than 1 mm to about 1 cm. Up to 25% specks and irregular sharp to diffuse patches of chlorite occur moderately commonly, but are not ubiquitous. About 1% fresh biotite is present in a few of the rocks. Groundmass textures are very finely to coarsely microequigranular to micrographic.

Many of the intrusive rhyolites resemble Corkscrew Rhyolite lava and ignimbrite of the Kungaree Volcanic Subgroup. This resemblance suggests that the intrusive and extrusive rocks are broadly cogenetic and of much the same Carboniferous age. Rhyolites in which phenocrystic feldspar is dominant over quartz are intergradational with, or older than, some elvans where the two lithologies occur in single intrusive bodies. They are older than: (a) named elvans, such as Tenavute Microgranite, in any single area; (b) un-named sparsely porphyritic dacites (below) to the east of the central isthmus of the Newcastle Range south of the Gulf Developmental Road; and (c) un-named, mostly sparsely to moderately porphyritic rhyolites in which quartz and feldspar phenocrysts are subequal, occurring in a northwest-trending linear zone of partly *en echelon* (Permian?—see below) dykes extending for 15 km between the northwestern part of the eastern lobe of the range and the vicinity of the Delaney Fault north of Georgetown.

Some microgranites in this miscellaneous grouping are elvans identical to Tenavute, Mount Departure, and Caterpillar Microgranites, although not in localities appropriate for formal assignment to those units.

Miscellaneous intermediate to basic intrusive rocks (part of CPa)

Miscellaneous intermediate to basic intrusive rocks in small bodies are rare in and around the outcrop area of the Newcastle Range Volcanic Group. The assemblage includes aphyric to moderately porphyritic dacites to microgranodiorites, quartz-trachyandesites to micromonzonites, andesites to microdiorites, a single olivine micro-gabbro, and local dark-coloured sparsely porphyritic lamprophyric rocks. Such rocks (with the exception of the lamprophyric ones which are rather exceptional) are locally marginal to acid ones in single intrusive bodies, especially dykes; they appear to be in part older, and in part younger, than the acid constituents. Intrusive dacites are known mainly from the east of the central isthmus of the Newcastle Range, south of the Gulf Developmental Road, where they are older than associated miscellaneous rhyolites (see above).

Discussion

The present outcrop area of the Newcastle Range Volcanic Group is delineated in many places by one or more of the associated intrusive units. This delineation is most nearly complete around the eastern lobe of the range, where Caterpillar Microgranite partly defines a polygonal ring-dyke system.

Since none of the intrusive units associated with the Newcastle Range Volcanic Group occupies a completely closed ring system, none of the extrusive blocks could have subsided uniformly as a single piston-like entity, although trapdoor-style or irregular subsidence could have taken place. Further, as discussed above, subsidence apparently took place at depth without being significantly propogated through to the palaeosurface and manifested in collapse, at least not during the time interval(s) during which preserved extrusive sequences were accumulating.

None of the stock-like bodies intruding Newcastle Range Volcanic Group is known to have domed the extrusive rocks, so that structural resurgence was not a feature of the group's evolution.

Since extrusive units in much of the Newcastle Range Volcanic Group young from south to north, it is assumed that the main intrusive units, and the structures which they delineate or occupy, do likewise.

"Depth aspect" of intrusive rocks and bodies

Among the acid intrusive rocks in many areas, such as the eastern and northern lobes of the Newcastle Range, there is a common tendency for aphyric to porphyritic, dyke and plug forming, rhyolitic to microgranitic rocks to be older than the markedly porphyritic elvans. These elvans occur in dykes, plugs, and small stocks and are commonly the most voluminous, as well as the most conspicuous, components of ring-dyke structures.

In their turn, elvans tend to cut across (or in some instances are marginal to) the variably porphyritic fine-grained granites of Eva Creek and Lubrina type. These granites commonly occur in small to medium-size stocks. Mafic minerals generally become common only at this stage.

The apparent progression culminates in coarse equigranular granites of Elizabeth Creek type, occupying large stocks and batholiths.

There is probably a similar progression among the intermediate to basic intrusives. The progression is not so clearly developed as among their acid counterparts, however, but perhaps only because of their scarcity at the structural level(s) now exposed.

The textural and structural progressions described above represent a qualitatively increasing "depth aspects" of the intrusive rocks and bodies. The "aspect" has undoubtably been influenced, if not controlled, by factors other than depth of emplacement *per se*, and so cannot be objectively quantified. Among these other factors would be: increasing heat flow; variable compositions and volatile contents of magmas, and; decreasing strength of wall rocks. Such factors might cause local and/or transient peturbations in the overall progression; they could be a function at least in part of magma-chamber zoning, and/or systematic long-term and large-scale variations in the entire tectonic-magmatic system. However, the overall progression is envisaged as a broad reflection of the medium to long-term ascent of a magma chamber system towards and into subvolcanic environments concomitant with extrusive activity, thickening of hot extrusive accumulations, and structural adjustments as appropriate.

With a few exception (the Eveleigh–Wirra and Bagstowe–Lochaber pairs of centred igneous structures), acid intrusive progressions in different areas do not significantly overlap, so that they are of no help in inferring relative ages of various extrusive sequences or of their structural frameworks. It is also difficult to judge the frequency with which short to medium-term intrusive progressions of the type discussed above (as well as extrusive zonations) might have been repeated in the region.

Maureen Volcanic Group

Introduction

The Maureen Volcanic Group (Appendix) is preserved in an independent subsidence structure of basinal form, with only rare intrusive rocks, 25 km west of the northern lobe of the Newcastle Range. The group crops out in an area of 80 km^2, and may extend farther northwest beneath Mesozoic and Cainozoic cover as far as 250 km.

The Maureen Volcanic Group contains Ironhurst Formation and the overlying Puranga Rhyolite, both of which contain subunits, named and un-named, of member status (Fig. 3; Appendix). Both formations are dominated by welded rhyolitic ignimbrite, although the Ironhurst Formation in particular has a substantial proportion of andesites and other intermediate rocks. Dips where measurable are moderate to gentle towards the centre of the basin. The Group is about 1000 m thick over most of its outcrop area; it attains a maximum thickness of about 1500 m near the Maureen prospect.

Rocks of the Maureen Volcanic Group either overlie Gilberton Formation in an apparently concordant—i.e. either conformable or disconformable—relationship, or rest directly, with major unconformity, on Proterozoic basement. The Group is overlain unconformably by Mesozoic and Cainozoic rocks, particularly in the north.

There is no direct independent evidence for the age of the Maureen Volcanic Group. Its proximity and overall similarity to the Newcastle Range Volcanic Group suggest a similar age.

Ironhurst Formation (Cr)

The Ironhurst Formation (Appendix) is the most extensive unit in the exposed part of the Maureen Volcanic Group; it crops out in a total of about 60 km^2, and is present in all but the northeastern and north-central parts of the outcrop area of the group. Total thickness ranges from about 600 m in the east (Maureen prospect area) to about 350 m in the west.

The Ironhurst Formation is markedly heterogeneous: the lowermost part of the formation in the holostratotype area (Appendix) consists of 100 m of aphyric to sparsely porphyritic rhyolite lavas interbedded with vitric volcaniclastic siltite (Cr_1). Coarsely autobrecciated aphyric lava, with clasts up to 3 m in maximum dimension, merges with a stock-like body of intrusive rhyolite 1 km north-northwest of Getty–CCE camp (7561–571078; Fig. 5). Overlying this lowermost part of the Ironhurst Formation is an interval, ranging from a few metres to 150 m thick, dominated by volcaniclastic arenite and siltite, and probable vitric fine-ash tuff, with interbedded rhyolitic ignimbrite, volcaniclastic rudite, and sparsely porphyritic lava (Cr_3).

These parts of the lower Ironhurst Formation pinch out laterally beneath Mesozoic cover about 4 km south-southwest of the holostratotype area. Their place is taken by a 100 to 300 m-thick sheet of welded rhyolitic ignimbrite (Cr_2) which crops out around the remainder of the periphery of the Maureen Volcanic Group. The lower part of this ignimbrite sheet is pale yellow-brown to grey and contains 5 to 10% quartz, feldspar, and biotite crystals (up to 2 mm), and sporadic lithic fragments up to 8 mm across. The upper part of the sheet is dark brownish grey to very dark-grey, lithic-rich (including andesite clasts), and slightly more mafic than the lower part; it is best developed in the western part of the exposed Ironhurst Formation.

The succeeding stratigraphic unit, the *Ant Hill Andesite Member* (Cr_a) (Appendix), is 50 to 120 m thick. It crops out discontinuously from 2 km west-northwest of the Getty–CCE camp, southwestwards and westwards to the Etheridge River, and then for 4 km along the river, in a total area of about 17.5 km^2. In most of its outcrop area, the andesite consists of a series of lava flows. However, in the holostratotype area it is doleritic and appears to be locally discordant; it may partly be a concordant sheet-like intrusive body. The Ant Hill Andesite Member is very dark grey to greenish grey, aphyric to microporphyritic, augite-bearing, and ranges in composition from trachyandesite to basaltic andesite.

The Ant Hill Andesite Member of the Ironhurst Formation is overlain by the *Womblealla Rhyolite Member* (Cr_w) (Appendix). This member crops out discontinuously in a 4 to 5 km-wide strip from 5 km northwest of the Maureen prospect area (Fig. 5) to, and along, the Etheridge River. It is 200 to 250 m thick. In the holostratotype area, near the Maureen main deposit, the Womblealla Rhyolite Member consists of moderately crystal-rich to crystal-rich and moderately lithic-rich welded rhyolitic ignimbrites and minor volcaniclastic siltite and arenite. The ignimbrites contain between 15 and 40% quartz and feldspar crystals up to 2 or 3 mm in maximum dimension, and rare chloritised biotite; altered xenocrysts of pyroxene and/or olivine also occur in some rocks.

Crystal contents of welded ignimbrites in the Womblealla Rhyolite Member decrease westward away from the holostratotype area: ignimbrites near the Etheridge River have between 3 and 5% quartz and feldspar crystals 0.5 to 2 mm in maximum dimension, and sparse biotite. Abundances of altered ferromagnesian crystals and xenocrysts in both crystal-rich and crystal-poor ignimbrites tend to increase upwards, and andesite fragments appear in the uppermost parts.

About 7 km southwest of the Getty–CCE camp, rocks of the Womblealla Rhyolite Member have been extensively fractured, possibly by overpressured hydrothermal fluids, and intensely altered.

The Womblealla member is overlain in the holostratotype area by an un-named andesite (Cr_4) about 60 m thick. Like the Ant Hill andesite, this sparsely porphyritic augite andesite is probably partly extrusive (lava) and partly intrusive. About 3 km west-northwest of the Getty–CCE camp it is fragmented and intensely altered. An isolated dacite above the Womblealla Rhyolite Member in the south-central part of the outcrop area of the Maureen Volcanic Group has been assigned to this unit; it contains biotite, ortho- and clinopyroxene, and b-quartz with pyroxene reaction rims, and is probably of hybrid origin.

Puranga Rhyolite (Cq)

The uppermost formation in the Maureen Volcanic Group is the Puranga Rhyolite (Appendix), which crops out in an area of about 20 km^2 in the northeastern and north-central parts of the exposed Maureen Volcanic Group.

The Puranga Rhyolite consists mainly of a 200 to 400 m-thick sheet of purplish-grey to cream, crystal-poor to moderately crystal-rich welded ignimbrite (Cq) which contains 5 to 10% quartz and feldspar crystals up to 3 mm in maximum dimension and is characteristically rich in clasts of rhyolite lava and ignimbrite. The lowermost 10 to 20 m and uppermost 10 m of this ignimbrite sheet are poorly welded and crystal-poor. The sheet is overlain by purplish, strongly oxidised, lithic-rich dacitic ignimbrite of unknown thickness (Fig. 5).

In the northeast, the lower part of the main ignimbrite sheet grades laterally (southwestward) and downward into coarse volcanogenic rudite (Cq_1), up to 80 m thick, of probable proximal lag-fall (Wright & Walker, 1977) origin. this in turn passes into apparently intrusive rudite 2 km west-northwest of the Maureen camp.

Dismal Creek Dacite (Cs)

Dismal Creek Dacite (Appendix) crops out in an area of almost 16 km^2, 10 km south of the Maureen volcanic Group and nearly 30 km west-northwest of Georgetown. It occupies a small, possibly centred, basin-like subsidence(?) structure, and is distinctive in being dominated by welded dacite ignimbrite. The *Huonfels Rhyolite Member* (Cs_h) (Appendix) crops out over 1 km^2 in the northern part of the Dismal Creek Dacite, 7 km south-southwest of Huonfels homestead (7561–418955).

The Dismal Creek Dacite is about 150 to 200 m thick as preserved: the upper limit of the unit is the present erosion surface. Over most of its outcrop area, it overlies the Gilberton Formation (including Spyglass Andesite Member) with either apparent concordance, or, locally, with sharp discordance.

The age of the Dismal Creek Dacite is probably Carboniferous, on the basis of its similarity and proximity to the Cumberland Range and Newcastle Range Volcanic Groups.

The bulk of the formation consists of a 30 to 50 m-thick sheet of greyish green welded rhyolite to dacite ignimbrite which ranges from crystal-rich to lithic-rich. The former contains up to 40% feldspar and quartz crystals up to 2 mm acros; the latter up to 50% by volume of a varied suite of lithic fragments, including rhyolitic to dacitic and rare andesite extrusive rocks, and basement-derived rocks. Both have rare, chloritised, hornblende and/or biotite crystals.

The Huonfels Rhyolite Member, which is overlain by the rocks described above, consists of welded, crystal-poor, rhyolitic ignimbrite about 30 to 50 m thick; it appears to be a single coling unit, if not a single flow. In places, the member is intensely sericitised.

Cumberland Range Volcanic Group

Introduction

The Cumberland Range Volcanic Group (Appendix) crops out in an area of 70 km^2, about 25 km southwest of Georgetown. It contains two formations, the Scrubby Creek Rhyolite (Cu) and the overlying Namul Dacite (Ct), which are each made up of several un-named members. The Group is dominated by welded rhyolitic to dacitic ignimbrites, but also has several discontinuous intervals of volcaniclastic rocks, and two of andesitic lava.

Topographically, that part of the Cumberland Range occupied by the Cumberland Range Volcanic Group is made up of western and central "blocks", and an eastern "arm". The sequence as a whole has the form of an asymmetrical east-west elongated, curvilinear basin or trough which occupies a marginal position within a ring-dyke structure. The cumulative maximum stratigraphic thickness of the Cumberland Range Volcanic Group is in the order of 1600 m. Most of this is attained in the central "block", where almost all units are present, and have their maximum development. Rocks of the Cumberland Range Volcanic Group either lie concordantly on Gilberton Formation, or with major unconformity directly on Proterozoic basement. The upper limits of the Group are defined by the present erosion surface.

A single plant fragment, identified as *Lepidodendron canobianum*, of probable Visean (Lower Carboniferous) age, has been recovered from one of the volcaniclastic intervals within the Scrubby Creek Rhyolite (Oversby & Morris, 1975). The Cumberland Range Volcanic Group is thus of approximately the same age as, or possibly a little older than, the Newcastle Range Volcanic Group to the east. It may be older than Dismal Creek Dacite and Maureen Volcanic Group sequences (above).

Scrubby Creek Rhyolite (Cu).

The Scrubby Creek Rhyolite (Appendix) is the most extensive unit in the Cumberland Range Volcanic Group, cropping out in an area of 40 km^2 in all but the north-central, eastern and southern parts of the Cumberland Range. It consists of five sheets of mainly buff to cream, welded, mostly moderately crystal-rich, rhyolitic ignimbrite (cf. Mackenzie & others, 1979). Three lenses, up to 170 m thick, of volcaniclastic rocks (Cu_2) are subsidiary constituents of the formation. Dark greenish-grey porphyritic andesitic lavas (Cu_1, Cu_3) up to 50 m thick overlie the first (lowermost) and third ignimbrite sheets, but are of relatively small total volume.

The Scrubby Creek Rhyolite is between 500 m and 700 m thick. Individual ignimbrite sheets are mostly up to 100 to 200 m thick. Volcaniclastic intervals are each up to about 30 m thick. The greatest preserved thickness of the formation occurs in the central "block" of the Cumberland Range.

The lowermost ignimbrite sheet contains about 35% quartz and K-feldspar crystals (up to 5 mm) in subequal amounts, 3% plagioclase crystals (up to 2 mm), and about 1% lithic clasts. The remaining sheets have about 15 to 20% quartz and feldspar crystals (up to 4 mm). Plagioclase content and proportion increase upward (from sheet 1 to sheet 5), and minor (1%) chloritised hornblende appears in sheet 5; these changes indicate an upward zonation towards more mafic compositions. All the ignimbrites have 1 to 2% chloritised biotite crystals (up to about 1 mm). All sheets contain angular lithic clasts, ranging from ~1% in sheets 1 and 3 to 25 or 30% in sheet 2. The clasts are dominantly of dark-grey, basement-derived metasediments with minor rhyolite and rhyolitic ignimbrite, and range from 3 mm to 2 cm in maximum dimension.

Volcaniclastic rocks in the Scrubby Creek Rhyolite are mostly sublithic, quartzose or feldspathic arenites and siltites, and lutites. Minor granite-cobble and quartz-pebble rudite and rare limestone occur locally.

Namul Dacite (Ct).

The Namul Dacite (Appendix) crops out in a 15 km-long arcuate belt in the eastern and southern parts of the Cumberland Range Volcanic Group; total outcrop area is about 25 km^2. The formation overlies Scrubby Creek Rhyolite discordantly.

The Namul Dacite consists of a lower sheet, about 20 m thick, of greenish-grey, crystal-poor to moderately crystal-rich, welded dacite ignimbrite (Ct) overlain discordantly by a moderately crystal-rich welded rhyolitic ignimbrite (Ct_1) about 50 m thick.

The lower ignimbrite contains quartz (5 to 7%), plagioclase (3 to 4%), and K-feldspar (2 to 3%) crystals up to 4 mm in maximum dimension, and partly altered hornblende (1 to 2%) and chloritised biotite (1%) up to 1 mm long. Lithic clasts, mostly 3 to 4 cm, but some up to 20 cm in maximum dimension, constitute 10% to 30% of the ignimbrite; they include basement-derived metasediment and granite, characteristic green rhyolite to dacite ignimbrite, and rare andesite clasts.

The base of the unit in the central-east is marked by a 10 to 30 m-thick possible ground lag (Walker & others, 1981) deposit of volcaniclastic rudite and minor feldspathic arenite. The rudite consists of angular clasts of dacite and dacitic ignimbrite mostly 5 to 15 cm across.

A welded rhyolitic ignimbrite sheet cropping out over about 1 km of the eastern arm of the Cumberland Range forms the uppermost part of the Namul Dacite.

It is similar in general appearance to the underlying dacite ignimbrite, particularly with respect to the abundant lithic clasts. However, it is much poorer in hornblende, and correspondingly richer in quartz and K-feldspar crystals.

The abundant clasts of green, chloritised rhyolitic to dacitic ignimbrite in the Namul Dacite are of unknown provenance and affinity, and no clasts of Scrubby Creek Rhyolite were observed. The unit may therefore have originated from outside the present outcrop area of Cumberland Range Volcanic Group.

Discussion

No extrusive units can be correlated with any confidence between the Maureen and Cumberland Range Volcanic Groups and the Dismal Creek Dacite. However, rocks of the Gilberton Formation underlie all three sequences, suggesting that they are broadly contemporaneous.

The Ant Hill Andesite Member of the Ironhurst Formation (Maureen Volcanic Group) may mark the same magmatic event as minor andesites in the Dismal Creek Dacite and Cumberland Range Volcanic Group. The main dacitic ignimbrite sheets of the Dismal Creek Dacite and Cumberland Range Volcanic Group (Namul Dacite), and the hybrid dacite in the Womblealla Rhyolite Member (Maureen Volcanic Group), may possibly represent the same precursor magma(s), much modified by fractionation, magma mixing, and wall-rock contamination.

In general terms, the Maureen and Cumberland Range volcanic groups, and the Dismal Creek Dacite, are equivalent to lower, heterogeneous, parts of the Newcastle Range Volcanic Group subgroups. No thick homogeneous units comparable to the Shrimp Creek and Jinker Creek rhyolites are preserved.

Intrusive Rocks associated with the Maureen and Cumberland Range Volcanic Groups and Dismal Creek Dacite

Introduction

As in the case of the Newcastle Range Volcanic Group, intrusive rocks associated spatially with the Maureen and Cumberland Range Volcanic Groups and the Dismal Creek Dacite are probably genetically related to the extrusive rocks. Rocks of the miscellaneous acid suite (CPr), which mostly occur in dyke swarms with a preponderance of northwesterly trends, more remote from the extrusive rocks, are probably of Permian age (see below).

Mount Sircom Microgranodiorite (Cga)

The Mount Sircom Microgranodiorite (Mackenzie, 1980) forms two irregular, stock-like, possibly flat-roofed bodies on the western side of the Cumberland Range; their total outcrop area is about 15 km^2. These bodies have intruded Proterozoic basement and all but the uppermost member of the Cumberland Range Volcanic Group, and are probably connected at shallow depth. A series of stock- and plug-like bodies of similar lithology to the main pluton, some of which are roughly elongated east-west, cut Proterozoic rocks to the south and southwest of the Cumberland Range area. Mount Sircom-type rocks also occur within the Mount Darcy Microgranodiorite to the north of the Cumberland Range area, but have not been differentiated from that unit.

The Mount Sircom Microgranodiorite consists mainly of grey to pink abundantly porphyritic hornblende-biotite microgranodiorite. In the main Cumberland Range outcrop area, it consists of phenocrysts of plagioclase (20 to 25%; An_{60}; 8 mm), quartz (3%; 1 to 4 mm), K-feldspar (3%; 1 to 3 mm), hornblende (2 to 5%; 12 mm), and biotite (1%; 1 mm) in a fine-grained mosaic of quartz (25 to 40%), plagioclase (20 to 25%), K-feldspar (5 to 10%), hornblende and biotite (1 to 3%), and accessory apatite and zircon. The feldspars are extensively altered to sericite and calcite; hornblende and biotite are partly altered to assemblages of chlorite, calcite, epidote, and Ti and Fe oxides.

Two main rock types occur in the bodies to the south and southwest of the Cumberland Range area. The commonest of these is an abundantly porphyritic hornblende-biotite microgranodiorite or microtonalite which contains 12 to 15% plagioclase (~An_{30}) and 5 to 7% quartz phenocrysts up to 1.2 cm in maximum dimension; it also has 2% biotite and 1% hornblende phenocrysts up to 3 mm in maximum dimension. The phenocrysts are set in a very fine-grained groundmass of quartz (25%), plagioclase (35%), K-feldspar (~5%), biotite and hornblende, secondary sericite and calcite, and accessory minerals. Biotite is strongly altered to chlorite + opaque oxide(s), epidote/clinozoisite calcite, and hornblende to clinozoisite + calcite. The second variant is a moderately porphyritic hornblende-biotite microgranodiorite consisting of phenocrysts of plagioclase (5%) up to 5 mm long, quartz (5%) up to 3 mm across, and hornblende and biotite(?) (1 to 2%) up to 3 mm long in a groundmass similar to that of the first type.

At least one of these Mount Sircom-type microgranodiorite bodies has strongly foliated margins.

In the Cumberland Range area, Mount Sircom Microgranodiorite intrudes up to at least the level of the main welded dacitic ignimbrite sheet of the Namul Dacite: on the basis of that relationship and its petrological similarity to the Namul Dacite, it is probably of Carboniferous age. However, Mount Sircom Microgranodiorite has strong geochemical similarities to Permian rocks in the region (Mackenzie, 1987), which may indicate that it was derived from a composition of similar source as were the Permian rocks. Alternatively, the granodiorite may be of Permian age; if so, its location, intrusive relationships, and petrological similarity to the Namul Dacite are probably fortuitous.

Prestwood Microgranite (Cgb)

The Prestwood Microgranite (White, 1959a; Mackenzie, 1980) comprises two large, arcuate, crudely concentric dykes, plus several minor dykes and plug-like bodies, in the same general areas. The inner main dyke, immediately northwest of the Cumberland Range Volcanic Group, is up to 1 km wide, and forms an irregular, south-facing, hook shape. The outer main dyke extends from 8 km west of Mt Sircom 21 km northwest and north to the Gilbert River near "Riverview" homestead; it ranges up to 500 m wide, and takes the form of the southwestern and western segments of a polygon.

The Microgranite intrudes Proterozoic basement rocks, and in one area it may intrude Mount Darcy Microgranodiorite (although field relationships between the two units are not clear-cut). Rhyolitic rocks that could be fine-grained equivalents of the Prestwood Microgranite cut the Cumberland Range Volcanic Group in two places. Its compositional similarity to ignimbrites in the Cumberland Range Volcanic Group, and its similarity to microgranites associated with the Newcastle Range Volcanic Group indicate that the Prestwood Microgranite is probably of Carboniferous age.

Prestwood Microgranite is pale grey, pinkish-grey, or pink, and abundantly porphyritic. It contains phenocrysts of quartz (10 to 12%; 14 mm, mostly 3 mm), K-feldspar (10%; up to 1.2 cm, mostly 2 to 5 mm long), plagioclase (24%; An_{30-40}; 1 to 4 mm), and biotite (1 to 2%; 1 mm) set in a fine to very fine-grained ground mass of the same minerals plus accessory zircon and magnetite(?). The rocks are slightly to moderately altered to sericite, clay(?) minerals, chlorite, and calcite.

Mount Darcy Microgranodiorite (Cgc)

The Mount Darcy Microgranodiorite (Mackenzie 1980) comprises a series of plugs and irregular stocks of microgranodiorite cutting Proterozoic basement rocks in a 50 km^2 area between the inner dyke of Prestwood Microgranite and the outcrop area of Dismal Creek Dacite. Two small bodies intrude Dismal Creek Dacite, and small stocks assigned to this unit also occur in the Mount Turner area, 17 km east of Mount Darcy.

The Mount Darcy Microgranodiorite consists predominantly of pale grey, abundantly porphyritic biotite microgranodiorite with prominent, generally well-rounded, quartz (7 to 10%) and euhedral to subhedral plagioclase (10 to 15%; $\sim An_{40}$; pronounced oscillatory zoning) and K-feldspar phenocrysts commonly 4 to 8 mm across. It also has 2 to 3% smaller (up to 3 mm) chloritised biotite phenocrysts. In some places, the rock has a very fine-grained groundmass of fine disseminated biotite, and appears relatively dark and more obviously porphyritic than the main, pale grey, variety, which has a coarser groundmass and larger biotite crystals. In the holostratotype area of the unit (Appendix), the pale grey microgranodiorite contains enclaves of the darker rock.

A 50 m-wide dyke and a 150 m-wide plug of porphyritic biotite microgranodiorite that crop out 1 km south of Mount Darcy have also been included in the unit. They contain 1 to 3% plagioclase phenocrysts up to 1 cm long, and biotite (1 to 2%; up to 2 mm) and rare rounded quartz (1 to 3 mm) phenocrysts. These bodies may be slightly younger than the bulk of the unit.

On the southern side of the Gulf Developmental Road, the biotite microgranodiorite has locally been intruded by narrow dykes of, and has apparently mixed to some extent with, a more mafic hornblende-biotite microgranodiorite. This rock contains about 20% plagioclase, hornblende, and small biotite phenocrysts, with scarce bipyramidal quartz phenocrysts; i.e. closely resembles the Mount Sircom Microgranodiorite.

Most phases of the Mount Darcy Microgranodiorite are moderately to strongly altered, mainly to propylitic assemblages (chlorite + sericite + epidote + calcite), and the Proterozoic wall rocks are also extensively altered, principally to sericite.

The Mount Darcy Microgranodiorite was originally assumed to be entirely of Carboniferous age. However, Rb-Sr isotopic data have yielded ages ranging from Siluro–Devonian to Permian (L.P. Black, pers. comm.). While it is likely that isotopic systematics have been disturbed as a result of the several episodes of intrusion and alteration, these data indicate that at least one part of the unit probably has a minimum age of Early Permian.

Miscellaneous intrusive rocks (parts of CPr and CPa)

Miscellaneous small intrusive bodies associated with the Maureen and Cumberland Range volcanic groups and Dismal Creek Dacite are predominantly felsic (CPr), and essentially identical to those associated with the Newcastle Range Volcanic Group, although considerably less abundant.

A much greater concentration of such bodies occurs at Mount Turner, 10 km northwest of Georgetown. There, a roughly north trending rhyolite dyke swarm is associated with locally brecciated rhyolite plugs in an area of altered basement granitoid. The location and petrology of the intrusive rocks, and the orientation of the dykes and alteration zones, imply that they are Carboniferous, although Rb-Sr isotopic data suggest an older age (L.P. Black, pers. comm.1985).

Discussion

None of the intrusive rocks associated with the Maureen or Cumberland Range volcanic groups, or with Dismal Creek Dacite, forms a complete ring-dyke structure encircling the associated extrusive rocks. The Prestwood Microgranite forms a crude, incomplete polygonal ring-dyke, offset to the northwest of the Cumberland Range Volcanic Group. These observations, together with the basin-like nature of the depressions which accommodate the extrusive sequences, suggest that:

(1) significant amounts of cauldron and/or caldera-type collapse, did not occur in some cases (Maureen, Dismal Creek);
(2) in the case of the Cumberland Range Volcanic Group, emplacement of the Prestwood ring-dyke was not necessarily accompanied by significant caldera collapse; and/or
(3) subsidiary(?) basinal subsidence, with maximum accumulation, and, subsequently, preservation, of extrusive rocks was offset to the southeastern side of the main ring-dyke/collapse structure.

Marquis Rhyolite (Cv)

Introduction

The Marquis Rhyolite (Appendix) occurs at Mount Tabletop (7560–565519), 10 km southeast of the Cumberland Range Volcanic Group and 25 m southwest of Georgetown, in two small outcrop areas of slightly more and slightly less than 1 km^2. Rocks assigned to the Marquis Rhyolite lies sharply and discordantly on Gilberton Formation.

The Marquis Rhyolits is made up of two un-named subunits of member rank, which are not in contact. These subunits consist of welded rhyolitic ignimbrite (Cv_1), and rhyolitic lava (Cv_2). They are both limited above by the present level of erosion.

Both members of the Marquis Rhyolite have previously been assumed to be of Carboniferous age. However, while no significant faults are known to lie between them, both members lie directly on Gilberton Formation at approximately equal elevations. This suggests that they are not separate outliers of a simple vertical succession. By the same token, there is no reason to infer radically different ages (such as Carboniferous for one and Permian for the other).

Subunit Cv1

Subunit Cv_1 crops out in a single area of 0.75 km^2. The member consists of 75 to 80 m of crystal-poor cream to green or purple welded rhyolitic ignimbrite in which columnar jointing is locally extremely well developed. Lithic clasts are abundant and ubiquitous.

Subunit Cv2

This part of the Marquis Rhyolite crops out in an area of slightly more than 1 km. It consists of sparsely porphyritic cream to purple rhyolitic lava 50 m thick, with subequal quartz and feldspar phenocrysts.

Butlers Volcanic Group

Introduction

The Butlers Volcanic Group (Appendix), with associated intrusive rocks, underlies an area of 40 km. The group is moderately heterogeneous, and contains three named formations. These are, in ascending stratigraphic order, Ballynure Rhyolite, Edmonds Creek Rhyolite, and McLennons Creek Rhyolite. The lower and upper formations each contains two sheets of welded ignimbrite. The middle formation consists of rhyolitic lava. The cumulative maximum stratigraphic thickness of the group is in the order of 500 m. This thickness is not attained in any simple single section, however. Rocks of the Butlers Volcanic Group lie with a major unconformity directly on Proterozoic basement. The upper limit of the group is defined by the present level of erosion.

The preserved sequence of the Butlers Volcanic Group as a whole has the form of a north-northeast-plunging trough which occupies a western marginal position within the Lochaber ring-dyke structure (see below).

Because of the predominance of welded rhyolitic ignimbrite in it, the Butlers Volcanic Group is assumed to be of Carboniferous age. The group might be younger than Paddock Creek Formation in the nearby Bagstowe centred igneous structure (see below) if these extrusive units collectively follow the trend of northeastwards younging shown by intrusive units in the combined Bagstowe and Lochaber structures. By extension of this argument, both extrusive assemblages in the Bagstowe and Lochaber structures could be older than Newcastle Range Volcanic Group farther to the north.

Ballynure Rhyolite (Cy)

The Ballynure Rhyolite (Appendix) is the least extensive preserved formation in the Butlers Volcanic Group, cropping out in a 2 km^2 area in the southwestern part of the group.

The Ballynure Rhyolite consists of two sheets of welded, mainly purple, rhyolitic ignimbrite. The lower sheet contains 30 to 50% quartz and feldspar crystals up to about 2 mm in maximum dimension. It also has minor chlorite aggregates after biotite(?) and up to 7% lithic clasts. The upper sheet, which lies discordantly on the lower one, contains 60% quartz and feldspar crystals 3 to 4 mm in maximum dimension, plus minor chlorite aggregates and partly to wholly chloritised hornblende crystals. Up to 20% lithic fragments up to 4 cm in maximum dimension also occur.

The maximum thickness of Ballynure Rhyolite in its holostratotype area (Appendix) is about 120 m. Of this, the lower ignimbrite sheet accounts for 50 m and the upper one for up to 70 m.

Edmonds Creek Rhyolite (Cx)

This formation (Appendix) crops out in, and can be inferred to underlie, a total of about 23 km in the southern half of the Butlers Volcanic Group outcrop area. Edmonds Creek Rhyolite is overlapped and cut out by the overlying McLennons Creek Rhyolite along an east-southeast-trending line about 8 km north-northeast of the southern tip of the preserved Butlers Volcanic Group.

The Edmonds Creek Rhyolite consists mainly of sparsely porphyritic pale brown to mid purplish-brown rhyolitic lava with up to 5% feldspar and sporadic quartz phenocrysts up to 1 mm in maximum dimension. The lowermost part of the Edmonds Creek Rhyolite locally consists of an interval, up to 10 m thick, of volcaniclastic arenites to medium-grained rudites.

In its holostratotype area (Appendix), the Edmonds Creek Rhyolite has an estimated maximum thickness of 60 m.

McLennons Creek Rhyolite (Cw)

McLennons Creek Rhyolite (Appendix) crops out in an area of 16 km^2 in the northern two-thirds of the Butlers Volcanic Group.

The formation consists of two sheets of welded, mainly mid or dark grey to brown and purple, rhyolitic ignimbrite. The lower sheet contains 10% to 20% quartz and feldspar crystals up to 2 mm in maximum dimension. Crystal contents and sizes locally increase upwards in the sheet. Autoliths, up to 20 cm in maximum dimension, occur sporadically in the lower McLennon Creek Rhyolite. Fiamme are commonly well developed. Local considerable, and apparently unsystematic, variations in the inclination of the foliation may mimic an irregular depositional surface on top of subjacent Edmonds Creek Rhyolite lava.

The upper sheet of McLennons Creek Rhyolite has 30% to slightly more than 50% quartz and feldspar crystals averaging 2 to 3 mm in maximum dimension. Again, crystal contents and sizes tend to increase upwards in the sheet.

The thickness of McLennons Creek Rhyolite in its holostratotype area is 150 m. Of this, the lower sheet accounts for 60 m, and the upper one for the remaining 90 m. However, at the northeastern corner of the main outcrop area, that part of the lower subunit between basement and intrusive Sues Creek Microgranite is in the order of 120 m thick; it is probably more than than 300 m thick in the Sues Creek area.

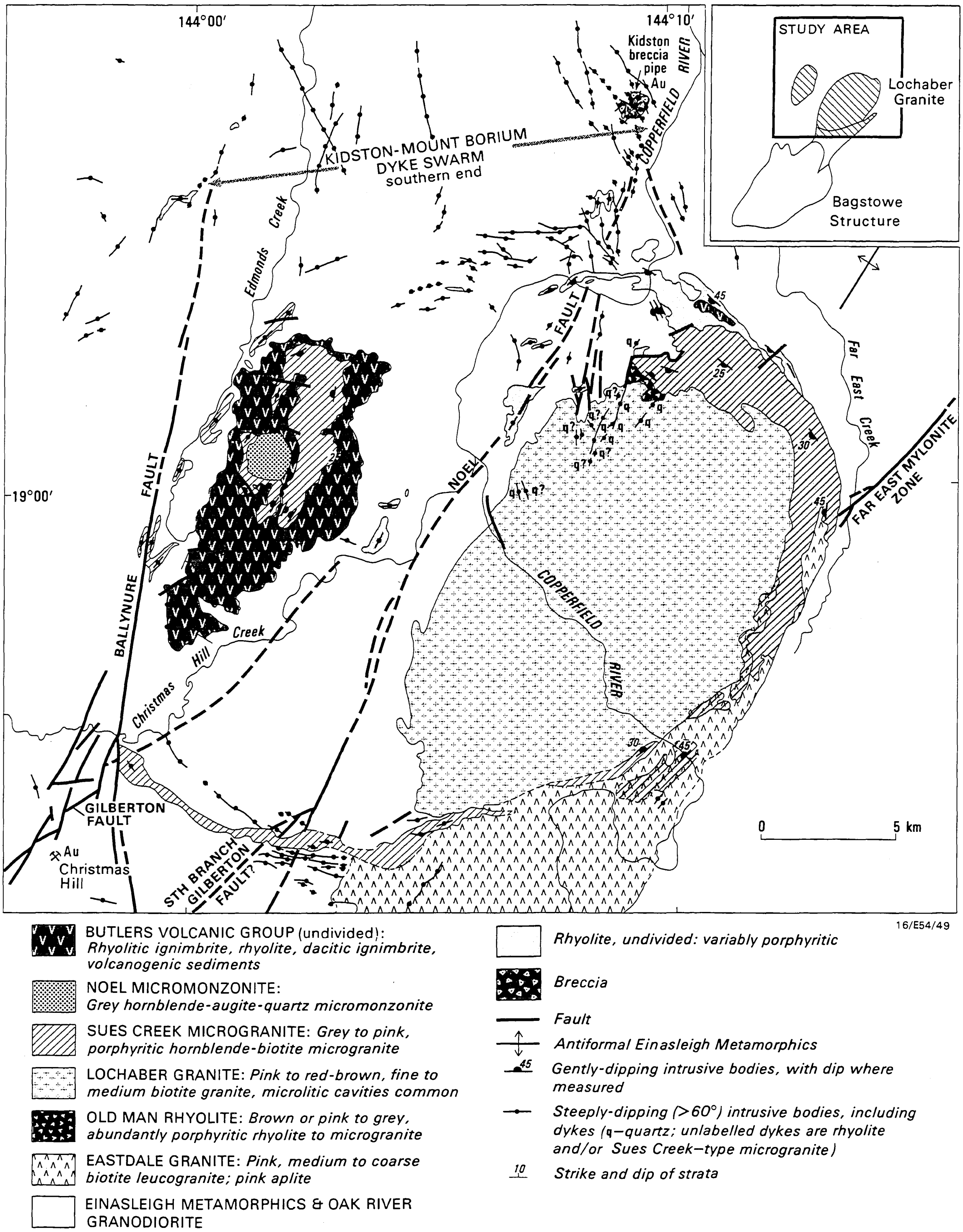

Fig. 3. Geology of the Lochaber ring-dyke structure. Based mainly on field research from 1979 through 1983 by I.W. Withnall (Geological Survey of Queensland), and from 1980 through 1983 by J.V. Warnick and R. McLeod (both then G.S.Q.), and B.S. Oversby.

Paddock Creek Formation (Cz)

Introduction

The Paddock Creek Formation (Appendix) is an extrusive constituent of the predominantly intrusive Bagstowe centred igneous (ring-dyke) structure. The main Paddock Creek Formation occurs in an outcrop area of about 9 km^2 at the northern edge of the Bagstowe structure. Several subsidiary outliers nearby total about 4 km^2. Rocks assigned to the formation are also present: in a series of outcrop areas within a roughly arcuate belt up to 16 km wide and totalling 16 km^2 in the central part of the Bagstowe structure; in an east-north-east-oriented strip of 2.5 km^2 adjacent to the southern part of the outer (Mount Rous) ring-dyke; and in an area of 1 km^2 at Pine Yard Mountain, 5 km farther south.

The Paddock Creek Formation is moderately heterogeneous. It is made up of three un-named subunits of member rank. In ascending stratigraphic order, these are: welded rhyolitic ignimbrite (Cz_1); volcaniclastic rocks (Cz_2); and welded dacitic ignimbrite (Cz_3). The formation lies with major unconformity on Proterozoic and Siluro–Devonian basement rocks.

The Paddock Creek Formation is judged to be of Carboniferous age because of the dominance of welded ignimbrite in it and its relationships to the intrusive rocks of the Bagstowe structure (see below). Since intrusive rocks in, and associated with, the combined Bagstowe and Lochaber structures show a general trend of younging from southwest to northeast, it may be that the Paddock Creek Formation is older than Butlers Volcanic Group of the latter structure.

Subunit Cz_1

This member of the Paddock Creek Formation consists of a single 50 m-thick sheet of grey to brown or purple, moderately crystal-rich, welded rhyolitic ignimbrite. It contains up to 25% quartz and feldspar crystals 1 to 2 mm in maximum dimension. Lithic clasts are abundant in the upper part of the sheet, and reflect a degree of local gradation upwards into the middle member, although the latter overlaps the lower one southwards and westwards.

Rocks tentatively assigned to the subunit at Wire Yard Mountain consist of brown, moderately crystal-rich, welded rhyolitic ignimbrite associated with probable volcaniclastic rocks (mainly arenites) locally.

Subunit Cz_2

The middle interval of the Paddock Creek Formation in the holostratotype area (Appendix) consists of 200 m of volcaniclastic arenite. This grades in the northwest to very coarse rudite with sporadic intercalations of possible rhyolitic lava.

The coarser volcaniclastic rocks contain angular to subrounded clasts mostly up to 10 cm in maximum dimension, but also up to boulder size in the northwest. These clastic rocks probably represent proximal lag-fall (Wright & Walker, 1977) deposits. Rocks assigned to the middle member of the Paddock Creek Formation adjacent to the Mount Rous dyke consists mainly of volcaniclastic rudite.

Subunit Cz_3

The upper part of the Paddock Creek Formation in its holostratotype area represents a return to welded ignimbrite accumulation. Poorly stratified rudite of probable lag-fall origin occurs in the northernmost 2 km^2, and probable ground-lag rudite (cf. Walker & others, 1981; Froggatt, 1981), is sporadically developed in the lowermost part of the sheet, of which 250 m is preserved. This upper sheet overlies the middle member sharply, and apparently concordantly. It consists of mid to dark grey to greenish-grey welded dacitic ignimbrite. The rock is moderately crystal-rich, with 5% to 10% of mostly feldspar crystals with rare chloritised biotite and/or hornblende crystals up to about 1 mm in maximum dimension.

Rocks assigned to the upper member of the Paddock Creek Formation in the central part of the Bagstowe structure are probably 80 m thick, and have up to 35% feldspar and variable quartz up to 3 mm in maximum dimension. These constituents are accompanied locally by up to 10% partly to wholly altered biotite up to 2 mm in maximum dimension, and rare altered hornblende(?). A major proportion of the quartz and felspar in the ignimbrite has apparently been derived from fragmented basement. Clasts, mainly of basement granitoids, up to about 1 m in maximum dimension, are virtually ubiquitous. With increase in the content of clasts, the rocks grade into medium to coarse-grained rudites. Some at least of these represent ground-lag concentrations, while others in several steeply discordant dyke-like bodies up to several metres wide are clearly intrusive. Intrusive volcaniclastic arenite also occurs locally.

Carboniferous and Presumed Carboniferous Intrusive Rocks associated with the Paddock Creek Formation and Butlers Volcanic Group

Introduction

Intrusive rocks associated with the Paddock Creek Formation and Butlers Volcanic Group occur in a series of bodies, which mostly define the ring-dyke and central stock components of the conspicuously annular (centred) Bagstowe and Lochaber structures.

Culba Granodiorite (Cgx)

The Culba Granodiorite (Withnall & Bain, 1980; Appendix) is the youngest intrusive unit in the Glenmore Batholith. It occurs mainly as a stock in the north-central part of the batholith, and in two subsidiary bodies in the southeast. The main body has the form of an irregular broad half-crescent, with a surface area of 35 to 40 km^2. The subsidiary southeastern bodies are irregular, but collectively elongated to the northeast. Together they occupy an area of a little more than 5 km^2.

Mid-grey, fine to medium-grained equigranular, hornblendebiotite granodiorite (Cgx) dominates the Culba Granodiorite. Hornblende and biotite, in crystals up to 2 mm long, together make up 5 to 10% of the rock. Quartz shows undulose extinction, and is commonly graphically intergrown with orthoclase. Rounded xenoliths of sparsely porphyritic hornblende-rich microdiorite or microtonalite are characteristic.

A minor, younger, variety of the unit (Cgx_1) which is marginal to the granodiorite, consists of greyish-pink, fine to medium-grained (but generally finer than the granodiorite) equigranular biotite granite. The rock contains 3% biotite.

Culba Granodiorite at the present level of exposure cuts Anning and Dumbano granites, which have been recrystallised adjacent to it. The unit abuts against, and is probably cut by, Mount Rous Microgranodiorite and Cranky Creek Granodiorite. The unit is also cut by Conical Knob Microgranite and by miscellaneous acid rocks. K-Ar isotopic ages on biotite/whole-rock pairs from Culba Granodiorite range from 335 to 326 Ma; the older end of this age range (i.e. pre-Mount Rous Microgranodiorite) is most likely.

Cook Microgranite (Cgw)

Cook Microgranite (Appendix) occurs in the Castle Hill Dyke, which is a northwest to north-northwest-trending body 4 km long and up to 1 km wide, 8 km south of "Glenmore". It is perpendicular to the adjacent Mount Rous Ring-Dyke (below).

Brownish-pink to pale-brown, mainly abundantly porphyritic, microgranite dominates the Cook Microgranite. The rock contains up to 40% subequal quartz and feldspar phenocrysts 2 to 4 mm in maximum dimension. Sporadic chlorite after biotite(?) also occurs.

As currently exposed, Cook Microgranite abuts against, and is probably cut by, Mount Rous Microgranodiorite; it probably cuts rocks assigned to the middle Paddock Creek Formation. The unit is assumed to be of essentially the same Early Carboniferous age as Mount Rous Microgranodiorite.

Mount Rous Microgranodiorite (Cgv)

This microgranodiorite (Appendix) occurs in two main bodies which together make up the Mount Rous Ring-Dyke of Branch (1966). The larger southern body is a subpolygonal dyke up to nearly 1 km wide. The second body is an irregular stock which is a slightly eastwards-offset subsidiary continuation of the northernmost part of the main body. Mount Rous Microgranodiorite is not present north of a small outcrop area surrounded by Old Man Rhyolite in Castle Hill Creek at 7659–141654, contrary to a previous interpretation (Branch, 1966).

Minor dykes of Mount Rous-type microgranodiorite occur outside the main intrusions, particularly in the south.

Pale to mid greyish-pink to pinkish-grey, abundantly porphyritic, microgranodioritic elvan dominates the Mount Rous Microgranodiorite. The rock contains 25 to 40% feldspar and scarce local quartz phenocrysts 2 to 8 mm in maximum dimension, and 5 to 10% hornblende crystals 1 to 5 mm long. Sparse biotite crystals up to 3 mm long occur locally. In places, the groundmass has a micrographic texture. Mafic xenoliths are common in the unit.

At the present level of exposure, Mount Rous Microgranodiorite partly cuts granitoid bodies of the Glenmore Batholith. In terms of the Bagstowe assemblage, the unit cuts rocks assigned to the middle Paddock Creek Formation, and probably also Cook Microgranite. It is cut by Old Man Rhyolite, and by miscellaneous acid rocks. Richards, & others (1966) reported a K-Ar isotopic age from the Mount Rous Microgranodiorite hornblende of 332 Ma (recalculated).

Cranky Creek Granodiorite (Cgu)

Cranky Creek Granodiorite (Appendix) occurs in the nearly 25 km^2 Four Mile Creek Stock of Branch (1966). The unit is dominated by pale to mid grey to pink, mainly abundantly porphyritic, biotite to hornblende-biotite granodiorite with 20 to 50% feldspar phenocrysts up to 5 mm long, and locally up to 25% quartz phenocrysts 0.5 to 2 mm across. The rocks contain 1 to 5% biotite, with up to 5% hornblende locally, in crystals mostly up to 2 mm long. Biotite and hornblende contents do not appear to vary regularly in any particular direction (contrast Branch, 1966). In some places, a patchy micrographic groundmass texture is developed. Mafic xenoliths are common in the unit.

As currently exposed, Cranky Creek Granodiorite cuts the upper Paddock Creek Formation and Culba Granodiorite. It is cut by Conical Knob Microgranite, Black Cap Diorite, Bagstowe and Eastdale granites, and by miscellaneous acid rocks. It is assumed to be of essentially the same Early Carboniferous age as Mount Rous Microgranodiorite.

Conical Knob Microgranite (Cgt)

The Conical Knob Microgranite (Appendix) occurs in two main elongate bodies, which together have been referred to previously as the East–West Ring-Dyke (Branch, 1966), even though they are well separated in the northwestern and southeastern parts of the Bagstowe structure. These bodies are more logically considered, in combination with Old Man Rhyolite of Branch's (1966) Pink Ring-Dykes and with adjacent unassigned trachyandesite to quartz andesite (below), as belonging to a single composite dyke, here referred to as the "Conical Knob–Old Man Ring-Dyke".

The southeastern body of Conical Knob Microgranite is 6 km long and up to nearly 1 km wide. Northeast of an area 6 km southeast of "Glenmore" it horsetails into a series of subsidiary dykes, which follow the eastern periphery of the Four Mile Creek Stock. The northwestern body of Conical Knob Microgranite is also 6 km long; it is up to 1.5 km wide.

Mainly pink, abundantly porphyritic, biotite to local hornblende-biotite microgranite dominates the Conical Knob Microgranite. The rock contains up to 60% subequal quartz and feldspar phenocrysts from 1 to 5 mm in maximum dimension. Sparse biotite crystals up to 3 mm long are accompanied by hornblende of similar size locally. Accessory fluorite has been reported (Branch, 1966). Micrographic groundmass textures occur sporadically.

In terms of the Bagstowe Structure, Conical Knob Microgranite as currently exposed cuts Cranky Creek Granodiorite, and is probably cut by Old Man Rhyolite. It is assumed to be of Early Carboniferous age.

Old Man Rhyolite (Cgs)

The Old Man Rhyolite (Appendix) constitutes the bulk of the Conical Knob–Old Man Ring-Dyke at the present level of exposure. It consists of a series of locally coalesced, individually commonly quite minor, dykes and plugs (the "Pink Ring-Dykes" of Branch, 1966) which are inseparable at 1:250 000 scale. Intrusive volcaniclastic rocks also occur within the area of the ring-dyke. A major bifurcation of Old Man Rhyolite around Conical Knob Microgranite in the northeast appears to consists of an older northern branch and a (presumably only slightly) younger southern one.

Old Man Rhyolite is dominated by mainly brownish-pink and abundantly porphyritic rhyolite with 25% subequal quartz and feldspar phenocrysts up to 3 mm in maximum dimension. Up to 3% biotite occurs locally in 1 mm-long crystals. Groundmass textures are micrographic in places.

At the present level of exposure, Old Man Rhyolite cuts rocks assigned to the upper Paddock Creek Formation, and probably also Conical Knob Microgranite. It is cut by miscellaneous acid rocks, but relationships to adjacent unassigned intermediate to basic rocks (trachyandesite to quartz andesite) sharing the Conical Knob–Old Man Ring-Dyke with it, are unclear. The unit is assumed to be of Early Carboniferous age.

Black Cap Diorite (Cgr)

The Black Cap Diorite (Appendix) lies mainly between the southwestern and northwestern parts of the main outcrop area of Bagstowe Granite (below) and its western apophyse. Its outcrop area forms a slightly irregular crescent 15 km long, and up to 2 km wide in the south. In view of the textures which suggest comingling of Black Cap Diorite and Bagstowe Granite magmas (Blake, 1981), both units are now treated as parts of a single "Black Cap-Bagstowe Stock".

Dark grey equigranular hornblende diorite dominates the Black Cap Diorite. In places, the rock grades into microdiorite. It is locally biotite and augite-bearing. Mostly sparse feldspar phenocrysts up to 5 mm in maximum dimension occur rarely, as do more mafic xenoliths. The rock is commonly intruded, and locally intricately net-veined, by Bagstowe Granite, against which it is apparently chilled (cf. Blake, 1981). Apparent hybrid rocks also occur at several localities.

Black Cap Diorite cuts, and has at least locally recrystalised, rocks assigned to the upper Paddock Creek Formation, as well as Cranky Creek Granodiorite. It is cut by miscellaneous acid rocks. It was probably emplaced at the present level of exposure at essentially the same time as Bagstowe Granite, and is assumed to be of Early Carboniferous age.

Bagstowe Granite (Cgq)

The main outcrop area of this unit (Appendix), which makes up the bulk of the composite Black Cap–Bagstowe Stock of this report, has been referred to previously as the "North-East Stock" (Branch, 1966). The Bagstowe Granite occupies slightly more than 25 km^2 outcrop area. A discontinuous apophyse up to 1 km wide, the "Central Ring-Dyke" of Branch (1966), occurs to the west of the main body. This apophyse appears to be locally flange-like in form.

Mainly pink and leucocratic, very fine to medium-grained equigranular, biotite granite of Elizabeth Creek type dominates the Bagstowe Granite. Biotite occurs as sparse crystals up to 2 mm long. Subsidiary rocks have inequigranular to rarely abundantly porphyritic textures; a maximum of 30% quartz and feldspar phenocrysts up to 1 cm in maximum dimension typify the latter. Micrographic groundmass patches occur locally. Miarolitic cavities are rare.

Bagstowe Granite cuts Cranky Creek Granodiorite and rocks assigned to the upper Paddock Creek Formation, which are at least locally recrystallised, at the current level of exposure. It is intimately mixed with Black Cap Diorite, and cut by the Eastdale Granite and miscellaneous acid intrusive rocks. The unit is assumed to be of Early Carboniferous age.

Eastdale Granite (Cgp)

Eastdale Granite (Appendix) occurs in an irregular, northeast-elongated, stock of 90 km^2 outcrop area, which was recognised but discussed only briefly by Branch (1966). The stock bridges the gap between the Bagstowe and Lochaber centred structures, without being geometrically a part of either.

The Eastdale Granite is dominated by mainly pink and leucocratic, medium to coarse-grained, equigranular biotite granite of Elizabeth Creek type. Biotite crystals constitute up to 2% of the rock, and are up to 2 mm long. Subsidiary varieties have an inequigranular texture. Aplitic veins are locally common. Any contact metamorphic aureole around the Eastdale Granite is inconspicuous, if present at all.

At the current level of exposure, the Eastdale Granite cuts Cranky Creek Granodiorite and Bagstowe Granite of the Bagstowe centred structure. It is cut by Sues Creek Microgranite and Lochaber Granite of the Lochaber structure, and by miscellaneous acid rocks. The rocks are assumed to be of Carboniferous age.

Lochaber Granite (Cgo)

This granite (White, 1959b; Appendix) crops out in an irregular southwest-elongated ovate stock of slightly more than 150 km^2 outcrop area, with an approximate centre located 15 km south-southwest of Kidston. The northeastern-most 40 km^2 part of the Lochaber Stock lies beyond the eastern boundary of the map area, but is shown in Fig. 3.

Pink and leucocratic, fine to medium-grained, biotite granite of Elizabeth Creek type dominates the Lochaber Granite. Most of the medium-grained rocks are equigranular. Fine-grained varieties are commonly inequigranular or sparsely to abundantly porphyritic, and grade into porphyritic microgranites in extreme marginal positions. Porphyritic rocks contain up to 50% quartz and/or feldspar phenocrysts from 1 to 7 mm in maximum dimension. Sparse (1 to 3%) biotite crystals up to 2 mm long are ubiquitous in all rocks. Sparse hornblende also occurs at least locally in the central part of the stock. Accessary topaz and fluorite have been noted (Branch, 1966). In many places, particularly in the north and around the eastern margin of the stock, groundmass textures are micrographic. Pegmatitic patches with miarolitic cavities are common in such rocks, and suggest proximity to the original roof of the stock. Subrounded xenoliths of grey equigranular microgranodiorite, up to 30 cm in maximum dimension are known from one locality in the north. Also mainly in the north, quartz-rich veins up to 2 m wide and several hundred metres long, with adjacent greisenised granite, strike roughly north. The Lochaber Mine worked wolfram with molybdenite in an east northeast-trending vein of this type.

As exposed, the Lochaber Granite cuts Eastdale Granite, although any contact metamorphic aureole is inconspicuous. The unit is cut by Sues Creek Microgranite and by miscellaneous acid rocks. Lochaber Granite is assumed to be of Carboniferous age.

Sues Creek Microgranite (Cgn)

The Sues Creek Microgranite (Appendix) mainly occurs in a series of dykes up to 1 km wide. These bodies are the most conspicuous components of an incomplete southwesterly-elongated, ovate ring-dyke zone, which is considered to define the outer periphery of the Lochaber centred structure. The Lochaber Granite and Butlers Volcanic Group sequence lie inside the Sues Creek dyke zone. In addition to the Sues Creek Microgranite, miscellaneous acid rocks occur in the zone, particularly in the north and east (Fig. 3), beyond the eastern boundary of the map area (below). Rocks assigned to the Sues Creek Microgranite also intrude the Butlers Volcanic Group as two closely adjacent, irregularly lobate north-northeast-elongated stocks, each of 10 km^2 outcrop area.

The Sues Creek Microgranite is an elvan, consisting predominantly of pink, abundantly porphyritic, biotite and hornblende-biotite microgranite. The rocks mostly contain 30 to 50% subequal quartz and feldspar phenocrysts. Quartz is mainly 1 to 4 mm in maximum dimension, but feldspars are up to 1 cm long. Biotite, and hornblende where present constitute 1 to 2%, in crystals up to 1.5 mm long. Hornblende most commonly occurs in subrounded dioritic xenoliths up to 1 cm across. Microdioritic xenoliths up to 20 cm across also are present in places.

At the present level of exposure, the Sues Creek Microgranite cuts Eastdale and Lochaber granites, as well as the whole of the preserved Butlers Volcanic Group sequence, the latter being at least locally recrystallised. The unit is cut by Noel Micromonzonite, and by miscellaneous acid rocks. It is assumed to be of Carboniferous age.

Noel Micromonzonite (Cgm)

The Noel Micromonzonite (Appendix) occurs in a near-circular plug of 3 km^2 outcrop area, 20 km southwest of Kidston; it represents the "Hornblende–Augite–Quartz Micromonzonite Plug" of Branch (1966).

The Noel Micromonzonite is dominated by mid grey, abundantly porphyritic, biotite-hornblende-augite quartz micromonzonite to micromonzodiorite. The rocks typically contain 25% feldspar and mafic phenocrysts. The feldspars are up to 3 mm long, with the mafics up to 1 mm long. Sparse dioritic xenoliths up to 1 cm across also occur in the rock.

The Noel Micromonzonite cuts McLennons Creek Rhyolite (upper Butlers Volcanic Group) and Sues Creek Microgranite at the present level of exposure. The unit is assumed to be of Carboniferous age.

Miscellaneous acid intrusive rocks (part of CPr)

Sparsely porphyritic intrusive rhyolites to microgranites in the area of the Butlers Volcanic Group and its named intrusive associates are younger then Sues Creek Microgranite. They are semi-continuous via the Kidston breccia pipe with similar rocks, which cut southern representatives of the Newcastle Range Volcanic Group (Fig. 3), a Carboniferous age is preferred for them.

Temporal relationships to generally similar rocks, which cut Paddock Creek Formation and most of its named intrusive associates except Bagstowe Granite are uncertain. It is likely that several generations of intrusive rhyolites to microgranites are present. Some of the rocks are probably of Carboniferous age. However, those in northwest-trending dykes are believed to be more likely Permian by comparison with a prefered structural trend evident in and adjacent to the main outcrop area of Agate Creek Volcanic Group (see below).

Discussion

"Depth aspects" of intrusive components of the Bagstowe and Lochaber centred igneous structures

In and adjacent to the intrusive sequence of the Bagstowe structure, there is a regularly increasing "depth aspect" progression from Castle Hill Microgranite to Elizabeth Creek-type Eastdale Granite via Bagstowe Granite. This Bagstowe progression is unambiguously overprinted by rocks of a separate, reverse, Lochaber progression.

The Lochaber progression begins with Lochaber Granite, and then passes to Sues Creek Microgranite, an elvan. The picture is complicated by unassigned rhyolites in dykes and plugs, which are spatially associated with both progressions.

At least some of these appear to represent the culmination of the reverse Lochaber progression, and to provide a connecting link with the the older part of a normal progression associated with the Wirra centred igneous structure to the north. Some of the rhyolites could also be of Permian age, and thus unrelated.

Another late Palaeozoic intrusive episode (but not part of a progression as now exposed), is represented by pre-Bagstowe Culba Granodiorite.

Palaeosurface fluctuations above the Bagstowe and Lochaber structures

The alternation of normal and reverse "depth-aspect" intrusive progressions between the Bagstowe and Lochaber centred igneous structures might indicate fluctuations of the palaeosurface above and adjacent to the structures. This could have been due to erosion following or accompanying uplift during emplacement of the reverse progression.

Galloway Volcanics (C)

Only a small marginal southern portion of less than 20 km^2 of the Galloway Volcanics as currently remaining after exclusion of the Maureen Volcanic Group occurs in the north-central part of the Georgetown Regional map area. The unit crops out 2 km northeast of the Maureen Volcanic Group, and 15 km west-northwest of the northern lobe of the Newcastle Range. The unit has not been included in the present study, so that no substantial information beyond that in Branch (1966) and Smart & Bain (1977) is available (however, most of the discussion by these authors deals with rocks now assigned to the Maureen Volcanic Group).

The Galloway Volcanics lie with major unconformity on Proterozic basement rocks, and are probably discordant with respect to a minor patch of Gilberton Formation. The unit is apparently dominated by sheets of welded rhyolitic ignimbrite and so is thought to be of broadly comparable Carboniferous age to the Newcastle Range and Maureen volcanic groups. The thickness of the unit is not known.

Agate Creek Volcanic Group

Introduction

The Agate Creek Volcanic Group (Appendix) represents the only extensive remnant of a demonstrably Permian extrusive sequence in the Georgetown region. The group is markedly heterogeneous and ignimbrite-poor. It is distinctive in containing a high proportion of andestic lava.

Permian extrusive rocks in the Bullseye Creek–Langlo Lake and Little Pocket areas, just west of the Georgetown Region map area (Mackenzie & others, 1985; Mackenzie, 1987a; Fig. 1), have the same general stratigraphic characteristics as the Agate Creek Volcanic Group, although ignimbrites seem to be somewhat better developed than in Agate Creek volcanics.

Agate Creek Volcanic Group rocks underlie one main roughly centred elongated basinal area (Agate Pocket) of 50 km^2, which lies 50 km south of Forsayth. Two subsidiary outcrop areas of rocks assigned to the group occur 2.5 km and 15 km to the northwest of the main one. A fourth outcrop area lies 5 km to the southeast, between the Percy River and the middle reaches of Granite Creek.

The Agate Creek Volcanic Group is made up of four formations which are, in ascending stratigraphic order, the Big Surprise Tuff, Talaveras Rhyolite, Black Soil Andesite, and Thunder Egg Rhyolite. The Black Soil Andesite contains un-named volcaniclastic subunits of member status. The Agate Creek Volcanic Group has an aggregate thickness of 900 m. As usual with extrusive sequences in the region, the full thickness is not developed in a single section. A probable 400 m in the northwestern half of Agate Pocket represents the maximum for any one area.

Rocks of the Agate Creek Volcanic Group either lie north of the Percy River with major unconformity on Proterozoic and Siluro–Devonian basement rocks, or (in the southeast) discordantly on Gilberton Formation. The group is limited upwards either by Mesozoic and Cainozoic rocks, or by the present level of erosion. No substantial representatives of a Carboniferous ignimbrite-dominated sequence lie directly below the Agate Creek Volcanic Group as preserved. This implies that some unknown, but conceivably substantial, thickness of Carboniferous extrusive rocks was eliminated from the Agate Creek area before Early Permian time (and possibly after emplacement of Yataga Granodiorite farther north in the latest Carboniferous or earliest Permian). The alternative, of complete non-deposition of any Carboniferous material seems unlikely. In fact, a remnant of welded rhyolitic ignimbrite crops out on the summit of a hill at 7660–709986. This outcrop area is too small to show on the Georgetown Region map. The ignimbrite rests on basement rocks at an elevation corresponding to the lower part of nearby Big Surprise Tuff (i.e. the hill was a palaeotopographic high at the time that the tuff accumulated). The rock is similar to ignimbrites in the lower and upper sheets of Bousey Rhyolite; the outcrop may represent an erosional outlier of one of these sheets, or of some other Carboniferous sequence.

The occurrence of elements of a Gangamopteris flora (White, 1965) suggest an Early Permian age for the Agate Creek Volcanic Group.

Big Surprise Tuff (Ps)

The Big Surprise Tuff (Appendix) crops out mainly in an area of 5 km^2 peripheral to the northwestern and northeastern parts of the main outcrop area, and cuts out southeastwards. Subsidiary outcrop areas of rocks assigned to the formation also occur: to the southeast between the Percy River and Granite Creek (3.5 km^2); about 2.5 km northwest of Agate Pocket (2900 m^2); and an additional 12.5 km farther northwest (3 km^2).

The Big Surprise Tuff is a homogeneous to moderately heterogeneous formation up to 180 m thick (between the Percy River and Granite Creek). It consists mainly of poorly sorted, locally crudely stratified, lithic and pumice-rich volcaniclastic arenites grading to rudites; crystal contents are variable. Clasts are angular to subrounded, and mostly consist of a variety of rhyolites and basement rocks up to nearly 1 m in maximum dimension locally. The coarsest rocks occur between the Percy River and Granite Creek. Groundmass shard pseudomorphs indicate, at most, only slight deformation and welding; most of the rocks were probably originally nonwelded. The unit probably originated from several separate sources.

Talaveras Rhyolite (Pt)

The Talaveras Rhyolite (Appendix) occurs only between the Percy River and Granite Creek, in areas totalling less than 2 km^2. It has a preserved volume of substantially less than 1 km^3.

The Talaveras Rhyolite is a homogeneous unit consisting of mainly reddish-brown, moderately crystal-rich to crystal-rich, welded rhyolitic ignimbrite. The rock contains 25 to 40% quartz and feldspar crystals, mostly up to 2 mm in maximum dimension, and 7% biotite flakes up to 3 mm across. Sporadic lithic clasts are up to 10 cm in maximum dimension.

In its holostratotype section (Appendix), the Talaveras Rhyolite is 80 m thick. About 1.5 km to the east, 250 m of the formation are preserved locally.

Black Soil Andesite (Pb)

The Black Soil Andesite (Appendix) is the most extensive and characteristic formation in the Agate Creek Volcanic Group. The formation crops out or is shallowly buried by Mesozoic–Cainozoic cover rocks over 30 km^2 in the Agate Pocket area. An additional 0.25 km^2 occurs 2.5 km northwest of Agate Pocket, and 0.5 km^2 is developed between the Percy River and Granite Creek.

The Black Soil Andesite is a heterogeneous formation dominated by basaltic andesite lava (Pb) with subordinate volcaniclastic interbeds (Pb_1). The lava locally has 1 to 3% feldspar and hypersthene phenocrysts up to 2 mm in maximum dimension. Possible altered pigeonite and olivine occur sporadically. Some intrusive rocks may be mixed with lava flows in the northwestern part of the main outcrop area.

The basaltic andesite lava is the primary host of all the agate in Agate Pocket. It occurs as amygdales in the upper parts of flows.

Up to five volcaniclastic interbeds of probable lacustrine origin occur within the Black Soil Andesite. They are grey, green, and/or brown, laminated to thin-bedded vitric lutites and siltites (including "porcellanite" and "ribbonstone" varieties). Medium to coarse crystal-rich arenite and fine to medium rudite are subordinate. The rocks crop out mainly in the central and southeastern parts of Agate Pocket. These volcaniclastic intervals are lensoidal, and range up to 130 m thick in the southeast. They are locally fossiliferous (White, 1965).

Within the central part of Agate Pocket, Black Soil Andesite probably has a total thickness of about 400 m. This thickness estimated on geological grounds is the same as that inferred from gravity modelling (Anfiloff, 1983). The Black Soil Andesite between the Percy River and Granite Creek is 80 m thick.

Thunder Egg Rhyolite (Pe)

The Thunder Egg Rhyolite (Appendix) makes up the ridge which forms the northeastern rim of Agate Pocket. It crops out in an area of nearly 10 km^2 and overlies Big Surprise Tuff in the extreme northwest, and Black Soil Andesite farther to the southeast.

The Thunder Egg Rhyolite consists mainly of rhyolitic lava, although it probably also includes some very high level intrusive rocks which cannot be differentiated. The rhyolite is typically sparsely porphyritic, with 3 to 5% quartz and feldspar phenocrysts. Feldspar phenocrysts are mostly 1 to 4 mm in maximum dimension, while quartz averages 0.5 to 2 mm.

The Thunder Egg Rhyolite is about 90 m thick as preserved in the area of its holostratotype section (Appendix). The stratigraphic contact with older Big Surprise Tuff and Black Soil Andesite is evidently slightly discordant. The original top of the Thunder Egg Rhyolite has been removed by erosion.

Presumed Permian Intrusive Rocks associated with the Agate Creek Volcanic Group

Introduction

Individually and collectively, intrusive rocks associated with the Agate Creek Volcanic Group tend to be elongated and/or aligned in a northwesterly to west-northwesterly direction.

Connie May Dolerite (Pgm)

The Connie May Dolerite (Appendix) crops out in two irregular areas totalling slightly less than 1 km^2 between the upper reaches of Agate and Spring Creeks, slightly more then 50 km south of Forsayth.

Mid olive green, fine-grained but abundantly porphyritic, augite dolerite dominates the Connie May Dolerite. The rocks contain 50% acicular, randomly oriented, feldspar and augite phenocrysts up to 1 cm long. Up to 10% opaque grains and acicular crystallites occur in the groundmass.

As currently exposed, the Connie May Dolerite cuts andesitic lava and volcaniclastics of the Black Soil Andesite (upper Agate Creek Volcanic Group). The unit is assumed to be of only slightly younger Permian age than the extrusive rocks.

Miscellaneous acid intrusive rocks (part of CPr)

Most of the unassigned acid intrusive rocks cutting, or otherwise closely associated with, the Agate Creek Volcanic Group are sparsely to moderately porphyritic rhyolites with subequal quartz and feldspar phenocrysts up to about 2 mm in maximum dimension. The rocks are typically purple or buff in colour, and broadly similar to Thunder Egg Rhyolite, with which they might be cogenetic.

Carboniferous and/or Permian Intrusive Rocks without extrusive associates

Introduction

A small number of intrusive units in the Georgetown region cannot be linked to any of the preserved extrusive rocks because of their geographic separation. Although the number of units involved is small, the outcrop areas, and volumes of material represented, are quite substantial.

Purkin Granite (Cgx)

The Elizabeth Creek-type Purkin Granite (Withnall & Bain, 1980; Appendix) crops out in two stocks in the extreme southern part of the Georgetown Region map. These extend beneath Mesozoic and Cainozoic cover farther south in the Hampstead (7658) and Chudleigh Park (7758) 1:100 000 sheet areas.

The smaller, western, stock of the Purkin Granite is exposed or shallowly covered in a total area of 90 km^2. Slightly more than 50 km^2 of this lie within the map area. The whole body probably has the form of a slightly irregular southwest-elongated oval whose approximate centre is situated 30 km south-southeast of "Gilberton". The eastern stock is hook-shaped, with a total exposed to shallowly covered area of 65 km^2 in the Georgetown Region and 300 km^2(?) farther south. There may be some connection between the two stocks at depth in the south.

Grey to pink and leucocratic, medium to coarse-grained equigranular biotite granite of Elizabeth Creek type dominates the Purkin Granite. Porphyritic rocks are present in the eastern stock where mid to dark-grey, and very coarse-grained, varieties also occur. Accessory fluorite is present rarely.

The Purkin Granite is surrounded at least locally by a moderately conspicuous contact metamorphic aureole within which basement rocks have been recrystallised. The aureole is about 200 m wide.

As exposed, the Purkin Granite intrudes only basement rocks. Richards & others (1966) obtained a K-Ar isotopic age of 311.5 Ma (recalculated) from biotite in Purkin Granite of the eastern stock. This date is very close to the one obtained from Elizabeth Creek Granite (*sensu stricto*) in the extreme north of the Georgetown Region. This is contrary to other indications of a systematic northward younging of intrusive and extrusive successions in the region.

Yataga Granodiorite (Pgy)

This granodiorite (Withnall & others, 1976; Appendix) makes up a nearly equidimensional, crudely polygonal, centred stock of 70 km^2 outcrop area centred 29 km north-northeast of Georgetown. The only marked departure from the generally regular shape of the body occurs in the form of a small west-facing hook-like apophyse in the south.

Within the Yataga Stock as a whole, there is a roughly concentric disposition of the member-equivalent subunits Pgy_1, Pgy_3, and Pgy_4. Subunit Pgy_1 occurs in an irregular small outcrop area of slightly less than 1 km^2 near the southern edge of the Yataga Stock, however. Outcrop areas of Pgy_3 and Pgy_4 (totalling 7 km^2 and 3 km^2, respectively) tend to be irregular and elongated to the north or north-northwest, rather than having boundaries parallel to the outer edge of the stock as a whole. Contacts between the subunits are mostly sharp, although intimate mixtures of rock types and intermediate or not easily assignable lithologies, complicate the situation locally.

The Yataga Granodiorite is surrounded by a conspicuous contact metamorphic aureole up to 500 m wide. Within the inner part of this aureole, intruded basement (Eitheridge Group) schist has been converted into biotite-sillimanite-cordierite hornfels.

Subunit Pgy_1 is characterised by mid to dark grey, fine-grained moderately porphyritic hornblende-biotite tonalite. The rock contains 15% feldspar and hornblende phenocrysts, respectively up to 1 cm and 4 mm long. These are accompanied by locally common quartz crystals 2 to 4 mm across. Hornblende phenocrysts con tain rare cores of relict clinopyroxene. The subunit has occasional metasedimentary basement xenoliths, and it is intricately veined by Pgy_2-type granodiorite.

A single small (less than 0.01 km^2) outcrop area of fine-grained porphyritic tonalite at 7661–714047, which may be related to Pgy_1, contains conspicuous black orthopyroxene phenocrysts 7 mm long, with less obvious feldspar, hornblende, and minor biotite phenocrysts between 4 and 6 mm long.

Subunit Pgy_1 was originally considered to antedate Pgy_2. However, relationships are now believed to indicate comingling of the magmas of the two subunits, with chilling and back-veining of Pgy_1 by the other material.

Subunit Pgy_2 is the most widespread subunit of the Yataga Granodiorite, making up nearly 80% of the exposed Yataga Stock. The subunit consists mainly of mid grey, medium-grained inequigranular hornblende-biotite granodiorite. There is also a subsidiary, somewhat darker and more tonalitic but otherwise similar, outer facies included in the subunit. This tonalitic facies and the dominant granodiorite grade gradually and continuously into each other.

Mostly altered orthopyroxene is almost ubiquitous throughout subunit Pgy_2. Relict clinopyroxene cores to hornblende crystals are common only in the most mafic rocks. The tonalitic rocks contain abundant, but inwardly decreasing, angular to subrounded cognate mafic xenoliths up to 40 cm in maxiumum dimension, and scattered clasts of metasedimentary basement. Common aplitic veins cutting the subunit are probably related to Pgy_4.

Subunit Pgy_3 consists mainly of mid grey, fine to medium-grained moderately porphyritic biotite granite with 15% feldspar phenocrysts up to 1.2 cm long. Biotite, in phenocrysts up to 6 mm long, is ubiquitous, and consitutes 5% of the rocks. Sparse quartz phenocrysts up to 5 mm across occur locally. Hornblende decreases in abundance from up to 2% in relatively mafic rocks to less than 1% in the more felsic ones. Mostly altered orthopyroxene grains, and core relics in hornblende, and clinopyroxene cores in plagioclase, are uncommon. Sparse chalcopyrite in disseminated grains, up to 3 mm across, is widespread. In places, granophyric groundmass patches and miarolitic cavities are sparsely developed. Xenoliths are rare; they are mostly angular to subrounded, and consist of basement rocks or Pgy_2-type granodiorite up to 30 cm in maximum dimension.

Subunit Pgy_4 is made up of pinkish-grey, fine to medium-grained equigranular granite containing up to 5% biotite. Miarolitic cavities, with oxidised sulphides are common, although accessary chalcopyrite grains are less abundant than in subunit Pgy_3. Groundmass patches of graphic intergrowths are restricted to the most felsic varieties of the subunit. In places, rare rounded xenoliths of Pgy_2- and Pgy_3-type granitoids occur.

Sporadic patches and dykes of greisen are present in all subunits of the Yataga Granodiorite, except Pgy_1. These are mostly situated in the central and northern parts of the Yataga Stock. The dyke-like greisen bodies are commonly 1 to 2 m wide, and tend to be north-trending. Copper mineralisation associated with quartz veins in greisen has been tested at the Dambo Prospect (7662–746086), within subunit Pgy_2.

At the present level of exposure, Yataga Granodiorite cuts only basement rocks. It is cut by north-trending dykes of porphyritic microtonalite; these are probably related to the Yataga Granodiorite, although treated here as unassigned intermediate to basic rocks (CPa). A K-Ar isotopic age from biotite of about 268 Ma (recalculated) has been obtained from subunit Pgy_2 (Withnall & others, 1976). Whole-rock Rb-Sr data from various subunits, together with ones from Pgy_2 and Pgy_3 biotites, have given a preferred age of 284±3 Ma.

The coarse-grained nature of the Yataga Granodiorite, in conjunction with the moderately large surficial extent of its outcrop area and width of its thermal aureole, suggests that it was emplaced at appreciably greater than subvolcanic depths. Some, and possibly most, of the thickness of originally suprajacent "roof" sequence was presumably made up of Newcastle Range Volcanic Group and/or other Carboniferous extrusive rocks.

Carnes Granodiorite (Pgc)

The Carnes Granodiorite (Mackenzie, 1980) forms a west-southwest-elongated, lozenge-shaped, stock about 17 km in area, centred 32 km west-southwest of "Green Hills" outstation, and 22 km northwest of the Gongora Granodiorite stock (discussed below).

It consists dominantly of mid grey, medium to coarse-grained, inequigranular, biotite granodiorite with about

5% K-feldspar and 5% biotite (up to 1.5 mm). The granodiorite is surrounded by a contact metamorphic aureole about 250 m wide.

The Carnes Granodiorite cuts only Proterozoic basement rocks, and was originally considered to be of mid-Proterozoic age. It is now considered to be essentially Early Permian, the same age as Gongora Granodiorite, discussed below.

Gongora Granodiorite (Pgg)

The Gongora Granodiorite (Mackenzie, 1980) forms a north-elongated, almost perfectly elliptical, stock of slightly more than 17 km^2 outcrop area 20 km north of "North Head" homestead. It consists dominantly of mid grey, medium to coarse-grained, inequigranular to weakly porphyritic, biotite granodiorite containing 20 to 25% K-feldspar and between 8 and 12% biotite (up to 3 mm). A porphyritic variant that occurs in places at the margin contains 5% feldspar phenocrysts up to 1 cm long, and 1 to 2% biotite crystals up to 4 mm long. It is considerably more potassic, and also more mafic-rich than the Carnes Granodiorite.

The Gongora Stock is surrounded by a conspicuous contact metamorphic aureole, about 200 m wide, in the inner part of which greenschist and lower amphibolite regional facies metasedimentary rocks of the Etheridge Group show development of andalusite and recrystallisation of mica.

Only Proterozoic basement rocks are cut by Gongora Granodiorite at the present level of exposure. The granodiorite was originally considered to be of mid-Proterozoic age, mainly because of its general similarity to nearby Forest Home Trondhjemite. However, the unit has yielded Rb-Sr whole-rock and biotite isotopic data which together suggest a minimum age of 255±11 Ma. A somewhat older real age, comparable to the approximately 275 Ma Rb-Sr (whole-rock and biotite pair) of Awring Granodiorite closer to Croydon (Mackenzie & others, 1985), for emplacement of Gongora Granodiorite seems likely.

Miscellaneous acid intrusive rocks (part of CPr)

Introduction: Unassigned acid intrusive rocks of late Palaeozoic age without extrusive associates in the Georgetown region typically occur in dykes, plugs, and small stocks. Many shown as substantial single bodies at the 1:250 000 scale of the regional map are actually composite structures made up of anastomosing dykes with subsidiary plugs, separated by irregular screens of intruded basement.

Collectively, these rocks constitute a heterogeneous class of aphyric to abundantly porphyritic rhyolites and microgranites, with some sparsely porphyritic dacites. Many of the rocks resemble, but are spatially and/or temporally distinct from, ones making up named units. In essence, the class represents the residuum of late Palaeozoic acid intrusive rocks remaining after discrimination of the named units, and differentiation of those observably associated with (and inferentially related to) one or other extrusive sequences.

Rock types: The most common rock type included in the class is sparsely to moderately porphyritic rhyolite to microgranite, with quartz and feldspar phenocrysts ranging in maxiumum dimension from less than 1 mm to about 2 mm. Quartz and feldspar are either subequal, or quartz is markedly subordinate to the latter. The rocks locally display columnar jointing. Abundantly porphyritic, more massive, microgranite of elvan type is less common. It mostly contains subequal quartz and feldspar, with the latter and locally the former up to more than 1 cm in maxium dimension. Small quantities (mostly up to about 5% but occasionally as high as 25%) of chlorite are present locally in all rock types, but identifiable (i.e. fresh) biotite and hornblende are rare. Sparsely to moderately porphyritic rhyolite to microgranite is locally autobrecciated. Intrusive and/or collapse rudites, made up basically of the same rhyolitic to microgranitic rock types with or without a variable admixture of noncognate subangular to rounded clasts, occur in a few places.

Distribution: Most of the unassigned acid intrusive rocks in the Georgetown region intrude or are spatially closely associated with the Newcastle Range Volcanic Group. They are less abundant in and adjacent to Maureen and Cumberland Range volcanic group sequences, Dismal Creek Dacite (where intrusive rudites are common, however), Galloway Volcanics, and Marquis Rhyolite.

However, away from preserved extrusive sequences, a conspicuous concentration of unassigned rhyolitic dykes and plugs is centred on Mount Turner, 12 km west-northwest of Georgetown. Intrusive and collapse rudites also occur in the area (Baker, 1978a, 1978b).

The rocks are uncommon in the north-trending area bisected by the Delany Fault between Georgetown and Forsayth. None occurs in the extreme western and southwestern parts of the region, although comparable (but possibly Precambrian) rocks are present farther west towards Croydon.

Age(s): In the Georgetown region as a whole, miscellaneous acid intrusive rocks have evidently been emplaced recurrently throughout late Palaeozoic time, so that meaningful correlations cannot be made between different types on a basis of lithology alone.

Those of the rocks which occur in bodies striking roughly northwest to southeast, individually and/or collectively, are believed to be of Early Permian age. This belief is based mainly on the observation that bodies of equivalent rocks intimately associated with the Agate Creek Volcanic Group (see above) have that trend. The rocks occupying west-northwest-trending dykes cutting Cranky Creek Granodiorite and Paddock Creek Formation above) are assumed to be of Early Permian age, on the same basis. A northwest-trending linear zone of dykes and plugs made up of sparsely to moderately porphyritic rhyolite to microgranite extending from about 10 km south of Forsayth to the southern part of the outer (western) dyke of Prestwood Microgranite near the Cumberland Range Volcanic Group, is also believed to be of Early Permian age, again based on its overall parallelism to the intrusive bodies associated with Agate Creek Volcanic Group.

By similar reasoning, all miscellaneous acid intrusive rocks with approximately northerly trends, or those in north-trending belts, are taken to be of Carboniferous age, unless additional data indicate otherwise.

Miscellaneous intermediate to basic intrusive rocks (part of CPa)

Introduction: Unassigned intermediate to basic intrusive rocks of late Palaeozoic age in the Georgetown region occur much less commonly than their acid counterparts, although the two classes are locally intimately associated. With only one exception, the intermediate to basic rocks occupy small and mostly scattered dykes and plugs. The one exception is in the Bagstowe structure, where a north-northeast-elongated stock of these rocks, 5 km long and up to 1 km wide, occupies the eastern part of the northwestern Conical Knob—Old Man Ring-Dyke (see above).

Rock types: As a whole, the class of miscellaneous intermediate to basic rocks consists of broadly similar fine to occasionally coarse-grained melanocratic rock types. In detail, known types range from trachyandesite or equivalents to basalt or equivalents. Rare dark-coloured lamprophyric rocks, including biotite and hornblende-rich varieties, are included in the class.

Distribution: Spatially, unassigned intermediate to basic intrusive rocks are most common in and adjacent to the Bagstowe structure, between it and the southern end of the Newcastle Range, and along the Delaney Fault. They occur sporadically in and adjacent to outcrop areas of the Agate Creek Volcanic Group, Newcastle Range Volcanic Group, and Yataga Granodiorite; none is present in the western half of the Georgetown Region.

Age(s): Miscellaneous intermediate to basic intrusive rocks were undoubtedly emplaced recurrently throughout late Palaeozoic time in the Georgetown region, as their acid counterparts evidently were. Problems of correlating among them are exacerbated by variable relationships to any associated miscellaneous acid intrusive rocks, which are themselves of uncertain age. In the Bagstowe structure, moderately porphyritic trachyandesite to quartz andesite in the elongate stock adjacent to the Conical Knob–Old Man Ring-Dyke is probably younger than Old Man Rhyolite, but older than miscellaneous acid rocks in minor west and north-northeast-trending (Carboniferous?) dykes. Similar porphyritic trachyandesite to andesite farther north occurs in north-trending dykes cutting the Paddock Creek Formation but in turn cut by northwest-trending (Permian?) acid dykes. Close to the inner edge of the southern Mount Rous Ring-Dyke, northwest to north-northwest-trending dykes of aphyric trachyandesite appear to be younger than roughly west-trending (Carboniferous?) acid intrusive bodies.

Miscellaneous intermediate to basic rocks between the Bagstowe structure and the southern end of the outcrop area of the Newcastle Range Volcanic Group occur in a broad, ill-defined, belt of mostly north to northeast-trending dykes. The rocks include aphyric microtonalite near Mount Hogan and aphyric dolerites farther north. At least one body of dolerite cuts a west-northwest-trending (Permian?) swarm of miscellaneous acid dykes.

These dolerites may be equivalent to similar ones in and adjacent to the Agate Creek Volcanic Group which postdate the Early Permian extrusive sequence.

A minor northwest-trending dyke of moderately porphyritic andesite too small to show on the map, associated with the Kidston breccia pipe, postdates the pipe; it may also be of Permian age.

North-trending dykes of moderately porphyritic microtonalite cutting Yataga Granodiorite are believed to be genetically related to that unit (R. Holmes, pers. comm.), and of not much younger age than it (i.e. maybe earliest Permian at the youngest). These dykes occupy the northernmost end of the fracture system making up the Delaney Fault, suggesting that sporadic tonalite and possibly other miscellaneous intermediate to basic rocks associated with the fault farther south could be of Late Carboniferous and/or earliest Permian age. They may also be related to aphyric microtonalite(?) in dykes (too small to show on the map) postdating miscellaneous acid rocks (in part related to Corkscrew Rhyolite?) on both sides of the central isthmus of the Newcastle Range in the area of the Gulf Developmental Road.

Aphyric monzonite in the south-central part of the Georgetown region, 22 km south-southwest of "Gilberton", is of unknown age and affiliation. So also are: aphyric dolerite cutting Newcastle Range Volcanic Group rocks on the eastern side of the eastern lobe of the Newcastle Range; and moderately to abundantly porphyritic lamprophyres 10 km southeast of Georgetown and between the central isthmus and eastern lobe of the Newcastle Range.

Discussion

Affinities between intrusive and extrusive rocks

Specific intrusive rocks cannot be equated objectively with particular extrusive ones on a basis of available data. However, similarities between distinctive and/or unusual intrusive and extrusive units, particularly ones that are closely associated, tend to suggest relationships involving somewhat more than mere coincidence. Notable examples of such distinctively similar associated units are the MacCallor Microgranodiorite–Routh Dacite (Newcastle Range Volcanic Group), and some rocks assigned to the Mount Sircom Microgranodiorite–Namul Dacite (Cumberland Range Volcanic Group). Unfortunately, most of the abundant intrusive and extrusive acid lithologies are anything but uniquely distinctive. However, among the ones which are, it is tempting to genetically equate the Eva Creek Microgranite with Shrimp Creek Rhyolite (both in the eastern lobe of the Newcastle Range).

All of the intrusive units spatially associated with known and inferred Carboniferous extrusive rocks in the Georgetown region are demonstrably or inferentially younger than those extrusives. No unequivocal nonconformable relationships are known. This suggests that, in any single area, extrusion and intrusion were manifestations of a single broad magmatic-structural cycle in which the former activity preceeded the latter in both space and time.

Regionally, there is no regular spatial or temporal pattern evident in the distribution of various intrusive lithologies, many of which were probably emplaced recurrently. For this reason, it is difficult to infer relative ages of rocks except in a very few specific localities where unequivocal cross-cutting relationships are observed.

Moderately to abundantly porphyritic Carboniferous micrograntes and microgranodiorites of elvan type in the Georgetown region have mineralogical and textural affinities with the "cauldron lavas" of Rhodes (1976). These have been interpreted as the defluidised residues of ignimbrite-generating magma. By comparison, many of the more widely distributed unassigned aphyric to sparsely porphyritic rocks of the same compositional range are closer to Rhodes' (1976) "framework lavas", inferred to have been drawn from the deeper, volatile-poor, parts of magma chambers.

However, age relationships between Georgetown region rocks tend to be the reverse of those quoted by Rhodes (1976), although an appropriately young "framework lava"-type assemblage is represented by young coarse-grained units, including Elizabeth Creek Granite and Yataga Granodiorite. The most complicated situation appears to occur in the Lochaber intrusive progression, where "cauldron lava"-type Sues Creek Microgranite is intermediate in age between "framework lava"-type Lochaber Granite and unassigned rhyolites.

Structure

Structure of the Gilberton Formation

Introduction

Irrespective of later deformation(s), variable degrees of structural complexity were almost certainly manifested in the Gilberton Formation during its original accumulation as a consequence of the effects of Late Devonian palaeotopography and syn-depositional high-angle faulting. Superimposed deformation immediately before and/or during (depending on locality) accumulation of late Palaeozoic extrusive sequences combined with these original complexities produced a sum-total structural pattern in the Gilberton Formation which is unsystematic and unpredictable at the semi-regional to regional scale. There probably never was a single Gilberton "basin" (White, 1965) in the sense of a simple subsiding depocentre.

North-trending faults cutting Gilberton Formation to the north of "Gilberton" might belong to the same system as the Somerset Fault (below).

"Gilberton" area north of the Gilbert River

In its most extensive outcrop area (i.e. between the Percy River and Granite Creek to the north of "Gilberton"), the Gilberton Formation has the structure of a partly high-angle fault-bounded basin. This basin has the plan shape of an irregular acute triangle whose apex points northeast. South-southeast-trending folds occur in Gilberton Formation adjacent to the southeastern boundary fault of the basin.

This northern Gilberton basin is crossed from northwest to southeast by a mainly fault-bounded block of rocks assigned to the Agate Creek Volcanic Group. The Agate Creek Volcanic Group rocks locally overlap the Gilberton Formation basin to lie directly on Proterozoic basement.

"Gilberton" area south of the Gilbert River

South of "Gilberton", preserved Gilberton Formation occupies a small north-northeast-elongated ovate basin which does not have significant bounding faults.

Mount Tabletop area

Gilberton Formation at Mount Tabletop occurs in a roughly rectangular, almost completely high-angle fault-bounded, basin. The long axis of this structure strikes east–west. Overlying units of the Marquis Rhyolite are mildly discordant with respect to the basinal structure.

Some of the faults associated with Gilberton Formation in the Mount Tabletop area might belong to the Somerset system (see below).

Marquis Hill Area

The Gilberton Formation near Marquis Hill, to the south of Georgetown, has the form of a small, irregular, north-trending basin lying between two *en echelon* segments of the Delaney Fault system.

Deformation antedating cauldron subsidence

There is some suggestion, from the degree of development of structures in areas where Gilberton Formation does not appear to have been involved in significant subsequent deformation, that a northwest- or north-northwest-trending horizontal compressional stress was active regionally at the time of accumulation of the formation. This stress regime is thought to have been responsible for the northeast-trending basinal structure in the main outcrop area of the Gilberton Formation north of "Gilberton". It may also have been responsible for the formation of local fault scarps by reactivation of fracture systems. The compression appears not to have produced clearly detectable structures in basement rocks of the Georgetown region, although it might have been related to a hypothetical "Big Bend" folding event (Bell, 1980) farther east.

Cauldron subsidence-related deformation

However, most occurrences of Gilberton Formation in the Georgetown region are overlain by late Palaeozoic extrusive rocks (see below). The formation has essentially the same local structure as the overlying rocks. In such situations, deformation was presumably mainly, if not wholly, induced by Carboniferous and/or Permian cauldron subsidence (in the widest sense).

Late Palaeozoic intrusive–extrusive structures

Introduction

Although precise details of the mechanisms of fracture initiation and propogation involved are subject to debate, it is routinely accepted that stresses caused by magma ascent at intermediate(?) to high crustal levels are accompanied by dilatant brittle fractures. Such stresses might dilate pre-existing crustal inhomogeneities under appropriate conditions. Once fractures had been opened ahead of (above) magma bodies, they would presumably be involved in a cause-and-effect relationship with continued magmatic activity by which they would become essentially self-perpetuating. Both would combine to significantly influence spatial and temporal dispositions, morphologies, scales, and developmental progressions of intrusive and extrusive features.

Geometry and evolution of fracture/intrusion systems: steep radial and steep to gentle concentric (or annular, and encompassing "classical" ring-dyke and cone-sheet forms, respectively) geometries of fracture/intrusion systems are commonly envisaged to represent particularly well-defined and distinctive end-member classes. They commonly accompany and merge with plugs and stocks which may represent cupolas connected to deeper batholith-scale masses (e.g. Clough & others, 1909; Anderson, 1936, 1938; Billings, 1945; Reynolds, 1956; Smith & others, 1961; Robson & Barr, 1964; Rast, 1970; Roberts, 1970; Pollard, 1973; Phillips, 1974; Koide & Bhattacharji, 1975; Walker, 1975; Bussel, 1976; Chapman, 1976; Knapp & Knight, 1977; Wells, 1978; Burnham, 1979; Bahat, 1980; Morgan, 1980; Shaw, 1980; Spera, 1980; Knapp & Norton, 1981; Druitt & Sparks, 1983; Lafrance & John, 1994).

According to this concept, any straightforward ascent of magma over a period of time could result in systematic modification of local fracture/intrusion systems. Alternatively, early systems could be obliterated and replaced by more extensive ones reflecting the broader influence of increased volumes of magma impinging on any particular structural level.

Vertically and laterally intricate to at least superficially unsystematic fracture/intrusion systems probably reflect variable responses to factors such as: volume and supply rate of magma; recurrent extrusion; physical (including thermal) magma heterogeneity in space and time; location, and form, of contemporaneous topographic "free" surface; location, nature, and orientation of crustal anisotropies; and magnitudes and/or orientations of external (semiregional to regional) principal stresses (e.g. Ode, 1957; Johnson, 1961; Bradley, 1965; Mudge, 1968; Fiske & Jackson, 1972; Rehrig & Heidrick, 1972; Johnson & Pollard, 1973; Pollard & Johnson, 1973; Pollard & Muller, 1976; Nakamura, 1977; Pitcher & Bussel, 1977; Pollard & Holzhausen, 1979; Davidson, 1980; Sharpe & Snyman, 1980; Spera, 1980; Francis, 1982; Gerla, 1982; Heidrich & Titley, 1982; Hyndman & Alt, 1983; Skarmeta & Price, 1984; Bacon, 1985; Spencer, 1985; Muller, 1986; Walker, 1986; Geoffroy & others, 1993; Marti & others, 1994; Potone & others, 1994).

Cauldron subsidence: steep concentric (ring-) fracture systems have traditionally been implicated in subsidence of cauldron blocks, with or without concomitant surficial caldera development. There is still some dispute about details of their relationships to various inferred stages of magma-body evolution. Also, overall inclinations (inwards or outwards) around circumscribed blocks (cf. Anderson, 1936, 1938; Smith, Bailey & Ross, 1961; Chapman, 1976; Smith & Bailey, 1968; Druitt & Sparks, 1983; Lipman, 1984; Marti & others, 1994) are commonly uncertain. Inclinations are usually assumed to be inwards on a basis of centripetal dips and other presumed subsidence-related deformational features in circumscribed blocks (e.g. Lipman, 1984). However, micro-earth activity at the major Rabaul Caldera (Papua New Guinea) apparently delineated an inter-volcanic ring-fracture system dipping steeply outwards to depths of approximately 4 km at least (Mori & McKee, 1987; Mori & others, 1989). Similarly, at Mount Pinatubo (Phillipines) a smaller (intra-volcanic) ring fracture was interpreted to be outward-dipping from siesmicity which followed the 1991 eruption (Mori & Eberhart-Phillips, 1993). Conceivable, cauldron blocks might be circumscribed by inwardly- and/or outwardly-dipping (and/or vertical) ring-fractures, depending on local conditions. In fact, the most recent information from Rabaul suggests such a situation there, with one sector of the ring-fracture system being inward-dipping (Stewart & Jones, 1993).

"Settling-in": Oversby & others (1980) introduced the concept of late-stage subsidence or "settling-in" of cauldrons and equivalent structures, mainly along components of fracture/intrusion systems. This "settling-in" was visualised as a fundamental and inevitable adjustment to differential thermal contraction in and adjacent to the structures, most particularly within underlying batholith-scale magma chambers. Cooling and solidification of magma in such chambers might have been accompanied by up to 20% volume contraction (cf. John & Blundy, 1993).

Manifestations of "settling-in" are mostly not conspicuous: among them are thought to be the ubiquitous faults along and locally between margins of intrusive bodies. A good example of what is considered to be a discrete "settling-in" fault zone makes up the northern, east-trending, part of the present fracture/intrusion system around the Eveleigh Cauldron of the Newcastle Range (see below).

Theoretically, the effects of "settling-in" should mimic and enhance those produced by any antecedent subsidence in extrusive sequences. However, the amount of appropriate contraction might only rarely be sufficient to produce major settling effects, particularly if most or all underlying magma chambers had tabular geometries.

Structural resurgence: is a common feature of major collapse calderas (Smith & Bailey, 1968; Steven & Lipman, 1976; Lipman, 1984). In the "classical" case, this consists of internal, approximately centrally-located and symmetrical, doming of the intra-caldera sequence (and presumably, subjacent rocks). In young calderas, this doming has major topographic expression; the annulus between resurgent dome and the caldera wall defines a "moat", which commonly acts as depocentre for distinctive late-stage sedimentation. Uplift forms can also be variable, ranging from excentric and/or asymmetrical domes and partial or hinged ("trap-door") uplifts, through wholesale elevation of entire caldera blocks with or without dip reversal, to broader subregional upwarps.

Influence of regional tectonic stresses: overall, most (but not all, e.g. Bacon, 1985) fracture/intrusion systems tend to be preferentially aligned perpendicular to minimum principal regional tectonic stresses (see, for example, citations above, plus Anderson, 1951; Jackson & Shaw, 1975; Nakamura & others, 1977; Francis & others, 1978; Chen & Moore, 1979; Pollard & others, 1982; Feraud & Campredon, 1983; Laughlin & others, 1983). Again, inconsistancies and deviations of variable magnitude up to at least semiregional extent may reflect influences of, for instance: significant pre-existing crustal discontinuities/inhomogeneities (cf. Delaney & others, 1983); and passive or active regimes of transtensional-transpressional deformation within, or between, *en echelon* segments of major transcurrent or oblique-slip faults (cf. Hutton, 1982; Coyle & Strong, 1986).

It has been suggested that surficial calderas (and, by implication, subjacent intrusive features) could be elongated parallel to minimum principal tectonic stresses as a consequence of "pull-apart" (Lachenbruch & Sass, 1978). Additionally, in the case of periodically evacuated magma chambers, large-scale wallrock spalling processes equivalent to borehole "breakout" (e.g. Bell & Gough, 1979; Fordjor & others, 1983; Springer and others, 1984), might also induce appreciable parallelism to minimum principal stress directions.

"Hot-spots": additional inconsistancies between individual morphologies and collective dispositions of fracture/intrusion systems might result from development over a fixed mantle "hot-spot". In a situation where the systems were developing in a migrating lithospheric plate, a complex interplay between the stress field associated with plate motion (minimum principal stress perpendicular to absolute movement direction), and stresses induced by the thermal plume and its trace, should be expected. Systems defining "hot-spot" traces would be characterised by systematic age trends along any individual trace, and consistent temporal relationships between two or more traces, irrespective of spatial irregularities (cf. Rhodes, 1968; Morgan, 1972; Suppe & others, 1975; Bowden & others, 1976; Turcotte & Oxburgh, 1978; Turner & Bowden, 1979; Pilger, 1983; Rahaman & others, 1984).

Structure of the Newcastle Range Volcanic Group and associated intrusive rocks

Introduction

Most of the preserved Wirra and Namarrong volcanic subgroups, and all of the Eveleigh subgroup, of the Newcastle Range Volcanic Group are preserved in structures of basinal form. These basins coincide with the southern, northern, and eastern lobes of the Newcastle Range respectively. Most of the preserved Kungaree Volcanic Subgroup, along with parts of the Wirra and Namarrong subgroups in the central isthmus of the range, occupies a grossly trough-like structure which contains several subsidiary basins.

Preserved Cumbana Rhyolite in the Georgetown Region map area defines most of the western half of a small basin. This has been erosionally separated from Newcastle Range structures proper.

The Wirra, Eveleigh, Namarrong, and Cumbana basins are broadly comparable in size and plan shape to many cauldron structures in general, including collapse calderas (cf. Steven & Lipman, 1976).

Inward dips at the margins of the basinal structures, and of the trough-like element, are mostly in the range of 10° to 20°. Steeper dips (up to 80° rarely) occur locally. Discontinuous folds and other, less systematic and/or more diffuse, dip reversals characterise a few areas.

The steepest dips in Newcastle Range structural elements are developed adjacent to bounding and internal high-angle faults (commonly represented by dykes and other intrusive bodies), and presumably result from normal drag.

Major systems of fractures (including faults) and/or intrusive bodies surrounding the basinal Newcastle Range elements are envisaged as being equivalent to "classical" ring-dyke structures. They are believed to have been "frozen" at different developmental stages and/or structural levels.

The fracture/intrusion systems associated with the Kungaree Trough presumably have a similar significance, despite geometrical differences.

As a collective structural whole, the Newcastle Range Volcanic Group sequences and associated rocks are believed to represent a composite volcano-tectonic cauldron, occupying the first rank (or apex) of a hierarchical series of subsidiary elements.

Eveleigh Cauldron

The Eveleigh Cauldron (Fig. 4) is trapezoidal in plan, with sides of about 28 km (west), 12 km (north), and 22 km (east and south).

Fracture/intrusion systems: the cauldron is almost completely circumscribed by a system of essentially vertical, linear to somewhat arcuate, dykes and minor stocks, with interconnecting intrusion-free faults. The intrusive bodies consist mainly of Caterpillar Microgranite, although Eva Creek Microgranite also occurs locally. The maximum demonstrable displacement, of at least about 1000 m, on this circumferential fracture-intrusion system has taken place in the southwest.

The circumferential fracture-intrusion system is mainly coincident with the present outer outcrop edge of the Eveleigh Volcanic Subgroup rocks. This outcrop edge lies "inside" the fracture-intrusion system only in the eastern Eveleigh Cauldron.

In the east and west, steeply dipping, dyke-filled radial branches of the circumferential fracture/intrusion system strike southwest to west and east-northeast into the interior of the Eveleigh cauldron. Other steep dykes, most conspicuous in the Caterpillar Range east of the Einasleigh River, radiate out in various directions away from the cauldron in the west, southeast, and southwest. Some of these locally turn towards parallelism with the circumferential system to define: a diffuse, partial outer concentric fracture-intrusion system in the west; and the northern half of an incipient concentric system partly circumscribing a block of basement rocks to the south.

Intrusive bodies occupying one or other of the steep fracture systems associated with the Eveleigh Cauldron locally impinge on the basinal extrusive sequence. Where this happens, the bodies commonly assume, wholly or in part, an attitude of gross concordance with respect to the sequence. Maximum developments of concordance occur at or close to stratigraphic contacts between: Gilberton Formation and Yellow Jacket Rhyolite; Beril Peak and Mosaic Gully rhyolites; and Mosaic Gully Rhyolite or Canyon Dacite and Shrimp Creek Rhyolite.

These concordant intrusive bodies need not represent cone-sheets in the "classical" sense (e.g. Anderson, 1936). The geometrical relationships between them and components of the high-angle circumferential system suggest, rather, a collective affinity with bell-jar plutons (Myers, 1975; Bussel & others, 1976; Pitcher, 1978).

Large irregular stocks of Caterpillar and Eva Creek microgranite cutting the north-central part of the Eveleigh sequence are connected to the fracture/intrusion system around the edge of the cauldron by the western internal component of the radial system. These microgranite stocks have grossly concordant upper terminations ("roofs"), and may be entirely sheet-like or tabular in form. Again, they may represent the upper parts of at least incipient bell-jar-type plutons.

Swarms of concordant intrusive bodies, apparently unconnected to any high-angle fracture/intrusion system, within Yellow Jacket Rhyolite in the northern and northeastern parts of the Eveleigh sequence are older than Caterpillar and Eva Creek microgranites. They apparently occupy an independent fracture system, comparable to the one occupied by concordant intrusive bodies interpreted as probable true cone-sheets in and adjacent to the Namarrong sequence (see below).

None of the fracture/intrusion systems outside the Eveleigh Cauldron is known to have undergone significant faulting movement. However, the western internal radial dyke occupies a line across which Yellow Jacket and Beril Peak rhyolites apparently die out southwards. This suggests that faulting took place during accumulation of the extrusive rocks. About 5 km to the north, a west-trending high-angle radial fault was probably active during accumulation of the Gilberton Formation, although it does not appear to extend above the base of the Yellow Jacket Rhyolite.

The eastern internal radial dyke occupies a minor fault across which there is no stratigraphic contrast comparable to that in the west. However, the dyke does mark the northern limit of circumferential folds (see below). In the south, the same folds abut against a high-angle radial fault which is one of several cutting the main circumferential fracture/intrusion system between the lower reaches of Pint Pot and Shrimp creeks.

An isolated outermost linear dyke of Caterpillar-type microgranite, subparallel to the eastern edge of the Eveleigh Cauldron, makes up Mount Nigger, 4 km east of the Einasleigh River and the circumferential fracture-intrusion system.

There are strong stratigraphic and structural indications (see above) that at least some major components of the fracture/intrusion systems of the Eveleigh Cauldron originated (as faults) during accumulation of the extrusive sequence. A few may even have originated during accumulation of the Gilberton Formation. On the other hand, the intrusive rocks delineating and defining many of the systems as coherent entities all postdate Jinker Creek Rhyolite. Emplacement of these mostly elvan-type rocks was thus very late in terms of the magmatic activity for which evidence is preserved.

Subsequent reactivation to produce the intrusion-free faults marginal to and/or cutting across the intrusive bodies, evidently also took place.

High-angle, intrusion-free, faults postdate the cir-

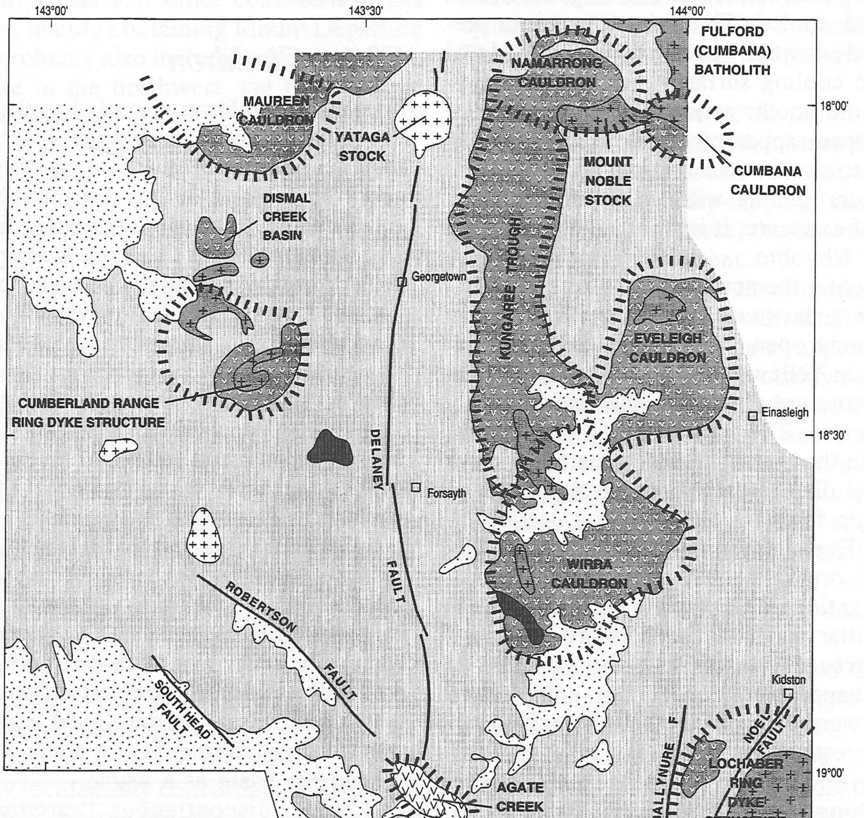

Fig. 4. The main late Palaeozoic structural elements in the Georgetown Region. Modified from figure marginal to Bain & others (1985).

cumferential and other fracture/intrusion systems associated with the southeastern Eveleigh Cauldron. In addition, the circumferential system is cut by a high angle fault, which makes up the present eastern lobe's range-front structure at the northern end of the cauldron. These late structures are examples of the late-stage "settling-in" faults of Oversby & others (1980).

Folds: discontinuous folds subparallel to the circumferential fracture/intrusion system (and thus styled "circumferential" folds, even though not in strictly appropriate positions) are conspicuous in the east-central part of the Eveleigh sequence. They also occur in the southwestern and north-central parts of the sequence.

The folds in the east-central area affect Yellow Jacket, Beril Peak, and Mosaic Gully Rhyolites. They are gently south-plunging, and consist of an outer (eastern) moderately open symmetrical syncline paired with an inner asymmetrical anticline, whose faulted western limb dips at up to 80°. Both folds appear to end at a dyke and a fault in the north and south, respectively.

The folds might be drape structures overlying major "blind" fracture/intrusion zones. Inclined Beril Peak Rhyolite in the folds has uniformly vertical columnar jointing, suggesting that deformation took place before the ignimbrite had cooled. The columnar joints presumably developed essentially perpendicular to the local palaeotopographic cooling surface.

The fold in the southwestern Eveleigh sequence is a moderately open, apparently essentially symmetrical, gently west to south-southwest-plunging syncline whose hinge occurs entirely within Canyon Dacite at the present level of exposure. It is overlain discordantly by Shrimp Creek Rhyolite.

The fold affecting the north-central part of the Eveleigh sequence (not shown on the Georgetown Region map) is a moderately open, gently west to northwest-plunging anticline in Yellow Jacket Rhyolite. The northern limb of this structure dips somewhat more steeply than the southern one. The fold is cut by the present range-front fault in the north. Its eastern part may have undergone sinistral displacement on a north-northeast-trending high-angle fault.

The northern Eveleigh sequence is also warped by a broad southwest or south-southwest-trending, south-plunging, faulted anticlinal flexure which is mostly obscured by Caterpillar and Eva Creek microgranites.

Rotated structural megablock: the structure of the Eveleigh sequence has been further complicated by conspicuous inward-tilting of the Yellow Jacket Rhyolite in the northwestern corner of the Eveleigy Cauldron, which is believed to have also been affected by "settling-in" faulting (see above).

This tilting, of about 60°, appears to reflect outwards (with respect to the overall basinal structure) rotation of a now-marginal block of about 1 km^3 of the extrusive sequence on a northwest-concave (in plan) and presumably listric normal fault.

Rotation of the Yellow Jacket Rhyolite on the presumed listric fault (above) may antedate emplacement of a grossly concordant swarm of individually elongate-wedge-shaped bodies of intrusive rhyolite/microgranite into the northwestern part of the Eveleigh sequence. These intrusive bodies, in turn, apparently antedate steep and concordant fractures occupied by Caterpillar and Eva Creek microgranites.

Outwards rotation of the megablock presumably relates to positive structural and/or palaeotopographic expression of at least the northwestern Eveleigh Cauldron. As discussed further below, rotation may have taken place before permanent establishment of the basinal structure; it could have occurred on the flank of a positive (constructional-extrusive?) palaeo-land form at the site of the cauldron.

"Settling-in" faults: the east-trending component of the present fracture/intrusion system around the Eveleigh Cauldron is interpreted as a "settling-in" fault zone. The zone, with a few small bodies of rhyolite, truncates larger bodies of rhyolite and microgranite, in part inferred from gravity data, known and interpreted to occupy the original circumferential fracture/intrusion system of the cauldron. The zone is cut by minor radial faults, postulated to be a second generation of "settling-in" structures.

Relationships to adjacent structural entities: the circumferential fracture/intrusion system of the Eveleigh Cauldron truncates the adjacent edges of the Wirra Cauldron and Kungaree Trough (see below). It is therefore evidently younger than them, at least in terms of its present geometry and occupation by Caterpillar Microgranite.

Wirra Cauldron

The Wirra Cauldron (Fig. 4) has the plan shape of an irregular rhomboid, with west-southwest to east-northeast and north-northwest to south-southeast axes of about 35 km and 30 km respectively.

Fracture/intrusion systems: like the Eveleigh Cauldron, the Wirra Cauldron is almost completely circumscribed by essentially vertical faults and intrusive bodies. However, the intrusive bodies are not as well developed as those associated with the former structure.

A shallow inwardly-convex structural embayment cuts into the southwestern part of the Eveleigh basin. This embayment appears to reflect a partial concentric fracture system surrounding a block of basement rocks outside the basin which has not undergone detectable upward or downward movement.

Other (radial and concordant) fracture/intrusion systems are only poorly developed in association with the circumferential system. Parts of two roughly concentric internal systems are developed within the Wirra basin. The outer one of these impinges on the system around the cauldron in the east and southeast, suggesting that it either has not developed completely, or that it was truncated during the last phase of cauldron faulting around the basin as a whole.

Folds: discontinuous "circumferential" folds, comparable to, but less well developed than, ones in the eastern Eveleigh Cauldron sequence (see above), occur in the southwestern part of the Wirra sequence. They affect lower Bousey Rhyolite and the underlying Gilberton Formation. These structures, consisting of a paired outer (western) syncline with an inner anticline, are open and shallowly north to northwest-plunging.

Unsystematically complex folds also occur in volcaniclastic rocks of the lowermost Bousey Rhyolite 3 km northeast of Fish Hole. These occur in a sequence which, as a whole, is moderately to steeply east-(inward-)dipping, and may be due to local soft sediment slumping. Other dip reversals north of Fish Hole seem only to reflect local drag on west-side-down (inside-up) high-angle faults.

Relationships to adjacent structural entities: the concentric fracture/intrusion systems around and within the Wirra Cauldron and basin (below) appear to pass northwards into the marginal Kungaree fracture/intrusion system, implying that the two systems are of equivalent age.

In the eastern part of the structural mergence between the Wirra and Kungaree fracture/intrusion systems, the combined systems are geometrically truncated and apparently cut by Caterpillar Microgranite occupying the circumferential fracture/intrusion system of the presumably younger (or more recently reactivated) Eveleigh Cauldron (above).

Namarrong Cauldron

The Namarrong Cauldron (Fig. 4) is irregularly elliptical in plan, with north-to-south and east-to-west dimensions of about 15 km and 20 km respectively.

Fracture/intrusion systems: the Namarrong Cauldron, by definition, is delineated by a moderately well-developed steep circumferential fracture/intrusion system; this is associated with an internal radial system.

Steep circumferential and other concentric dykes and elongate plugs, mainly containing Mount Departure Microgranite but probably also including the small stock of Lubrina Granite in the northwest, cut the northern part of the main concordant system (see below). They locally become overall concordant themselves.

By contrast with the Eveleigh and Wirra cauldrons, the best-developed fracture/intrusion system of the Namarrong Cauldron is not a steep one, but instead broadly concordant with respect to the basinal extrusive sequence which it cuts. This concordant system was clearly antedated by the original fractures of the circumferential system, even though intrusive bodies occupying the latter are partly of the same age, and partly younger, than intrusive components of the former.

The concordant fracture/intrusion system is most extensive in the lower half of the Brodies Gap Rhyolite, in the northern and western parts of the Namarrong Cauldron. The system passes eastwards (and downwards) into basement rocks, without significant steepening. It is covered east of the Einasleigh River and its anabranch, but its reappearance may be marked by a zone of sporadic steep dykes to the north of Mount Max.

The maintenance of shallow inward dips below the base of the extrusive sequence and Gilberton Formation suggests that the intrusive bodies represent true cone sheets, and are only incidentally concordant with respect to a basinal structure which had already been formed at the time that they were emplaced.

The southern sector of the concordant fracture/intrusion system merges with the Brodies Gap Fault Zone (below).

The margins of the body of Elizabeth Creek Granite (*sensu stricto*) which intrudes the southeastern part of the Namarrong Cauldron are controlled at the present level of exposure by a combination of steep fractures (south and east), the shallowly-dipping intrusive contact with lowermost Namarrong Volcanic Subgroup (north), and the two together (west). Fractures controlling the southern edge of the granite probably represent a rejuvenated eastern extension of the Brodies Gap Fault Zone. Those in the east are aligned with the steep fracture/intrusion system around the northern periphery of the Namarrong Cauldron.

Brodies Gap Fault Zone: this fault zone, at the southern edge of the Namarrong Cauldron, apparently underwent north-side-up movement before formation of the concordant fracture/intrusion system.

Marked stratigraphic contrasts occur on either side of this fault zone at the present level of exposure. In particular, thicknesses of Twin Dams and Dagworth andesites, and of Corkscrew Rhyolite, are distinctly different on either side of the zone. These contrasts suggest that the Brodies Gap Fault Zone, or a precursor feature (hinge line?), was active during accumulation of the extrusive sequence.

Apparently, the Brodies Gap Fault Zone and associated faults, as well as the internal radial system, significantly disrupted the Namarrong Cauldron before initiation of the main concordant fracture/intrusion system. This disruption evidently accompanied uplift at the site of the cauldron. The disruption and uplift are believed to have antedated inception of the cauldron as such, because of the stratigraphic evidence that early subsidence was greater at the western periphery of the structure than elsewhere, i.e. it was independent of the symmetry of the structure as it subsequently developed. The uplift event was thus not properly one of structural resurgence.

Accepting the above, the (now) steep Brodies Gap Fault Zone, along with other steep components of the concentric fracture/intrusion system, are inferred to have originated as outwardly-dipping (relative to the superimposed basinal structure) features with a reverse component of nett movement.

At its western end, the Brodies Gap Fault Zone merges with a steep internal radial fault in a complex and poorly understood area of minor blocks and slices. Other steep faults, which probably belong to this radial system, form the northern edge of the main preserved development of Twin Dams and Dagworth andesites, and the fracture-controlled western margin of the Mount Noble Stock (Elizabeth Creek Granite).

Steep linear fault segments, which have the same sense of inside-up movement as the Brodies Gap Fault Zone, and which are presumably related to it, trend north-northwest about 1 km west and 2 km east of Cattle Creek.

The main part of the Brodies Gap Fault Zone is now envisaged to represent a major extension related transfer structure (Oversby, 1987).

Folds: the central Namarrong Cauldron is warped by a northwest-trending, north-plunging, anticlinal flexure whose faulted hinge zone is occupied by Elizabeth Creek Granite in the southeast.

Dip reversals of up to 75° also occur in the west-central Namarrong Cauldron. These reversals occur in a north-northwest-trending zone at least 1 km wide lying between a high-angle west-side-down (inside-up) fault/dyke zone in the west, and a 40°-east-dipping sheet of intrusive rhyolite-microgranite in the east. Contacts between "slices" of rocks, internally west-dipping, appear to dip east (inwards) at moderate angles, subparallel to the intrusive sheet. They presumably represent related, but mainly intrusion-free, fractures (faults?), which might be listric at depth (hence "reverse" drag against them).

Relationships to adjacent structural entities: the present southwestern margin of the Namarrong Cauldron is partly defined by a high-angle fault, which is a northern continuation of the fracture/intrusion system marginal to the Kungaree Trough.

An equivalent situation occurs in the southeast, although the Kungaree Trough's boundary fault is apparently displaced by the southern part of the Namarrong Cauldron's steep circumferential system. This southern part of the circumferential system is defined by the Brodies Gap Fault Zone (below).

Cumbana Cauldron

The Cumbana Cauldron (Fig. 4) as preserved, including that part east of the Georgetown Region map area, is incompletely ovoid. It has an east-southeast to west-northwest long axis of about 12 km.

Fracture/intrusion systems: the Cumbana Cauldron is bounded in the south at the present level of exposure by a wide arcuate dyke of Mount Departure-type microgranite. The northern boundary of the cauldron is marked by a body of Elizabeth Creek Granite, whose intrusive margin is steep and arcuate, presumably as a reflection of original fracture control.

Relationships to adjacent structural entities: the size, location, and contained stratigraphic sequence of the Cumbana Cauldron suggests that it may have once combined with the nearby Namarrong Cauldron to make up a single larger structural element.

Kungaree Trough

The elongate Kungaree Trough (Fig. 4) is a rift-like cauldron delineated by approximately north-trending fracture/intrusion systems. It has diffuse, and locally (north) overprinted, margins. As a consequence, it is less well-defined than the other Newcastle Range cauldrons.

Fracture/intrusion systems: marginal and external fracture/intrusion systems delineating the Kungaree Trough along trend are predominantly steep, and linear to moderately arcuate. Individual components locally strike in markedly different directions from the collective average.

Significant west-trending systems associated in the Kungaree Trough, in addition to the Brodies Gap Fault Zone separating it and the Namarrong Cauldron (above), are: the Gulf Highway Fault Zone, in the area of the Gulf Developmental Road; and the Spear Creek Fault Zone, about 10 km farther south (Fig. 2). The sense of displacement on both fault zones as a whole is north-side-down. Between the two fault zones Kitchen Creek Rhyolite outliers mostly have near-horizontal contacts with subjacent Routh Dacite. These contacts are interpreted to represent a single sole or detachment structure. Their structural, rather than stratigraphic, nature is revealed by steep and markedly discordent (with respect to the attitudes of associated contacts) inclinations of eutaxitic foliations in the Kitchen Creek Rhyolite outliers. Columnar jointing in the same outliers is approximately perpendicular to the contacts with Routh Dacite, indicating that the foliations were deformed before the ignimbrite had cooled. The contacts themselves, where observable, are sharp; the adjacent Kitchen Creek Rhyolite has undergone a much greater degree of compaction and/or rheomorphism than the bulk of the unit, suggesting ductile deformation and consistent with an origin before Kitchen Creek Rhyolite had substantially cooled.

The normal, rather than thrust, sense of movement on these structural contacts is indicated by the preservation of younger-on-older stratigraphic relationships, even though part of the full sequence developed to the north of the Gulf Highway Fault Zone has apparently been eliminated.

Reverse drag developed in Kitchen Creek Rhyolite adjacent to some of the steep normal faults suggests that they have listric geometries, and may have developed contemporaneously with the near-horizontal detachment. It is suggested that the two types of structures were originally linked geometrically, and related genetically. They probably formed concurrently with extrusive activity as a structural response to east–west extension along the central isthmus of the Newcastle Range

These Gulf Highway and Spear Creek fault zones are probably accommodation zones equivalent to a second-order transfer fault (Etheridge, 1987).

A north-central splay of the Spear Creek Fault Zone is occupied at least locally by intrusive ignimbrite similar to Kitchen Creek Rhyolite.

North of the Gulf Highway Fault Zone, a marginal and external fracture/intrusion system is developed mainly on the western side of the Kungaree Trough. South of the Spear Creek Fault Zone an equivalent system occurs mainly on the eastern side of the cauldron. Marginal and external fracture/intrusion systems are about equally developed on each side of the Kungaree Trough between the two west-trending (transfer) fault zones. These observations are consistent with differential rotations of southern, central, and northern blocks, separated by transfer zones, within the cauldron.

The arcuate western part of a grossly concordant fracture/intrusion system, which is probably older than the adjacent moderately arcuate marginal and external system, at least locally, occurs in the extreme western part of the Kungaree Trough in the Fiery Creek area. In addition, concordant intrusive sheets, which are continuations of marginal and external dykes, occur within the extrusive sequence: on the same (western) side of the cauldron in the Gulf highway area; on the western side of the cauldron farther south in the area of debouchement of the Etheridge River; and on the eastern side of the trough in the upper reaches of Spear Creek.

In the Gulf highway area, the change in attitude from steeply dipping and discordant to gently dipping and overall concordant takes place across the main, essentially intrusion-free, boundary fault without appreciable displacement. This is taken to indicate that early faulting and later fracture/intrusion were independent events. The same situation probably exists in the upper reaches of Spear Creek. However, in many other areas, late-stage movement (rejuvenation?) of the Kungaree Trough's boundary fault has cut the intrusive bodies. In the area of debouchement of the Etheridge River to the west, the change in attitude of intrusive bodies takes place at the apparently non-faulted (but probably dilated) stratigraphic base of probable Bousey Rhyolite.

Radial fracture/intrusion systems are not apparent in the Kungaree Trough at the present level of exposure.

Stocks of Talaroo and Tenavute microgranites, and of MacCallor Microgranodiorite, within the western

Kungaree cauldron, are associated with rather diffuse, steep, meridional branches of the marginal and external fracture/intrusion system. These branches at least locally occupy east-side-down faults. The original roof of the Talaroo Microgranite stock was probably approximately horizontal, and slightly discordent with respect to the dipping extrusive sequence.

On the other hand, structural controls of north-elongated MacCallor Microgranodiorite and unassigned rhyolite to microgranite stocks in the axial part of the Kungaree Trough are not apparent at the present level of exposure and/or scale of mapping.

Subsidiay cauldron elements: the marginal and external fracture/intrusion system to the west of the present edge of the Kungaree cauldron in the Fiery Creek–Gulf highway area is distinctly arcuate. The equivalent system to the east of the trough in the upper reaches of Tabletop and White Springs creeks is also arcuate. These two arcuate systems are incompletely connected across the trough at the present level of exposure by components of the mostly intrusion-free (and at least in part older) Gulf Highway Fault Zone (Fig. 2). They, with early concordant intrusive sheets within the Kungaree Trough sequence in the Fiery Creek area (above), define diffuse western and southern edges of an asymmetrical basin/cauldron structure.

This local structural element is partly occupied by the main preserved development of Shamrock Rhyolite. The basin/cauldron also contains the only known occurrences of Talaroo Microgranite, reinforcing the interpretation of it as a distinct structural entity.

An overlapping, probably younger, subsidiary basin/cauldron element is occupied mainly by Routh Dacite, Corkscrew Rhyolite lava, and Kitchen Creek Rhyolite in the block bounded to the north and south, respectively, by the Gulf Highway and Spear Creek Fault Zones (Fig. 2). This second basin/cauldron contains the main preserved developments of Routh Dacite and Kitchen Creek Rhyolite. It has a proximal lag-fall facies of the latter. In contrast, the main preserved development and lag-fall facies of the Corkscrew Rhyolite ignimbrite to the north of the debouchement of Fiery Creek do not seem to be associated with any similar structure.

Folds: folds and dip reversals are also present in the Kungaree Trough. The best-developed folds occur in the northwest. They consist of a paired north-northeast-trending outer (western) syncline with an inner anticline. The folds deform the Corkscrew Rhyolite; they are open to moderately open, and plunge gently north. They are overstepped northwards by Brodies Gap Rhyolite, and pass south into a zone of low-angle rhyolite/microgranite sheets.

The main dip reversals in the Kungaree Trough take place across the Gulf Highway and Spear Creek fault zones. Both fault zones occupy broad anticlinal hinges. The Brodies Gap Fault Zone, between the Kungaree and Namarrong cauldrons, does not appear to occupy an equivalent hinge.

Discussion

The assemblage of individual interrelated cauldron structures within which the Newcastle Range Volcanic Group accumulated make up a composite structural entity which is regarded as a first-order (rank) cauldron; the subsidiary constituent cauldrons are thus of second and lower order, depending on their spatial/temporal dimensions (cf. Oversby & others, 1980).

Semi-regional controls of the Newcastle Range composite cauldron (below) include ones which relate ultimately to the regional tectonic regime during Carboniferous time. The composite cauldron qualifies to be regarded as a volcano-tectonic structure ("complex"). Constituent second-order and lower-rank cauldrons probably also qualify to be so regarded, although somewhat more ambiguously because of their smaller size and less-intricate stratigraphic/structural nature.

As with extrusive activity, structural and intrusive activity in the main Newcastle Range was evidently diachronous; it commenced in the Wirra Cauldron and progressed generally northwards. Original relationships between the Eveleigh Cauldron and main range elements cannot be inferred from preserved relationships. The best that can be said is that the most recent fracture/intrusion architecture of the Eveleigh Cauldron, at the level now exposed, almost certainly postdates that in adjacent parts of the main Newcastle Range.

Semi-regional controls of composite Newcastle Range Cauldron: It is probably significant that preserved Newcastle Range Volcanic Group rocks, along with the western edge of the Fulford Batholith, occur mainly at and east of the contact between Einasleigh Metamorphics and lower-grade parts of the Etheridge Group. Available data indicate that this contact is primarily a metamorphic lithofacies (schist/gneiss) transition; it is probably partly coincident with an original stratigraphic-sedimentological transition. As exposed, the contact does not seem to coincide with any appreciable fault or equivalent structural discontinuity, although the original transition might have been manifesting some deeper and/or more diffuse zone of crustal weakness than is now evident. Perhaps such a zone of crustal weakness might have been formed by a south-southeastwards-trending system of splays off the Palmerville Fault (or, more properly, its late Palaeozoic precursor/s) where it changes direction markedly between the Mitchell and Walshe Rivers, about 60 km northwest of Chillagoe.

The metamorphic lithofacies transition in itself would presumably have been a zone of some degree of ductility contrast during late Palaeozoic time. Such contrast would make the transition belt susceptible to preferential dilation by a near-meridional maximum principal stress during the Carboniferous. This preferential dilation would have facilitated magma channelling.

The metamorphic lithofacies transition is assumed to have an overall westward dip at and at least immediately subjacent to the present surface. However, geophysical (gravity) anomalies believed to be mainly reflecting the Newcastle Range Volcanic Group sequence and associated intrusive rocks, as well as the surficial development and probable gravity expression of the western Fulford Batholith, extend appreciably east of the transition in outcrop. These observations suggest that if the Einasleigh Metamorphics/lower-grade Etheridge Group transition was indeed responsible for localising Carboniferous magma ascent, then it must widen significantly at depth, and/or take on an eastward inclination below the present level of exposure.

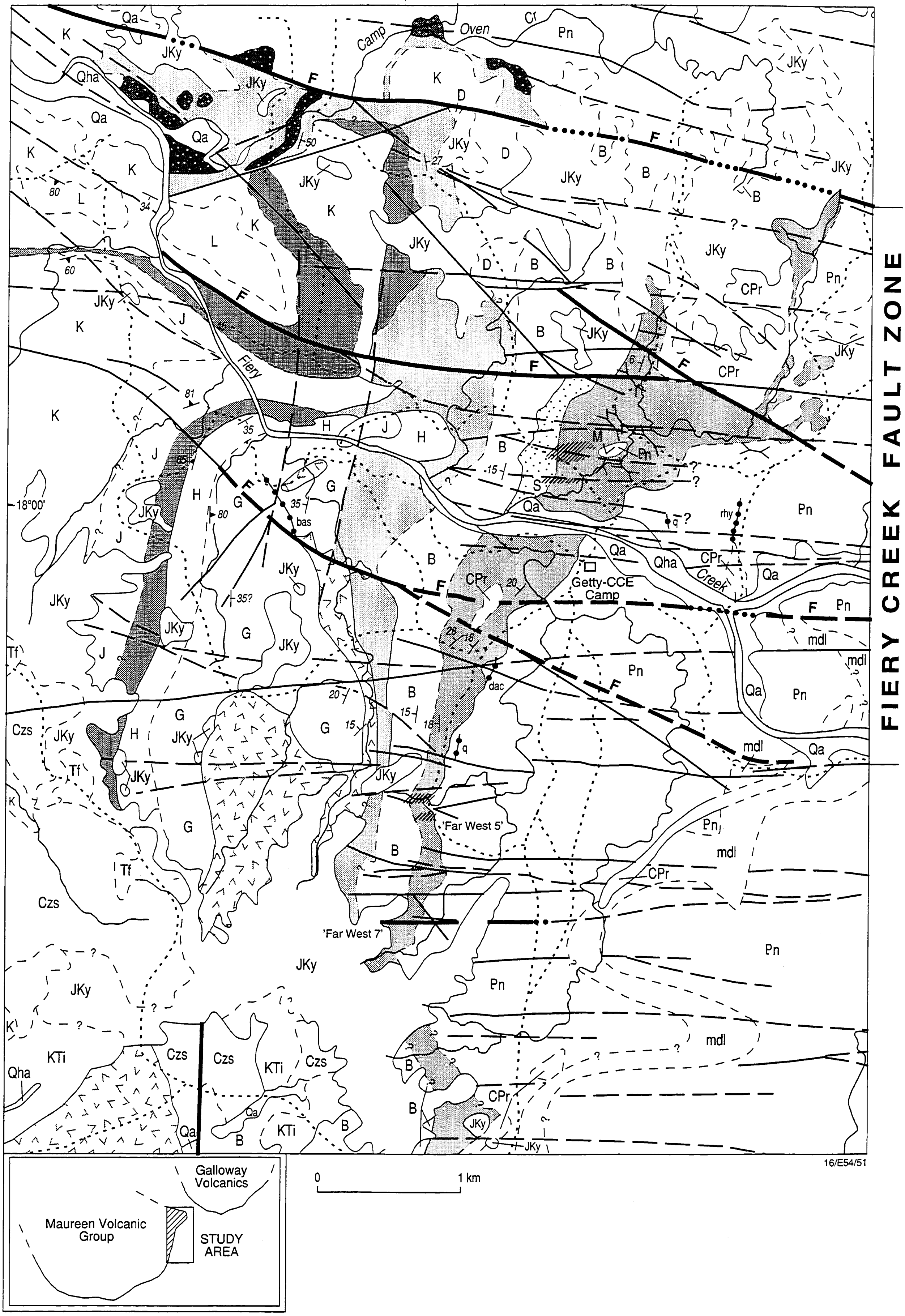

Fig. 5. Detailed geology of the Fiery Creek Fault Zone, northeastern Maureen Cauldron; based mainly on field research in 1977 and 1978 by D.E. Mackenzie. In legend, notations in brackets after descriptions of Maureen Volcanic Group rocks are unit codes of Bain & others (1985). Modified in part from Mackenzie & others (1979).

CAINOZOIC	Holocene			Qha	*Active alluvium, mainly sand*
	Quaternary			Qa	*Inactive alluvium,soil*
	Tertiary to Quaternary			TQs	*Sand, soil, alluvium*
	Tertiary			Tf	*Nodular ferricrete, laterite, deep weathered horizons*
MESOZOIC	Late Cretaceous to Tertiary		Bulimba Fm	KT	*Immature kaolinitic, siliceous, or ferruginous quartz sandstone and conglomerate*
	Late Jurassic to Early Cretaceous		Gilbert River Fm (Yappar Mbr)	JKy	*Mature to supermature kaolinitic quartz sandstone and conglomerate*
UPPER PALAEOZOIC	Carboniferous (to Permian ?)			CPr	*Unassigned rhyolites, mainly intrusive*
		Maureen Volcanic Group	Puranga Rhyolite	L	*Dacitic ignimbrite; some agglomerate. Hornblende phenocrysts* (=Cq)
				K	*Rhyolitic ignimbrite and agglomerate; some rhyolite and rhyolite breccia* (=Cq)
				J	*Massive, very coarse-grained polymict rhyolitic agglomerate; intrusive in part* (=Cq_1)
			Ironhurst Formation		*Fine-grained aphanitic basalt or andesite* (=Cr_4)
				H	*Strongly flow-banded / laminated porphyritic rhyolite* — Wombleallla Rhyolite Member (=Cr_w)
				G	*Rhyolitic tuff, ash, agglomerate, minor ignimbrite; minor tuffaceous sandstone* — Wombleallla Rhyolite Member (=Cr_w)
					Fine-grained aphanitic basalt / andesite Ant Hill Andesite Member (=Cr_a)
					Quartz, micaceous, quartz-lithic, and quartzo-feldspathic sandstones; siltstone; rhyolite: inset flow-banded rhyolite, rhyolitic agglomerate (=Cr_3)
				D	*Brecciated glassy rhyolite, rhyolite agglomerate, rhyolitic agglomerate or ignimbrite* (=Cr_3)
				B	*Flow-banded rhyolite, variably brecciated glassy rhyolite, rhyolitic tuff* (=Cr_1)
	(Devonian ? to) Carboniferous		Gilberton Formation		*Med-coarse-grained micaceous quartz sandstone,quartzo-feldspathic sandstone, conglomerate, siltstone, shale; minor rhyolite, rhyolitic tuff: inset - fine micaceous sandstone*
PROTEROZOIC			Cobbold Metadolerite	mdl	*Metadolerite, amphibolite, metagabbro*
			Lane Creek Fm *(schist phase)*	Pn	*Schist,gneiss, quartzite, migmatite*

M *Main 'Maureen', uranium-fluorite deposit*

S *South uranium-fluorite 'lode'*

'FAR WEST 5'
'FAR WEST 7' } *Other significant uranium-fluorite occurrences*

Areas of uranium mineralisation (approximate)

Geological boundary,position accurate

Geological boundary, position approximate

Geological boundary, position doubtful

F *Fault, position accurate*

F *Fault, position approximate, or doubtful*

Fault, concealed

Lineament, clearly defined

Lineament, less clearly defined

Lineament, obscure or doubtful

Dyke: q - quartz, bas - basalt (=CPa), *dac - dacite* (=CPr), *rhy - rhyolite* (=CPr)

20 *Dip and strike of bedding*

80 *Dip and strike of igneous layering / banding*

Costean

Road, track

Stream

16/E54/52

Structure of the Maureen and Cumberland Range Volcanic Groups

Maureen Cauldron

The main occurrence of the Maureen Volcanic Group defines a near-circular half-basin of slightly more than 20 km diameter (Fig. 4). The structure is truncated in the north by the west-northwest-trending Fiery Creek Fault Zone (Fig. 5). Marginal dips are mostly about 15 to 20°, decreasing to near-horizontal at the north-central limit of exposure.

Scattered inliers within, and subsurface data from beneath, extensive Mesozoic–Cainozoic cover north and northwest of the main outcrop area of Maureen Volcanic Group (Smart & Bain, 1977) suggest that the basinal Maureen Cauldron is elongated northwest, subparallel to the Etheridge River, for about 25 km more than is apparent from its exposed (southeastern) part.

Fracture/intrusion systems: the Fiery Creek Fault Zone probably forms the northeastern limit of the Maureen Cauldron, and apparently separates this cauldron from a subsidiary structure to the northeast containing the Galloway Volcanics. Elsewhere, because a peripheral fracture/intrusion system is absent, the limits of the cauldron can only be defined by the present limits of the inward-dipping extrusive-sedimentary sequence.

Faults and intrusive bodies are rare within the Maureen Cauldron. The main internal faults present are steep, north to north-northeast-trending, and occur in the southeastern part of the structure.

Fiery Creek Fault Zone

In addition to an expanded Gilberton Formation, the area of the Fiery Creek Fault Zone has the greatest thickness (estimated at about 1500 m) and variety of preserved Maureen Volcanic Group rocks. The only rhyolitic lava known in the group (in lowermost Ironhurst Formation), and a possible proximal lag-fall rudite facies of Puranga Rhyolite occcur in the vicinity of the fault zone; both have probable intrusive equivalents within the fault zone itself.

The Fiery Creek Fault Zone may represent a transfer structure equivalent to the Brodies Gap Fault Zone of the northern Newcastle Range, with which it is in line, and shares the same cumulative sense of movement (south-side-down). Both Fault Zones contain uranium mineralisation. No major connecting faults have been mapped in the intervening 25 km of basement rocks. However, it may not be fortuitous that the Yataga Granodiorite occupies the area where any connecting structure(s) would intersect the Delaney Fault.

Structure of the Galloway Volcanics

Details of the structure within which the Galloway Volcanics, as currently defined, occur have not been investigated in this study. According to Branch (1966), the formation occupies a basinal "cauldron subsidence area" which also contains rocks now assigned to the Maureen Volcanic Group in its southwestern extremity. Smart & Bain (1977) showed that the Maureen and Galloway sequences are almost completely separate in the subsurface to the northwest of their outcrop area, and it seems likely that they and the structures within which they occur evolved wholly or in part as separate entities. This is particularly so because of the interpretation that the Fiery Creek Fault Zone was active at the northeastern edge of the Maureen structure at the time of accumulation of the Gilberton Formation and Maureen Volcanic Group. At the present level of exposure, the Galloway structure is partly circumscribed by a steep arcuate fracture/intrusion system. It has also been intruded by stocks of Elizabeth Creek-type granite to the east of the Georgetown Region map area. The few available data suggest either that the extrusive sequence has been resurgently domed by these bodies, or that it had a pre-intrusion structure more complex than that of a simple basin (or both).

Cumberland Range structural elements

The preserved Cumberland Range Volcanic Group sequence has the form of an elongate arcuate basin, with inward dips mostly less than 20°. The axial trace of the Cumberland Range Basin is mainly within the Namul Dacite.

Fracture/intrusion systems: As with the Maureen structure, there is no evidence of a coherent circumferential fracture/intrusion system associated with the Cumberland Range Basin.

Exposed extensions of a possible trapdoor caldera margin beneath Namul Dacite (see above) may be represented by north and northwest-trending high-angle faults, and a local elongate dyke of unassigned rhyolite, near the northeastern edge of the Cumberland Range Basin. However, movement on the fault was west sideup, the reverse of that expected on a caldera-margin fault. Any southwestern extension of the possible margin would extend beneath Cainozoic cover of the Gilbert River and Scrubby Creek drainages, towards the southeastern end of the outer dyke of Prestwood Microgranite.

The Cumberland Range Basin could be a product of asymmetrical structural resurgence over and around the Mount Sircom Microgranodiorite. However, there is no consistent reversal of dip in the extrusive sequence adjacent to the intrusive body.

Fractures associated with the Cumberland Range Basin are mostly steep, linear to slightly arcuate, and intrusion-free faults. They make up a radial system focussed on the northwestern margin of the Mount Sircom Microgranodiorite. The main strike directions represented are: north-northeast, north-northwest, northwest, and east-west; only one northeast-trending fault is known. All fault sets cut the Cumberland Range Volcanic Group, and apparently also the Mount Sircom Microgranodiorite. Movement histories were evidently locally complex, even though nett displacement on many of the faults was negligible.

Northwest-trending faults in the southern part of the Cumberland Range apparently underwent nearly 1 km of dextral movement after accumulation of the Namul Dacite, and possibly also after emplacement of Mount Sircom Microgranodiorite. An almost north-northeast-trending fault has apparently localised a similar amount of post-Namul Dacite sinistral movement. These two fault sets may represent a reactivated older conjuate shear system reflecting a horizontal, north-northwest-trending, maximum principal stress.

The fault between the main lobe and eastern arm of the Cumberland Range appears to have been responsible for dextral movement, plus upward pivoting of the northeastern block about a hinge at the southern end of the fault (the dextral component of nett slip on the fault was shared with subparallel ones to the south). Gilberton Formation and Scrubby Creek Rhyolite were involved in this movement. However, the same fault seems to show sinistral displacement (with south-side-up pivoting about the southeastern hinge) of Namul Dacite. The contact between Scrubby Creek Rhyolite and Mount Sircom Microgranodiorite appears to have been moved dextrally by the fault. However, the contact may be misaligned mainly owing to a previously (pre-intrusion)-displaced stratigraphic contact controlled by the upper termination of the Mount Sircom Microgranodiorite.

The main pair of Mount Sircom Microgranodiorite stocks have upper terminations ("roofs"), which are broadly concordant with respect to the Cumberland Range Volcanic Group sequence. The roof of the eastern body is localised at the contact between the lower two welded ignimbrite sheets of the Scrubby Creek Rhyolite, while that of the western one lies at the base of the Namul Dacite. Both stocks are probably part of a single body, which may be ultimately sheet-like or tabular.

Cumberland Range ring-dyke structure (Fig. 4): The Cumberland Range Basin is rather tenuously associated with incomplete, crudely polygonal outer and inner parts of a concentric fracture/intrusion system delineated mainly by Prestwood Microgranite. Microgranite of the outer part of the system crops out to the west of the currently preserved basin; northwestern occurrences of microgranite belong to the inner part. The postulated trapdoor caldera margin covered by Namul Dacite may be an additional outer part of the concentric system, possibly indicating that Prestwood Microgranite was emplaced between accumulation of Scrubby Creek Rhyolite and Namul Dacite. By extension, Prestwood Microgranite would thus be older than the main Mount Sircom Microgranodiorite. The last inference is supported by isotopic data.

Western Prestwood Microgranite in the outer part of the concentric fracture/intrusion system consists of a conspicuous west-northwest to north-trending main dyke, with aligned elongate plugs to the north. These bodies line up with a short dyke of unassigned rhyolite on the northern side of the Gilbert River. This rhyolite may either be part of the same system as the Prestwood Microgranite, or of an older one believed to be represented by rhyolite dykes at Mount Turner (see below).

The western Prestwood Microgranite bodies, and the dyke of unassigned rhyolite, are connected and partly cut tangentially by high-angle faults which are mostly subparallel to the Somerset Fault. These younger faults effectively represent reactivations of original fractures in the outer concentric system. Edges of major Prestwood Microgranite bodies and/or reactivated fractures marginal to them have apparently undergone minor east-side-down movement, indicated by displacements of basement boundaries.

The Prestwood Microgranite component in the inner part of the concentric fracture/intrusion system to the northwest of the Cumberland Range consists of one main and several subsidiary bodies. The subsidiary bodies are all plugs or steep dykes. That part of the main body on the northeastern side of the Gilbert River is steep-sided, with northerly and southerly-directed, dyke-like, apophyses at its eastern end. The form of the main body to the southwest of the Gilbert River is unclear; it could be partly or entirely sheet-like. In that case, the whole of the main northwestern body of Prestwood Microgranite could represent an incomplete bell-jar pluton.

The main northwestern body of Prestwood Microgranite is cut, without appreciable displacement, by the north-northeast-trending Somerset Fault (or a reactivated southern extension of it) to the northeast of the Gilbert River.

There does not appear to be any radial fracture/intrusion system developed in association with the concentric one occupied by Prestwood Microgranite, at least at the present level of exposure.

Other structural elements in the Cumberland Range—Maureen Belt

The outcrop area of combined Dismal Creek Dacite plus Gilberton Formation, between the Cumberland Range and Maureen sequences, is remarkably similar in plan shape to that of the Cumberland Range Volcanic Group. The preserved form of the combined units defines the structural Dismal Creek Basin.

Dismal Creek Dacite and subjacent Gilberton Formation are gently to moderately steeply (5 to 55°) inward-dipping in the western half of this Dismal Creek structure. However, they have been extensively disturbed and intruded in the eastern half of the structure (where Gilberton Formation occurs alone). The zone of maximum disturbance crosses Gilberton Formation immediately east of the main area of Dismal Creek Dacite. This zone is bounded by north-northwest and north-northeast-trending, probably post-Gilberton Formation but pre or early syn-Dismal Creek Dacite, intrusion-free high-angle faults. The disturbed zone contains a concentration of pipes, plugs, and dykes of unassigned rhyolite and intrusive rudite.

An outlier of Dismal Creek Dacite in the northeastern part of the Dismal Creek Basin has a local development of probable lag-fall rudite (not distinguished separately on the Georgetown Region map). This suggests that the area coincides with one or more eruptive centre(s).

The main fractures associated with the Dismal Creek sequence are steep, intrusion-free faults which trend mainly north-northwest and north-northeast. These trends are suggestive of a conjugate shear system reflecting a north-directed horizontal maximum principal stress. The faults, and ones in and adjacent to the zone of maximum disturbance across the Dismal Creek Basin, may be related to the nearby north-northeast-trending Somerset Fault. There has been no major displacement of basement rocks on the Somerset Fault, at least at the present level of exposure.

Mount Darcy Microgranodiorite occurs mainly between the southern edge of the Dismal Creek Basin and the northern edge of the main (inner) body of Prestwood Microgranite (above). Intrusive bodies of Mount Darcy Microgranodiorite are irregularly distributed; they are apparently all steep-sided plugs and stocks of very variable plan shape. Four bodies in a northeast-trending group to the southeast of the basin are each elongated from northwest to southeast; these are the only ones which show any degree of preferred alignment or orientation.

Rocks assigned to Mount Darcy Microgranodiorite postdate a swarm of overall north-trending (i.e. subparallel to the Somerset Fault) dykes of unassigned rhyolite. The swarm is centred on a group of plugs of similar lithology, with intrusive and collapse rudites, at and near Mount Turner, 20 km east-southeast of the Dismal Creek area (Baker, 1978; Baker & Horton, 1982), which define the Mount Turner Intrusive Centre. The dyke swarm lies about 10 km north-northeast of, and is roughly aligned with, the (northeastern) end of the eastern arm of the Cumberland Range Basin. This alignment suggests some developmental relationship between the swarm, the Mount Turner centre, and the postulated trapdoor caldera margin underlying Namul Dacite (see above). However, isotopic dating suggests that the late Palaeozoic rocks in the Mount Turner centre are younger than any part of the preserved Cumberland Range volcanic sequence. Dismal Creek Dacite, and the Dismal Creek structural basin, seem likely to be more closely related to it, implying equivalent (Permian) ages.

Roughly north-trending, high-angle, faults (and/or the intrusive bodies occupying them) are dominant in the Dismal Creek and Mount Turner areas. They are inferred to be part of a (mainly intrusion-free) system whose main representative is the Somerset Fault (below). Equivalent fractures/intrusions are markedly rare in the Cumberland Range area.

The Somerset Fault system is essentially orthogonal to west-trending elements of the Electric Light Fault system (below) farther east. It is parallel or subparallel to the sporadically intrusion-filled fractures collectively making up the Delaney Fault (below), also to the east. The Somerset system is also effectively parallel to a north-trending system of rhyolite dykes (which locally contains northeast-trending dykes) south of the Newcastle Range.

Discussion

Evidence outlined in the preceding sections suggests that the Dismal Creek Dacite and Cumberland Range Volcanic Group, with associated intrusive rocks and Gilberton Formation, comprise a complex, first-order volcano-tectonic structure analogous to the composite Newcastle Range cauldron (see above). It is less clearly defined than the Newcastle Range structure, partly because of the deeper level of erosion, but probably also because it was originally a more subtle feature.

Transitory early igneous activity, marked by extrusion of the Spyglass Andesite Member of the uppermost Gilberton Formation, was probably essentially contemporaneous with, or was closely followed by, tensional and/or shear movement on high-angle fractures of the Somerset Fault System. This early activity was apparently confined to the Dismal Creek area.

Subsequently, extrusion of silicic Scrubby Creek Rhyolite took place in the Cumberland Range area. Extrusion of the unit is postulated to have been accompanied by some degree of trapdoor cauldron (caldera?) collapse along the southernmost segment of the circumferential fracture-intrusion system; it was possibly followed by emplacement of Prestwood Microgranite into the same segment and its extensions to the west. Prestwood Microgranite was also intruded between the Dismal Creek and Cumberland Range areas, possibly as an incomplete bell-jar pluton. An episode of broad structural resurgence may have accompanied emplacement of the Prestwood Microgranite, resulting in extensive removal of Scrubby Creek Rhyolite.

Succeeding accumulation of intermediate Namul Dacite was accompanied by renewed subsidence. The next(?) major phase of igneous activity shifted back to the Dismal Creek area, and resulted in accumulation of the decreasingly silicic-upwards Dismal Creek Dacite, accompanied and/or followed by emplacement of unassigned rhyolites with accompanying polygenetic volcaniclastic rudites there, and at a secondary northern centre of activity (with mineralisation) in the Mount Turner area.

This activity was apparently followed by intrusion of Mount Darcy Microgranodiorite, and its mineralisation. Emplacement of these intrusive phases may have been controlled in part by an incipient outermost concentric fracture/intrusion system circumferential to the Dismal Creek and Cumberland Range areas combined (assuming that unassigned rhyolites were intruded at this time along the course of all or part of, and/or in alignment with, the older main Prestwood Microgranite dyke south of "Riverview"). Intrusion of the main concentration of Mount Darcy Microgranodiorite bodies may have been accompanied by further broad structural resurgence, with erosion in the apical area of the uplift which resulted in removal of Cumberland Range Volcanic Group and Dismal Creek Dacite from all but their main source/subsidence areas. The possible uplift would have needed to be positioned such that it efficiently destroyed any overlap between the two extrusive sequences. Much Gilberton Formation must also have been removed during this (and earlier) episodes of structural resurgence. The remaining remnants are all in areas peripheral to the main occurrences of Mount Darcy Microgranodiorite.

Semi-regional controls of structures in the Cumberland Range—Maureen Belt: The preserved Cumberland Range Volcanic Group and exposed intrusive associates (except those tentatively assigned to Mount Sircom Microgranodiorite to the south and southwest of the Cumberland Range Basin) straddle the slate/schist metamorphic lithofacies boundary. This boundary crosses exposed Etheridge Group stratigraphic units at the present level of exposure. The metamorphic lithofacies boundary has an overall more northwesterly trend than the schist/gneiss transition farther east; it is is presumed to dip broadly eastwards.

Other late Palaeozoic features in the Cumberland Range–Maureen belt are spatially independent (east) of the metamorphic transition. This suggests that the transition in itself may not have been an important controller of magma emplacement, at least at the structural levels now exposed. However, no other potential control is evident from available data.

Structures between the Cumberland Range–Maureen Belt and Newcastle Range

Delaney Fault

The overall steep and north-trending Delaney Fault (Fig. 4) is one of the emost conspicuous fracture systems in the Georgetown Region in terms of its image on aereal photographs, although it is commonly difficult to locate on the ground. The fault is of obscure origin, and may be of considerable original age. However, most constituent fractures have not detectably displaced any units, irrespective of age. An exceptions is a post-Robin Hood Granodiorite (mid-Palaeozoic) but probable pre-Agate Creek volcanics sinistral component of movement evident in displacement of the granodiorite margin near the southern end of the Delaney Fault. This may equate with apparent syn-Gilberton Formation movement of the same sense to form a small pull-apart basin between two *en echelon* fractures (cf. Mann & others, 1983), approximately 5 km northwest of Forsyth. These observations suggest strike-slip movement during latest Devonian and/or earliest Carboniferous time under the influence of a roughly northwest-trending and horizontal maximum principal stress. The only other suggestion of such a stress regime is the southwest-trending basinal form of the main outcrop area of the Gilberton Formation to the north of "Gilberton" (see above), assuming that such form is partly or wholly of compressive structural origin.

During the main part of late Palaeozoic time, the Delaney fault evidently responded in a very limited way to the east–west horizontal minimum principal stresses active in the nearby Cumberland Range–Maureen Belt and Newcastle Range (above). Despite its favourable meridional trend, it was only dilated in short sections south of Forsyth to the extend that moderately-sized dykes and plugs of rhyolite and andesite (CPr, CPa respectively) were emplaced along it. The Delaney Fault also evidently exerted some subtle control over earliest Permian emplacement of the Yataga Stock (below). Possibly this peculiar late Palaeozoic behaviour was due to the situation of the fault approximately midway between two cauldron belts—extension in both belts may have interacted in the intervening area to reduce tension, or even to product compression.

Yataga Stock

The Yataga Stock as a whole is near-equidimensional and crudely polygonal, with only a very poorly developed elongation manifested in the local hook-like apophyse extending from its southern edge. However, Yataga Granodiorite subunits developed within the core area of the stock tend to be irregularly north to north-northeast-trending, while superimposed steep linear dykes of unassigned—but possibly cogenetic (Richard Holmes, pers. comm.) microtonalite (included in CPr)—also have essentially meridional trends.

These observations suggest that magma precursor to rocks within the area of the Yataga Stock was emplaced, at least at the structural level now exposed, under the influence of a weak and/or transitory tensional stress field perpendicular to the trend of the Delaney Fault System. Such tension might have been a general characteristic of the stress field affecting the Georgetown Region as a whole during earliest Permian (and latest Carboniferous?) time, or it might have been a consequence of the effects of anisotropies defined mainly by meridional components of the Delaney Fault System on local intrusion-generated dilatant stresses associated with the ascending Yataga Granodiorite.

Country rocks surrounding the Yataga Stock (mainly Proterozoic Lane Creek Formation with abundant Cobbold Metadolerite) have apparently not been deformed by it, suggesting a passive mode of emplacement.

The probable earliest Permian Yataga Stock straddles the northern exposed part of the Delaney Fault. No displacements of the periphery of the Stock are evident, and it apparently represents a "stitching" pluton with respect to the northern Delaney Fault, implying no significant post-stock (earliest Permian) faulting at least locally. The Stock lies in the area where a structure (unknown at the present level of exposure) joining the Brodies Gap and Fiery Creek Fault Zones would intersect the Delaney Fault.

The Yataga Stock, which has no significant gravity expression, is centred variously 17 km east-southeast of proximal Maureen Volcanic Group rocks in the Maureen Prospect area, about 45 km east-southeast of the Maureen gravity minimum, about 20 km south of the Galloway minimum, the same distance east-northeast of the core of the Namarrong Cauldron, and 40 km west of the "Cabana" gravity minimum.

A direct genetic relationship between these known/inferred Carboniferous features and the Stock seems unlikely in view of the apparent temporal distinctiveness of the latter. Thus, the "repeat" distances presumably have no significance in terms of depths to sites of coeval magma generation or "diapir" separation. However, there may be an indirect relationship in that the intermediate location of the Yataga Stock between apparently older features could be due to restriction in the area physically available for the Stock to be emplaced into imposed by one or more (all?) of these features.

The Bagstowe and Lochaber centred igneous features

Bagstowe structure

Introduction: Branch (1966) considered that the Bagstowe structure was made up of three main concentric systems of steep dykes associated with six stress foci ("centres") marked by roughly equidimensional intrusions, plus three concentric systems of gently to steeply dipping intrusive sheets and one steep radial system.

The structural pattern as currently perceived is broadly comparable to Branch's, although there are a few differences of variable significance. In particular, Branch's "Grey Ring-Dykes" and their associated "Centre 2" are not now recognised; instead, the rocks involved are considered to be basically extrusive, and assigned to the Paddock Creek Formation. The "Pink Ring-Dykes" (now Old Man Rhyolite) and misleadingly styled "East–West Ring-Dyke" (now Conical Knob Microgranite) of "Centre 5", with (tentatively) the "Trachyandesite Ring-Dyke" (now unassigned trachyandesite to quartz-andesite) of "Centre 3", are combined into a single dyke system (Conical Knob–Old Man) centred in the vicinity of the original "Centre 5" (with "Centre 3" being consequently not recognised). The edge of the "Four Mile Creek Stock" (name retained), which contains only Cranky Creek Granodiorite in the current scheme, is tentatively judged to belong partly to the same "Centre 5" system; the old "Centre 4" is thus also not now recognised. The "Northeast Stock" and "Central Ring-Dyke" (of Bagstowe Granite) are combined with the intervening body of Black Cap Diorite (not previously differentiated) into a composite Black Cap–Bagstowe Stock, disposed about Branch's original "Centre 6". No radial fracture/intrusion systems are now recognised as components of the Bagstowe structure proper; "radial dykes" previously identified are now seen as an extension of a northwest-trending linear system made up of unassigned acid intrusive rocks (CPa), discussed separately.

The main intrusive units contributing to the Bagstowe structure at the present level of exposure, with the sole exception of Cook Microgranite, are inferred to mostly define various southwestern segments of three irregularly ovate, but basically concentric, fracture systems. These systems overlap each other from southwest to northeast along a zone of roughly bilateral symmetry coinciding with the major axis of the Bagstowe structure as a whole. However, the absence of detectable northeastern components of the concentric systems is not entirely due to this overlapping, but also reflects a real tendency for each system to become irregular and die out in that direction. The southwesternmost and presumably oldest of the systems, occupied by the Mount Rous Ring-Dyke, is succeeded to the northeast by one containing the younger Conical Knob–Old Man Ringdyke. This second system probably also controlled emplacement of the adjacent elongate stock of unassigned trachyandesite to quartz-andesite. A third fracture system, presumed to be the youngest because of the ages of rocks postulated to be defining it, is interpreted to have influenced the form of, and rock distributions adjacent to, the western to southwestern edge of the Black Cap–Bagstowe Stock. Only the Four Mile Creek Stock (Cranky Creek Granodiorite), which is apparently intermediate in age between the Mount Rous and Conical Knob–Old Man Dykes, stands out as a fairly major, and thus possibly independent, departure from the overall temporal, spatial, and geometrical regularity of the other main components of the Bagstowe structure; it is discussed further below.

Structure of the Paddock Creek Formation: the outcrop area of Paddock Creek Formation containing the type section of the unit at the northern edge of the Bagstowe Structure has the form of a slightly arcuate, south-southwest to southwest-trending, open basin. The contact between the Formation and basement rocks at the present edge of this basin lies at a somewhat variable elevation around 700 m.

Outliers of upper Paddock Creek Formation to the east and south-southwest have essentially horizontal basal contacts which also lie a few tens of metres above and below 700 m.

Rocks assigned to the same (upper) part of the Formation within the main Bagstowe structure probably form part of an essentially horizontal single ignimbrite sheet. Apparently unsystematic local dip variations, both towards and away from the central area of the Bagstowe structure, probably reflect oversteepening adjacent to ignimbrite feeder dykes and high-angle fracture (fault)/intrusion zones, and/or original draping over palaeotopographic basement irregularities. The base of the sheet is known to lie at an elevation of 680 to 720 m in the Oakey Creek–TeaTree Creek area, to the southeast and east-southeast of "Glenmore". Farther west and north, the basal contact is mostly covered by the valley-bottom alluvium of Castle Hill, Old Man, and Cattle Camp Creeks, although it most probably lies between 660 m and 720 m. The base of the sheet lies below 640 m in the area of the junction of Castle Hill Creek and the Gilbert River, about 3.5 km west-southwest of "Glenmore", suggesting that the sheet as a whole has an overall westward dip in the order of only 1°.

Hornfelsed upper Paddock Creek Formation(?) associated with Black Cap Diorite and Bagstowe Granite about 4 km east-northeast of "Glenmore" has contacts with the intrusive rocks ranging in elevation from about 750 m (southwest) to 800 m (northeast).

The above observations on the elevation of the base of the Paddock Creek Formation in its various areas of preservation, coupled with those relating to the distribution of constituent subdivisions, suggest an increasing degree of late syn- or post-extrusive subsidence towards the core area of the Bagstowe structure, plus outward tilting or doming at the edge of the core itself (which is considered further below).

The suggestion of subsidence contrasts with the slight doming postulated for the same area at the time that at least the lower and middle subunits of the Formation accumulated (see above). The maximum amount of subsidence, between the base of rocks assigned to the lower Paddock Creek Formation at Wire Yard Mountain and the upper part of the unit in the area of the junction of Castle Hill Creek and the Gilbert River, about 10 km to the north-northwest, is in the order of 150 m (about half that of the postulated antecedent uplift).

Sporadic north-trending steep dykes of unassigned acid and intermediate to basic rocks, as well as two subparallel northern apophyses of the main Conical Knob–Old Man Ring-Dyke, which are semi-independent of the main Bagstowe structure (see below) occur in and adjacent to the type section of Paddock Creek Formation. Although the intrusive rocks are younger than the Paddock Creek Formation as preserved, they may be a manifestation of fractures which controlled extrusion of the sequence. The same might be true of the northwest to north-northwest-trending Castle Hill Dyke (Cook Microgranite) farther south (see below).

The roughly north-trending belt from which the Paddock Creek Formation is postulated to have originated (see above) is aligned with the southern Ballynure Fault. The belt could represent an extension of the fault which was propagated, or reactivated, southwards as a zone of steep brittle tensional fractures by a meridional horizontal maximum principal stress during late Palaeozoic time.

Culba Stocks: bodies of Culba Granodiorite, although occurring within the area of the Bagstowe structure, show only a vague tendency to participate in its geometry. Trends of the rather irregular boundaries of these bodies have probably been controlled partly by local folds and faults in the Einasleigh Metamorphics, with some degree of constraint imposed by the distribution of pre-existing Proterozoic to early Palaeozoic granitoids.

Castle Hill Dyke: the early Castle Hill Dyke of Cook Microgranite is conspicuously discordant in strike with respect to other components of the Bagstowe Structure in its vicinity, and thus presumably of independent or semi-independent origin.

Mount Rous Dyke: extrapolation from present occurrences indicates that the Mount Rous Microgranodiorite defines the southwestern half of a potentially subpolygonal to ovate fracture system with major (southwest to northeast) and minor axes of about 15 km and 10 km, respectively, and a southwesterly-directed apex. The axes intersect approximately 8 km southwest of "Glenmore".

Specific local influence on the geometry of the Mount Rous Ring-Dyke has evidently been exerted by the steep contact between Culba Granodiorite and Dumbano Granite, plus rocks tentatively assigned to Anning Granite in the Gilbert River to Pine Yard Mountain area. This contact is unlikely to be a product primarily of dyke-associated faulting, because no Culba Granodiorite occurs immediately east of it. For the unit to have been displaced and lost either above or below the present level of exposure would require not only quite major movement, for which there is no other indication, but also other special features such as at least partial sheet-like form. The implication is that the contact had essentially its present position and trend before the Mount Rous dyke was emplaced.

Conical Knob-Old Man Dyke: the composite partial ring-dyke containing Conical Knob Microgranite, Old Man Rhyolite, and probably unassigned trachyandesite to quartz-andesite, occupies the southwestern two-thirds of a slightly irregular, but not detectably polygonal, ovate system with a similarly directed apex, and with major (southwest to northeast) and minor axes of about 16 km and 14 km respectively; the area of intersection of these axes is 5 km northeast of "Glenmore".

Four Mile Creek Stock: much of the slightly to moderately irregular northeastern to southeastern margin of the Four Mile Creek Stock, which is believed to postdate the Mount Rous Ring-Dyke, essentially coincides with a sector of the apparently younger Conical Knob–Old Man Ring-Dyke. The coincidence seems too close to be entirely fortuitous. The appreciably less regular southwestern margin of the Four Mile Creek Stock is roughly aligned with the periphery of the Black Cap–Bagstowe Stock and steep sections of its flange(?)-like apophyse of Bagstowe Granite. The margin has an apparent sinistral offset of about 1.5 km occupied by a northeast-trending steep dyke of unassigned rhyolite (CPr); the offset may be a primary feature of the Four Mile Creek Stock's margin, rather than a product of subsequent fault displacement. The moderately irregular northwestern contact between the Four Mile Creek and Black Cap–Bagstowe stocks trends northeast and is nearly linear; it is subparallel to, but about 4 km southeast of, the major axis of the overall Bagstowe structure. The form of the Four Mile Creek Stock is judged to have been controlled partly by an early development of the same fracture system into which the Conical Knob–Old Man Ring-Dyke was emplaced, and partly by northeast-trending fractures which might represent a diffuse system controlling the trend of the Bagstowe structure as a whole. In this interpretation, the Four Mile Creek Stock is envisaged as being closely allied spatially, temporally, and geometrically to the Conical Knob–Old Man fracture/intrusion system, rather than to any of the other major components of the Bagstowe structure. It is assumed to be centred, at least potentially, in the same area 5 km northeast of "Glenmore" as is the Conical Knob–Old Man Ring-Dyke (see above). This suggests some direct or indirect relationship between the various rocks whose emplacement was linked to development of the Conical Knob–Old Man fracture system.

Black Cap-Bagstowe Stock: the northwestern to southern edge of the Black Cap–Bagstowe Stock, as well as the adjacent subparallel contact between the two units within the stock, and the external western apophyse of Bagstowe Granite, define a quadrant of an irregular circular to southwest-pointing, slightly ovate potential fracture system about 5 km in diameter and centred 10 km or so northwest of "Glenmore".

The Bagstowe Granite apophyse appears to be in part a flat-bottomed ("floored") flange extending from the edge of the main body, and whose form has been locally controlled by horizontal or shallowly dipping fractures.

The rather irregular southeastern edge of the Black Cap–Bagstowe Stock appears to have been controlled by a mainly southwest-trending fracture system, although it has been displaced locally by a minor, intrusion free, northwest-trending fault.

Minor Intrusive Bodies: moderately to steeply dipping sheets and plugs of miscellaneous acid intrusive rocks (CPr-mainly rhyolites in this instance) associated with the Bagstowe structure within which Branch (1966) discriminated "Outer", "Middle", and "Inner Cone Sheet" swarms, define a roughly concentric fracture pattern. Within the system as a whole, components broadly attributable to Branch's "Outer", "Middle", and "Inner" parts can be identified, although not entirely as separate entities because they tend to merge. Also, they are by no means all cone-sheet-like in attitude.

The intrusive bodies are concentrated, and locally coalesced, between the Mount Rous and Conical Knob–Old Man dyke systems, and to the south, west-southwest, and northwest of the Mount Rous dyke. They locally coincide with the northern edge of the main Culba Granodiorite Stock. Collectively, the bodies make up an irregular and rather diffuse, east-northeast-elongated, roughly rectangular, system with a minor (north-northwest to south-southeast) axis of about 25 km and which is incompletely closed to the west but open to the east at the present level of exposure. The system represents a second (i.e. additional to the Four Mile Creek Stock) departure from the overall regularity of the Bagstowe structure; its major axis intersects that of the Bagstowe structure in the "Glenmore" area.

Emplacement of intrusive bodies has apparently been controlled by a combination of arcuate west-southwest to east-southeast-trending, characteristically moderately to steeply (40° to 60°) inward (with respect to the major axis of the system)- dipping fractures, and steep, more typically linear fractures trending north to northwest and (rarely) northeast.

Inward-dipping bodies are concentrated mainly in two swarms (essentially Branch's "Outer Cone Sheet" system) between the outer southern edge of the Conical Knob–Old Man dyke, 5 km south-southeast of "Glenmore" and the area of Hanns Table Mount (7659–966647), and the northern edge of the Culba Granodiorite. In the west, they appear to be postdated by at least some of the more nearly linear and north-trending steep bodies. They are also postdated by steep northwest-trending dykes of miscellaneous intermediate to basic rocks (CPa) adjacent to the inner southern edge of the Mount Rous dyke.

The Mount Rous dyke appears to have acted as a buttress to resist propogation of southern components of the outer fracture/intrusion swarm at the present level of exposure.

Branch's "Middle" and "Inner Cone Sheet" swarms are appreciably less well-developed than the "Outer" one; northern components of both tend to be steep, linear, and north-trending (cf. the northern part of the Conical Knob–Old Man dyke, above).

Although the rocks were probably emplaced recurrently over a relatively long period of time, many are apparently intermediate in age between components of the Conical Knob–Old Man Ring-Dyke and those of the Black Cap–Bagstowe Stock; the time represented is assumed to mark the principal interval during which the fractures occupied by the rocks were generated.

Discussion: at first analysis, inferred syn or post-Paddock Creek Formation subsidence towards the core area of the Bagstowe structure (see above) could be assumed to have been produced mainly by inside-down faulting on the fracture systems which contain the Mount Rous and Conical Knob–Old Man ring-dykes. However, contacts between basement units and rocks assigned to the middle Paddock Creek Formation within about 2 km of each other on either side of the southern Mount Rous dyke lie at essentially the same elevation (about 700 m), indicating no appreciable displacement on at least that (well-defined) part of the fracture/intrusion system itself. Similarly, displacement across the Conical Knob–Old Man Ring-Dyke is inferred to have been, at most, negligable. Thus, the possible 150 m of subsidence between Wire Yard Mountain and the area of the junction of Castle Hill Creek and the Gilbert River (see above) seems likely to have been distributed by warping and/or diffuse minor faulting across the full distance (of nearly 12 km) involved.

Assuming that all contacts between rocks assigned to the upper Paddock Creek Formation and adjacent units, including younger Black Cap Diorite, represent an essentially single stratigraphic level, and comparing their variations in elevation (see above), the conclusion can be reached that the extrusive sequence is slightly and irregularly, but persistantly, tilted southwestwards away from the core area of the Bagstowe structure. Such tilting could be assumed to reflect resurgent structural doming of the sequence by the Black Cap–Bagstowe Stock, particularly since no Paddock Creek Formation overlies the main body of Bagstowe Granite at the present levels of exposure of up to slightly more than 900 m elevation. However, in the area of the southern Black Cap–Bagstowe Stock and the head of Tea-Tree Gully, 4 km to the north-northeast, the base of Jurassic Hampstead Sandstone lies close to 780 m. Southwestwards, this basal plane descends irregularly, but without crossing any known post-Jurassic faults, to around 650 m in the upper reaches of Mica Schist Creek and its tributaries. These observations are taken to indicate that tilting of the upper Paddock Creek Formation(?) sequence could have been at least partly caused by regional or subregional Mesozoic and/or Cainozoic deformation, and that any earlier effect of structural resurgence can not be demonstrated unambiguously.

These observations and extrapolations demonstrate the similarities in size and form of the main fracture/intrusion systems postulated to make up the Bagstowe structure. However, the northeastwards repeat distance between them, as defined by the areas of intersections of their axes, decreases from 12 km to 5 km in sympathy with decreasing inferred age, while (as noted above) the "depth aspect" of the rocks emplaced into the systems increases, implying that real variations in structural levels currently exposed might be involved.

Other major components of the Bagstowe structure have not been controlled so obviously by the same or similar basement contacts, although sheets of miscellaneous acid intrusive rocks (CPr) are locally concentrated at and adjacent to the northern edge of the main Culba Granodiorite Stock.

Lochaber Structure

Introduction: at the present level of exposure, the Lochaber structure as a whole (see Fig. 3) is comparable to the adjacent Bagstowe structure in being elongated from southwest to northeast, although its axis of bilateral symmetry lies 12 km to the northwest of the latter's.

The Lochaber structure is slightly ovate, with a southwesterly-directed apex; its major and minor axes are about 25 km and 20 km long, respectively. The area of intersection of the two axes lies in the vicinity of the junction of Christmas Hill Creek and the Copperfield River, 15 km southwest of Kidston. This area is also the one in which the probable northeastern continuation of the Noel Fault and any structure(s) projected from the eastern end of the Gilberton Fault, as currently identified, would intersect.

Individual major intrusive components of the Lochaber structure tend not to have the marked spatial and temporal regularity with respect to the form of the structure as a whole, shown by those making up the Bagstowe structure.

Like the Bagstowe structure, the Lochaber structure has no obvious radial components.

Structure of the Butlers Volcanic Group: like the Paddock Creek Formation (see above), the outcrop area of the Butlers Volcanic Group has the form of an elongate shallow basin, with marginal dips of mostly up to 25°. The basin trends southwest, subparallel to elongate plugs of Sues Creek Microgranite which locally define the periphery of the Lochaber centred structure (see below).

This Butlers basin may represent the keel of a fold developed locally just inside the edge of the Lochaber structure, comparable to the discontinuous circumferential folds within the Eveleigh Volcanic Subgroup in the eastern lobe of the Newcastle Range. Such folds may have formed in response to a "space problem" resulting from subsidence of extrusive sequences on inward-dipping fracture or hinge zones.

The outcrop area of Butlers Volcanic Group also represents an igneous centre, as indicated by the bodies of Sues Creek Microgranite and, most notable because of its uniquenes, Noel Micromonzonite, concentrated within and adjacent to it.

Lochaber Stock: the Lochaber Granite, which is probably the oldest intrusive component of the Lochaber structure, makes up a stock occupying much of the southeastern half of the Lochaber Centred Igneous Structure, east of the Noel Fault and its probable extension. The stock is a slightly irregular ovate body with major and minor axes of about 18 km and 10 km, respectively; these axes intersect each other about 15 km south-southwest of Kidston.

The major axis of the Lochaber Stock strikes slightly more north and south than the parallel axis of the coupled Bagstowe–Lochaber structure. However, like most of the morphological components of that structural duo, the apex of the Lochaber Stock points in a southerly direction.

The northern to southern edge of the Lochaber Stock coincides with the local inner edge of the circumferential zone around the Lochaber structure as a whole. The stock may have at least partly inward-dipping walls. The common high-level or near-marginal aspect of the Lochaber Granite, particularly in the northern part of the Stock, suggests that much, if not all, of the original roof lay not far above the present level of exposure.

Sues Creek Dykes: the periphery of the Lochaber Structure is defined mainly, but by no means entirely, by a series of steep and elongate, linear to arcuate, dykes and plugs with rocks assigned to the Sues Creek Microgranite. These intrusive bodies are best developed in the southwestern two-thirds of the structure, and are assumed to have been emplaced into a continuous or semi-continuous fracture system which was generated at an intermediate stage in the evolution of the structure, although apparently after the Butlers Volcanic Group as preserved had accumulated.

The geometry of this fracture/intrusion system has evidently been influenced locally by the north-northeast-trending Ballynure Fault (or its precursor mylonite zone (Figs 3,4), and possibly also to a degree (just beyond the eastern edge of the Georgetown Region map area) by the northeast-trending Far East Mylonite Zone and/or the intersection/intergradation between this zone and the more meridional Werrington Fault.

The main occurrences of Sues Creek Microgranite within the outcrop area of the Butlers Volcanic Group appear to be partly dyke-like and partly sheet-like. The latter portions have evidently been localised at or near the stratigraphic contact between the two ignimbrite sheets making up the McLennons Creek Rhyolite. Overall, the bodies are irregularly elongated in a north-northeasterly direction. This elongation may reflect the local development of an inner concentric fracture system.

Minor intrusive bodies: all but the westernmost part of the fracture/intrusion system around the Lochaber structure occupied by bodies of Sues Creek Microgranite appears to have been used, in a somewhat more diffuse reactivated form, by the miscellaneous acid intrusive rocks (CPr) which postdate the microgranite.

Many of these rocks occupy steep and locally coalesced arcuate dykes and elongate plugs. However, those bodies associated with the edge of the older stock of Lochaber Granite in the northeastern to southeastern segment of the system are shallowly to moderately (20° to 45°) inward (with respect to the core of the Lochaber structure as a whole)-dipping. The correspondence between the distribution of these inward-dipping sheets and the edge of the Lochaber Stock seems too close to be fortuitous. It may be that the attitude of the sheets and their precursor fractures reflect local stress reorientation adjacent to the rigid walls of the stock which has a partly or wholly cone-sheet or bell-jar-like geometry.

In the north-northeast, steep dykes of miscellaneous acid rocks diverge northwestwards to north-northeastwards from the fracture/intrusion system around the Lochaber structure to become part of the diffuse belt of dykes and plugs between it and the southeastern Wirra Cauldron (southern Newcastle Range).

A few dykes and small to large plugs also occur inside the circumferential system; these are localised in part along a probable extension of the Noel Fault, and in part within an un-named fracture zone (lacking detectable displacement) up to slightly more than 1 km wide which trends north from the northwestern part of the Lochaber Stock to merge with the extension of the Noel Fault in the vicinity of the Copperfield River, 6 km south-southwest of Kidston. The dykes of miscellaneous acid rocks (CPr), which diverge north-northeastwards from the fracture/intrusion system around the Lochaber structure in this area to extend semi-continuously to the Kidston mineralised breccia pipe, are aligned with the coalesced Noel Fault and un-named fracture zone, and presumably mark a tensional extension of it beyond the boundary of the exposed Lochaber structure.

Quartz-filled tensional fractures with marginal greisen cutting Lochaber Granite in the northern part of the stock are roughly aligned with the un-named fracture zone, suggesting some connection with either initiation or early tensional reactivation of it.

Displacement on the circumferential fracture/intrusion system of the Lochaber structure can only be inferred tentatively in the south. There, local juxtaposition of the lower and upper subunits of the Einasleigh Metamorphics across the system may be a product of such displacement. However, lack of appropriate structural data from the metamorphic rocks involved precludes estimation of the magnitude or sense of any such displacement.

Noel Stock: the Noel Micromonzonite, which may be the youngest unit within the area of the Lochaber structure (except for unrelated Mesozoic and Cainozoic rocks) occurs in an essentially equidimensional (in plan view) small stock cutting Butlers Volcanic Group and Sues Creek Microgranite near the western periphery of the structure. The Noel Stock could originally have had a near-concordant upper termination at about the same level as the sheet-like Sues Creek Microgranite.

The Noel Stock appears to be structurally independent of any part of the Lochaber structure proper, and it seems likely to be a superimposed feature unrelated to the stress field/s which controlled emplacement of other intrusive units in the structure.

Eastdale Stock

Although the stock of Eastdale Granite is not considered to belong to either the Bagstowe or Lochaber structures proper, some sharing of structural control with both can be inferred. In particular, the roughly linear southeastern edge of the stock is aligned with the contact between the Four Mile Creek and Black Cap–Bagstowe stocks of the Bagstowe structure, and with the eastern periphery of the Lochaber structure. It is also nearly in line with brittle structures at the southwestern end of the Far East Mylonite Zone.

Most of the northern edge of the Eastdale Stock coincides with the periphery of the Lochaber structure, with no Eastdale Granite known within the structure to the north of the circumferential Sues Creek dyke. This implies that at least the southern periphery of the Lochaber structure could have been controlled by a steep plane of contact between Eastdale Granite and basement rocks, following the reasoning for similar situations in the Bagstowe structure (see above).

Purkin Stocks

The two stocks of Elizabeth Creek-type Purkin Granite in the southeastern-most part of the Georgetown Region may be apophyses of a more extensive batholithic body concealed beneath Mesozoic and Cainozoic rocks farther south.

The western stock has the outline of a half-circle, as exposed; it lies entirely within Einasleigh Metamorphics. The eastern stock has the plan shape of a blunt, east-facing, hook; it straddles the boundary between Einasleigh and Juntala Metamorphics.

In setting at least, the stocks may be related to the Bagstowe and Lochaber Centred Igneous Structures, as discussed further below.

Semi-regional controls of Bagstowe and Lochaber structures plus Eastdale and Purkin stocks

The trends of the overall Bagstowe and Lochaber structures, as exposed, suggest emplacement under the influence of a southwest to northeast-trending horizontal maximum principal stress, rather than the more meridionally oriented one inferred to have been active elsewhere in the Georgetown Region during Carboniferous time.

In general terms, the Bagstowe and Lochaber structures, plus Eastdale Stock, are superimposed on, and confined to, a major basement block. This basement block is northeast- to almost north-northeast-trending. It is bounded in the northwest and west-northwest by the currently steep Gilberton and Ballynure faults, and in the southeast and east-southeast by the equally steep Werrington Fault and Far East Mylonite Zone (in its rejuvenated brittle manifestation) (Figs 3,4); the Noel Fault bisects the northeastern part of the block. The precursor of the Gilberton Fault is interpreted to have been a major mylonitic boundary, of probable early Palaeozoic age, between two structural domains.

North-northeast-trending faults north of the Bagstowe structure are parallel to the Ballynure Fault, and presumably belong to the same system. They appear to have undergone post-Gilberton Fault but pre-late Palaeozoic (unassigned intrusive rhyolite, CPr) sinistral movement. The Ballynure Fault itself has seemingly been overprinted by Siluro–Devonian Oak River Granodiorite between "Fernhill" outstation and upper Edmonds Creek, about 10 km north of its intersection with the Gilberton Fault. Likewise, the Noel Fault has been overprinted at Kidston. Thus the structural blocks separated by these two faults were "stitched" by late Palaeozoic time, and the fractures themselves could only exert influence on magmatic or structural activity as far as (and possible up to, in terms of crustal level) their overprinted sections.

The basement block itself consists mainly of Einasleigh Metamorphics, with an irregular contact between the postulated lower (calc-silicate facies) and upper (biotite facies) subunits extending roughly along its axis as far northeast as the Eastdale Stock. Juntala Metamorphics occur in the southeast as far north as the southeasternmost part of the Bagstowe structure.

The Eastdale Stock coincides with the narrowest part of the block where it changes trend. The Bagstowe and Lochaber structures lie respectively in the southwesterly- and more northerly-widening parts of the block beyond this area of necking. The only major dislocation known to occur within the block is represented by the Noel Fault, which cannot be traced to the southwest beyond the northern edge of the Bagstowe structure.

Geophysical (gravity) data, discussed further below, suggest that the main mass of intrusive material associated with the Bagstowe and Lochaber structures at depth coincides roughly with the exposed Lochaber Stock. However, it is apparently elongated to the north-northwest, rather than to the northeast as the stock is. The Bagstowe structure is marked by a gravity trough which links the Lochaber feature with an almost equally well-marked one coinciding closely with the eastern outcrop area of Purkin Granite. The gravity trough marking the Bagstowe structure is at its narrowest between the Mount Rous and Conical Knob–Old Man ring-dykes. These data suggest that the localisation of the Bagstowe and Lochaber structures within the axial zone of the basement block bounded by the Gilberton–Ballynure–Werrington-Far East faults is maintained at depth, and implies that the axial zone, indeed the entire block, has some more fundamental significance than its surface features suggest.

It is possible that some of the apparently discrete major basement faults in the southeastern part of the Georgetown Region are actually folded continuations of each other, i.e. a single system (cf. Withnall, 1985). The overall distribution of Proterozoic metasedimentary units and subunits, in and adjacent to the basement block with the Bagstowe and Lochaber structures, suggests that the block is occupied by the hinge zone of a complex shallowly northeast-plunging upright antiform. An equivalent, but southwest-plunging, structure apparently occurs to the east of the Georgetown Region map area. Reversal of plunge probably takes place in the general Eastdale Stock–Lochaber structure area.

As noted above, the southern end of the diffuse north-northwest-trending "Kidston–Mount Borium swarm" of steep dykes and plugs between the Lochaber structure and the eastern Wirra Cauldron diverges from the circumferential fracture/intrusion system around the Lochaber structure. In the north it passes into an incipient steep circumferential system at the northern and northeastern edge of a shallow arcuate embayment into the southeastern Wirra Cauldron, and into the system(s) associated with the eastern Wirra (particularly that part extending from the eastern corner) and southern Eveleigh cauldrons. Between these two gradational ends of the swarm, individual intrusive bodies trend mostly north-northwest to northwest. However, northerly to north-northeasterly and northerly to easterly trends are developed locally. Trends of the swarm as a whole, and of individual components, appear to be completely independent of basement features at the present level of exposure. The minimum density of intrusive bodies is in the Oak River section of the swarm. Local concentrations of bodies with some degree of radial disposition of dykes at Kidston, Mount Borium, and 8 km east of "Beverly Hills" presumably indicate stress concentrations above and around point centres of intrusion.

Structure of the Agate Creek Volcanic Group

The main 14 km x 6 km Agate Creek Volcanic Group outcrop area has a basinal structure. Probable lacustrine interbeds in the Black Soil Andesite strongly suggest that the palaeotopographic expression during accumulation of at least that part of the group was also basinal. The present structural basin is elongated from northwest to southeast; its southwestern edge appears to be entirely faulted, but the northeastern edge only partly so. Boundary and internal faults make up a wide southeastern extension of the conspicuous Roberton Fault (Fig. 4). Although the Agate Creek Basin trends obliquely across the line which would be followed by any southern extension of the Delaney Fault, the only possible manifestation of that fault are a pair of minor south-southeast-striking fractures which cut northeastern marginal parts of the basin. Nonwelded pyroclastic Big Surprise Tuff possible vented from, and Thunder Egg Rhyolite probable "roots" into, a northwest-striking fracture/intrusion system occupied by rhyolitic (CPr) dykes and plugs. Black Soil Andesite may similarly be underlain by minor bodies of intrusive andesite (CPa).

Dispositions of subsidiary outcrop areas of Agate Creek Volcanic Group rocks reinforce the northwest to southeast elongation of the main basin. The southeastern subsidiary outcrop area also has the same elongation, and the same trend of its main bounding faults. However, the exteme northwestern one, in the Bald Mountain area, has its elongation and fault trends to the northeast. These subsidiary outcrop areas are dominated by rocks assigned to the Big Surprise Tuff, suggesting that each overlies a vent.

The association of known and inferred northwest-trending structural features associated with the Agate Creek Volcanic Group may be marking a Permian accomodation zone.

In its most recent manifestation, the Robertson Fault has displaced Hampstead Sandstone (Jurassic) in a south-side-down dip-slip plus possible dextral strike-slip (according to displaced contacts in the Etheridge Group) manner. The South Head Fault, subparallel to and approximately 20 km southwest of the Robertson Fault (Fig. 4), has also undergone post-Hampstead Sandstone south-side-down (at least) movement.

Discussion

General

The various discrete and nested basin and trough-like structures defined by the Carboniferous ignimbrite-dominated sequences of the Georgetown Region, particularly those surrounded partly or entirely by fracture/intrusion systems, can be considered comparable to calderas. Like calderas, they were mainly formed by vertical subsidence rather than by any region-wide compressive deformation. Stratigraphic evidence suggests that, like calderas, they mark the main centres of extrusive activity above periodically evacuated magma chambers, and they underwent some degree of subsidence during and/or after the course of that activity. Some might also have had a degree of negative palaeotopographic expression, although that is uncertain. However, there is no compelling reason to believe that the extreme stage of caldera collapse was ever reached.

On the other hand, some structures appear to have been palaeotopographically positive at least temporarily during accumulation of their extrusive sequences. They may all have acquired the major part of their subsidence geometries at a late, essentially post-extrusive, stage (and possibly at entirely subsurface levels, particularly if bell-jar geometries of plutons were typical) when intrusive rocks and structures attained their highest crustal levels.

Extensional nature of structures

Overall orientations and alignments of dykes and other intrusive bodies, extrusive centres, and the subsidence structures themselves, suggest that the regional minimum principal stress was horizontal and approximately east-to-west-trending during the Carboniferous magmatic activity in the Georgetown Region (cf. Nakamura, 1977). Lack of evidence for a region-wide compressional deformation of appropriate age implies that this minimum principal stress probably represented an extensional tectonic regime. The currently preferred interpretation of tectonic setting envisages northeastern Queensland at a passive continental margin of upper-plate type (Lister & others, 1986) during late Palaeozoic time.

While "classical" extensional structures, such as listric normal faults with reverse drag of extrusive rocks, have so far been detected with a moderate degree of certainty only in the central and northern Newcastle Range sequences, and in the Bagstowe structure, asymmetrical (trapdoor) cauldrons are common in the Georgetown Region, and probably throughout northeastern Queensland. These imply that most marginal, and probably some internal, fracture/intrusion systems associated with the cauldrons incorporate important listric elements.

Rocks with a postulated listric fault sole or detachment in the central Newcastle Range (Fig. 2) occur south of and are separated from counterparts in an apparently complete stratigraphic sequence by a fault zone which is essentially orthogonal to the dominant northerly trend of other structural features in the area. This fault zone is believed to be equivalent to a second-order transfer fault (Bosworth, 1985; Etheridge, 1987). Other accomodation zones separating areas of contrasting structural geometry, particularly of marginal fracture/intrusion systems, and/or intrusive–extrusive stratigraphy, can be identified between and within component cauldrons of the composite Newcastle Range structure as a whole. Such zones include the Gulf Highway and Brodies Gap fault zones.

The zones are typically expressed as complex belts of fault-bounded blocks and slices; andesitic lavas seem to be preferentially developed along and adjacent to them, suggesting a "leaky" behaviour. The fundamentally similar Brodies Gap and Maureen fault zones line up with each other, suggesting a close relationship, although no connection is clearly detectable at the present level of exposure. However, the Yataga Stock lies between the two zones; also, some of the zones can be detected in basement as intruded and mineralised, albeit diffuse, "lines" (cf. Bain & Withnall, 1980).

Collective and individual relationships in the late

Palaeozoic ignimbrite-dominated sequences of northeastern Queensland suggest a regime of extensional and intrusive–extrusive structural interactions (Fig. 6a) in which the amounts or rates, or both, of magma-associated displacements (Fig. 6b) were cumulatively so much greater than the ones induced by extension that manifestations of the latter process were supressed and/or overprinted virtually out of existance (cf. Etheridge, 1986; Oversby, 1987).

Further investigations could well lead to recognition of some special manifestations of extension in this volcano-tectonic environment, possibly including pseudo-(structural) resurgence (cf. Oversby, 1987, Fig. 1a).

"Repeat" distances

Carboniferous: The most common maximum "repeat" distance between major known and inferred Carboniferous features in the Georgetown Region, such as the axial zones of the Cumberland Range–Maureen and overall Newcastle Range gravity troughs (see below), is 45±5 km. It is probably significant that this distance is essentially the same as the interpreted current depth to the base of the crust in the region (cf. Dooly, 1980). If the "repeat" distance between the axial zones of the overall Newcastle Range and "Conjuboy" gravity troughs (below) has significance in terms of crustal thickness, then the crust must in fact have been significantly thicker during at least some part of Carboniferous time than it is at present. However, the satellitic Newcastle Range gravity feature (see below), which is suggested (below) to represent one or more episode(s) of magma generation and ascent late in the evolution of the postulated sub-Newcastle Range batholith as a whole, could be a consequence of an offset effect. If this is the case, the more meaningful "repeat" distance in terms of crustal thickness might be the one between the "Conjuboy" gravity trough and this satellitic gravity feature. Again, this distance is, at least locally, in the 45±5 km range. It is mainly for this reason that the postulated "Conjuboy" batholith is tentatively equated in broad temporal and genetic terms more directly with the satellitic part of the Sub-Newcastle Range body than with its main axial culmination.

The 5 to 30 km range of separations between the range of individual Carboniferous intrusive–extrusive and structural centres of activity, and commonly coincident gravity minima (see below), in the Georgetown Region, tend to cluster at distances of 10, 20, and 30 km, plus or minus a few km. These distances presumably represent second and lower-order "repeat" distances, and/or offset effects, and/or manifestations of crustal thinning. Similarly, distances between at least moderately to steeply-dipping circumferential fracture/intrusion systems and internal centres of activity and/or gravity minima within centred structures might give an order-of-magnitude indication of depth to the foci from which the intrusion-related stresses of an individual system emanated as good as, or better than, surficial dips of intrusive contacts, assuming that such foci were peak or ridge-like in form.

The various separations ("repeat" distances) among and between exposed and postulated Carboniferous igneous centres may equate directly with depths below the coeval palaeosurface to crustal horizons at which major magma bodies were initially generated and then split up into subsidiary bodies which continued their ascent separately (cf. Vogt, 1974; Windley & Davis, 1978; Rickard, 1984).

Some of the "repeat" distances could also reflect an offset effect, whereby successively younger magma batches of approximately equal volume were displaced laterally from zones of preceding activity and stabilisation. This might have occurred for one or more of a variety of reasons, such as: previous total removal of material of appropriate melting point from source areas in zones of early activity; effective deactivation of any pre-existing channels available for magma ascent in such zones by consolidation of intrusive bodies emplaced during the earlier episode(s) of magmatism; and a tendency for new channels generated and/or reactivated by magma-induced stresses to propogate preferentially at the ductility contrasts afforded by margins of, or via existing discontinuities outside, such already-consolidated bodies, rather than within or through them. The possibility that particular horizons and/or intervals changed positions and thicknesses through time also cannot be ignored, although such potential changes are difficult to identify because of "slop" in critical data relating to temporal relationships.

These lines of reasoning interconnect, admittedly somewhat tenuously, to suggest that major batches of Carboniferous magma in the Georgetown Region were generated at or close to the base of a sialic crust, of about the same thickness as it is currently, and that the 45±5 km separation between major features is the first-order "repeat" distance which reflects this. Additionally, there is an implication in the reasoning that there may have been a first-order subregional to regional eastward shift in major batholith generation in and at least immediately east of the Georgetown Region. Northward, and less common southward (e.g. Warby Structure–Branch, 1966), younging of the main suprajacent structures and/or high-level intrusive to surficial extrusive igneous components associated with individual batholithic bodies would thus be a superimposed second-order phenomenon.

Sparse seismic refraction and reflection data, of variable age, accuracy, and reliability, suggest only a single intra-crustal discontinuity, lying at a depth of about 20 km, in the Georgetown Region. Farther south (Galilee and Bowen basins), however, additional discontinuites at about 5 km and 25 to 30 km have also been inferred (cf. Dooly, 1980). These seismically interpreted discontinuitues, if real in physical terms, might have exerted some control(s) on separation of subsidiary magma batches from parental batholithic masses.

Permian: Separation distances between the northwest-trending belts of known and inferred Permian features in the region average about 45 km. Subsidiary occurrences of rocks assigned to the Agate Creek Volcanic Group at Bald Mountain and to the north of "Gilberton" lie about 20 km northwest and southeast, respectively, of central Agate Pocket.

Subsurface form of structures

Progressively decreasing inward dips suggest that subsidence structures are funnel or keystone-shaped overall, rather than piston or cone-like. The downwardly contracting form of the subsidence structures presumably focussed on apical areas of underlying magma chambers,

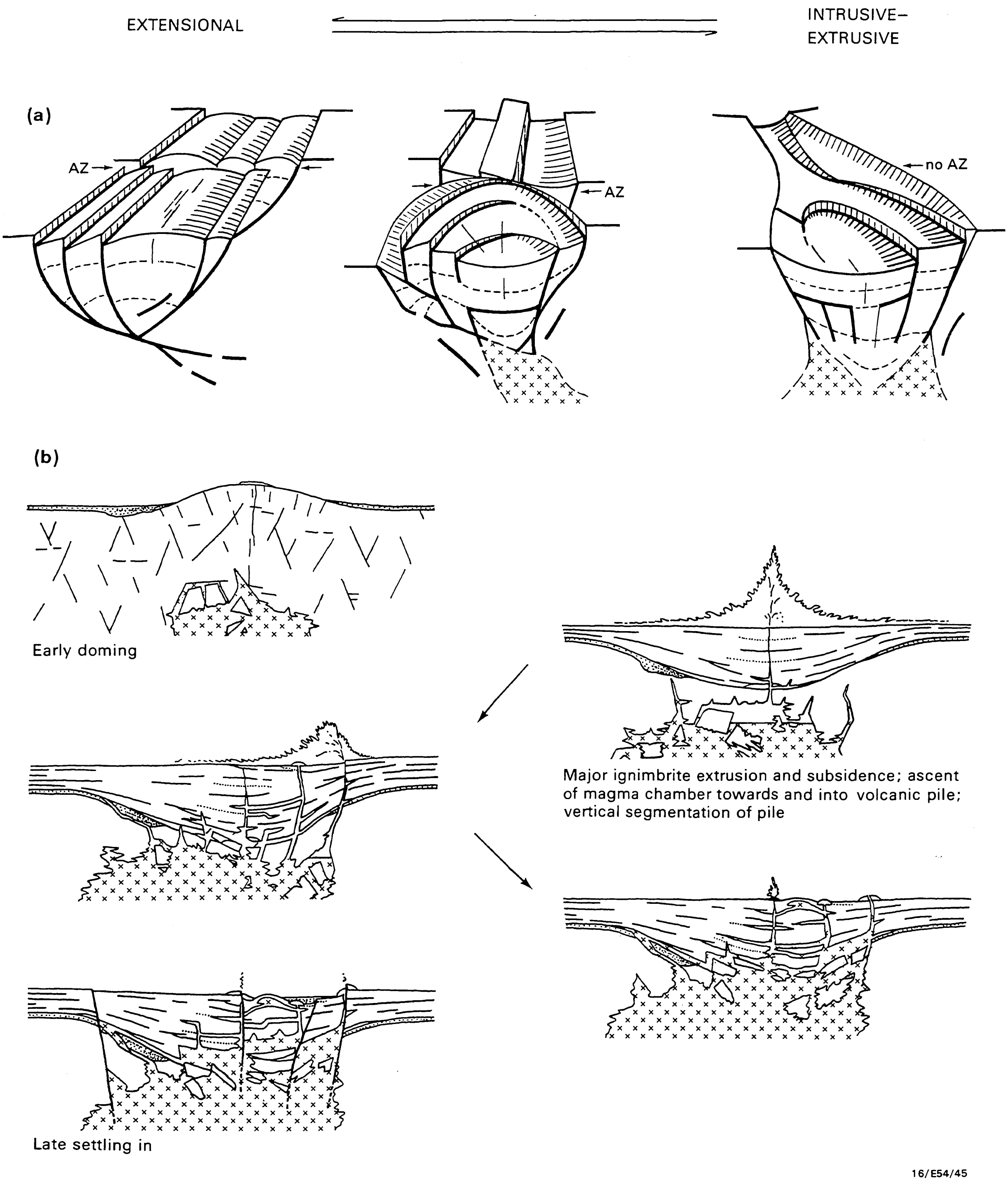

Fig. 6(a). Diagrammatic consequences of extensions (lateral) and intrusive–extrusive (vertical) structural interactions in ignimbrite-related cauldrons. The extension-dominated geometry (left) displays "pseudo-resurgence" produced by large-scale reverse drag on symmetrically inward-facing listric normal faults, i.e. this scenario requires an inward-dipping ring-fracture system. AZ = accommodation zone. Modified from Oversby (1987).

Fig. 6(b). Vertical-only intrusive–extrusive structural effects produced by progressive magma chamber ascent towards and into an ignimbrite-dominated sequence accumulating in a cauldron lacking significant palaeotopographic caldera expression. Late "settling-in" postdates magma ascent. This scenario is independent of ring-fracture dips. Modified from Oversby & others (1980).

represented now by intrusive bodies. Inwardly directed deformation would solve a "space problem", necessary for continuance of subsidence. Inward dips need only be as great as the complement of that on the relevant fracture/intrusion system. Formation of basins and troughs could account for up to 50% of total subsidence (Walker, 1984), and would remove any requirement for the outward dips on fracture/intrusion systems which are sometimes postulated as the means whereby subsidence can be sustained (e.g. Druitt & Sparks, 1982, 1983). Outward dips are contra-indicated by most field data.

Radial and circumferential folds, and rare strike-slip faults, inside circumferential fracture/intrusion systems could represent secondary accomodations to local "space problems" caused by, for example: perturbations in strike and/or dip of the circumferential system; and development of multiple, variably inclined, subsidence surfaces.

The absence of appropriately distributed outward dips within Newcastle Range and other structures indicates that they did not undergo resurgent doming. However, the differential tilting and/or erosion inferred from stratigraphic evidence may reflect various scales and styles of wholesale uplift, although without any reversal of structural form.

The presence of an outwardly dipping listric fault surface in the northwestern Eveleigh basin is not easily explained. The feature suggests megaslumping outwards from the basin. This slumping may reflect an original (constructional) domal palaeotopography of the structural basin (cf. Baker, 1981), or it may have taken place during an episode of wholesale uplift of the cauldron as a piston-like entity. This uplift, if it occurred, must have antedated development of the local circumferential fracture-intrusion system which cuts the listric fault.

Regional Geophysical Signatures associated with Late Palaeozoic Rocks and Structures

Gravity

Carboniferous

Outcropping intrusive and extrusive components of the Newcastle Range Cauldrons, as well as the western Fulford Batholith, are superimposed on an undulating, broadly north-trending, Bouguer gravity trough (BMR, 1987b). This trough probably at least in part reflects the main mass of a continuous or semicontinuous batholithic body of Carboniferous granitoid(s) (possibly mainly of Elizabeth Creek-type) at depth, maybe in the order of 5 km or less (cf. Plouff & Pakiser, 1972). Subsidiary keels and other, more equidimensional, gravity minima within this trough presumably represent major crestal culminations ("cupolas", in a broad sense), and/or "roots", of the postulated batholith, irrespective of surficial expression. Similarly, the Carboniferous igneous rocks and structures developed at the present level of exposure probably also represent at least subdued upper culminations via intermediate fracture/intrusion systems, irrespective of details of the local gravity field. In practice, developments of Carboniferous rocks and significant gravity minima commonly correspond closely in location, although not necessarily in final areal extent or two-dimensional geometry (cf. Steven & Lipman, 1976; Lipman, 1984) throughout the Georgetown Region, indicating that many, if not all, surficial features have a direct one-to-one correspondence with major underlying batholithic culminations in at least location.

A north-northeast-trending gravity minimum between "Robin Hood" homestead and "Old Robin Hood" outstation lies at the top of the southwestern gradient into the Newcastle Range trough, to which it might be related. However, there is no obvious reason for its location or magnitude in terms of outcropping late Palaeozoic rocks.

The overall Newcastle Range gravity trough consists of a main axial portion, with a satellitic feature which diverges northeast to north-northeast from near the contact between the main Newcastle Range and the eastern lobe of the range. The preserved Eveleigh Volcanic Subgroup and marginal parts of the main outcrop areas of Caterpillar and Eva Creek microgranites in the central to east-central Eveleigh Cauldron coincide with one of two main gravity minima within the satellitic feature. The separation distance of the circumferential fracture/intrusion system around the Eveleigh Cauldron from this gravity minimum ranges from about 7 to 20 km. The second minimum in the stellitic Newcastle Range gravity trough occurs in the vicinity of "Cabana", adjacent to the north-central edge of the preserved part of the Cumbana Cauldron. These two gravity minima are 40 km apart. This satellitic gravity feature attains its maximum separation, about 30 km, from the main axial portion of the overall trough in the north. Data from exposed rocks (see above) suggest that the main axial culminations of the postulated sub-Newcastle Range batholith, as reflected in the extrusive sequences of the Wirra, Kungaree, and Namarrong cauldrons and associated fracture/intrusion systems, reached the upper crust and in part vented at the palaeosurface (in a broadly decreasing temporal progression from south to north) before the satellitic one did. This in turn implies that the magma precursor(s) of the satellitic feature was/were generated at a late stage in the evolution of the sub-Newcastle Range batholith as a whole.

There is only one major gravity minimum evident in the main axial portion of the Newcastle Range trough; it coincides with the northeasternmost (mainly covered) part of the Wirra Cauldron and lies about 35 km from the Eveleigh Cauldron minimum (above). The Wirra Cauldron minimum is about 30 km from thick developments of Routh Dacite lava and proximal lag-fall rudite in the Kitchen Creek Rhyolite to the south of the Gulf Developmental Road. It is also about 15 to 25 km from the type area of the MacCallor Microgranodiorite, rhyolitic lava, and the main exposed development of volcanigenic clastic rocks in lower Bousey Rhyolite of the Fish Hole–Mount Bousey area. In turn, the thick Routh Dacite lava and lag-fall Kitchen Creek Rhyolite south of the Gulf highway lie between about 20 to 25 km from the near-coincident main development of Shamrock Rhyolite, lag-fall Corkscrew Rhyolite ignimbrite, and outcropping Talaroo Microgranite. These near-coincident features lie at a comparable range of elevations from the main occurrences of Twin Dams and Dagworth andesite lavas, lag-fall Brodies Gap Rhyolite, and Lubrina Granite in and adjacent to the western and northern Namarrong Cauldron. The circumferential fracture/intrusion system around this cauldron varies from about 5 to 10 km from the core of the structure.

To the west of the Newcastle Range, components of the Cumberland Range, Dismal Creek, and Maureen centred igneous structures are also superimposed on a gravity trough of varying magnitude. The average maximum distance between the main axial zones of the Cumberland Range-Maureen and overall Newcastle Range gravity troughs is in the order of 50 km. Minima within the Cumberland Range–Maureen trough coincide with outcropping Mount Darcy Microgranodiorite and Prestwood Microgranite in the core of the postulated composite Cumberland Range–Dismal Creek structure (see above), and with an area of probable Maureen Volcanic Group covered by Upper Cretaceous or Tertiary Bulimba Formation slightly more than 30 km west-northwest of the Maureen Prospect (Smart & Bain, 1977). These two minima have a separation of about 45 km. Centres of significant magmatic-structural activity in the Cumberland Range–Maureen belt, (marked by preserved Cumberland Range Volcanic Group plus major occurrences of Mount Sircom Microgranodiorite, by Dismal Creek Dacite, by proximal Maureen Volcanic Group extrusive rocks plus the Fiery Creek Fault Zone, and by the Mount Turner intrusive centre with its mineralisation), are separated by distances of between 5 km and 30 km from one or other of the two main gravity minima in the belt. The main dyke of Prestwood Microgranite at the periphery of the composite Cumberland Range–Dismal Creek structure lies at a variable distance of from about 10 to 15 km beyond the Mount Darcy gravity minimum and coincident occurrences of Prestwood Microgranite in the core of the structure.

The next substantial gravity trough east of the Newcastle Range lies outside the Georgetown Region map, between "Conjuboy" (7860–620328) and the upper reaches of Elizabeth Creek to the east of Mount Surprise. This trough is probably a somewhat modified expression of another late Palaeozoic (Carboniferous?) batholithic culmination, now largely concealed beneath Cainozoic extrusive cover of the McBride Province. However, undated "Elizabeth Creek" and tentative "Herbert River" granites are recorded from limited inliers near the northwestern edge of McBride Province cover in the Mount Surprise area (e.g. Branch, 1966). This "Conjuboy" gravity trough trends slightly more to the west of north than the Newcastle Range one, suggesting that magma was emplaced under the influence of a stress field of slightly different orientation (and age?). The main axial zones of the two gravity troughs are between about 80 and 90 km apart in the north and south, respectively. However, the northern part of the "Conjuboy" trough is about 50 km away from the satellitic Newcastle Range gravity feature. These spatial relationships suggest that the "Conjuboy" gravity trough/batholithic culmination might be temporally and genetically more directly related to the cause(s) of the satellitic Newcastle Range feature than to the main axial zone, as discussed further below.

In the dyke belt and subdued gravity trough between the southern Newcastle Range and Bagstowe–Lochaber structures, local intrusive centres represented by the sparsely gold-mineralised Mount Borium plugs and crudely radial dykes, and comparable features 9 km east of "Beverly Hills", both lie roughly 20 km from the gravity minimum which coincides with the northeasternmost Wirra Cauldron (see above). The broadly similar, albeit more significantly gold-mineralised (on present indications), Kidston breccia pipe is situated about 25 km from the Mount Borium and "Beverly Hills" intrusive centres, and about the same distance from the only significant gravity minimum in the Bagstowe–Lochaber belt. This gravity minimum coincides with the southern edge of the Lochaber Granite stock. Preserved Butlers Volcanic Group and outcropping intrusive associates are about 15 km from the gravity minimum, and also from the Kidston breccia pipe. The Lochaber stock and circumferential fracture/intrusion system around the overall Lochaber structure are both distinctly excentric in relation to the gravity minimum, being approximately centred respectively 8 km north-northeast and slightly less than 15 km north-northwest of it. As noted above, the subparallel major axes of the individual Bagstowe and Lochaber structures are 12 km apart, while major intrusive components of the Bagstowe structure have separation distances between projected geometrical centres ranging from 5 to 12 km. The core area of the Black Cap-Bagstowe Stock lies about 12 km from the main Bagstowe-Lochaber gravity minimum, and inferred Paddock Creek Formation extrusive centres are between about 10 and 20 km from the central Black Cap–Bagstowe Stock. Gold mineralisation at Christmas Hill, 2.5 km north of the main outcrop area of Paddock Creek Formation, which is probably in a basically similar setting to that at Kidston, is slightly more than 10 km from the central part of the stock. The Bagstowe–Lochaber belt gravity minimum is separated by about 45 km from the next one to the southwest in what appears to be the "refracted" section (see above) of the same semi-regional trough/batholithic culmination, which coincides with the eastern exposed Purkin Granite. Farther south, the effects of Devonian–Carboniferous (and probably also older) Bundock Basin sedimentary rock fill, and/or Mesozoic–Cainozoic cover, apparently obscure the gravity signatures of exposed and any concealed late Palaeozoic igneous rocks.

No significant positive gravity anomalies coincide with Carboniferous intrusive–extrusive rocks or structural features in the Georgetown Region, suggesting that none is associated with major single intrusive bodies of mafic rock(s). This contrasts with the situation in some other provinces characterised by important centred igneous structures (e.g. Bott & Tuson, 1973; Cook & Murphy, 1952). However, there is a single, well-defined and conspicuous, although not very intense, gravity maximum centred on "Bolwarra" homestead (7763–004748), to the north-northwest, which could represent a completely buried mafic intrusion.

Permian

Outcrop areas of Agate Creek Volcanic Group have no discernable regional gravity expression, nor do any of the subparallel (northwest to southeast) fracture/intrusion belts inferred to be of Permain age. Gongora Granodiorite is marked by a gravity hole, but Carnes Granodiorite is gravimetrically invisible (BMR, 1987b).

Magnetics

Carboniferous

Aeromagnetic data over the Newcastle Range and other outcrop areas of Carboniferous ignimbrited-dominated sequences (BMR, 1987a) show several groups of conspicuous anomalies; ground-checking of some of these in the Newcastle Range has indicated considerable local complexity.

Extrapolation from the ground-checked anomalies suggests that most are within, or not far below, Newcastle Range Volcanic Group and/or associated intrusive rocks, but they do not appear to have any surficial manifestation. The anomalies do not coincide with exposed andesitic rocks; a few are spatially associated with exposed faults and dykes, but most are not. One anomaly in the northwestern part of the southern lobe of the Newcastle Range can be linked to the outcropping part of a body of Cobbold Metadolerite. However, this anomaly is minor relative to many of the others.

An important observation is that none of the groups of conspicuous magnetic anomalies is coincident with a marked gravity peak. This indicates that unexposed mafic intrusions are probably not responsible for them.

Permian

The outcrop area of Agate Creek Volcanic Group and associated rocks has an irregular magnetic "topography" similar to that shown by Carboniferous extrusive sequences.

An annulus of marked magnetic anomalies around the Yataga Stock probably mark its contact thermal aureole (BMR, 1987a).

Synthesis of Stratigraphic and Structural Evolution of Late Palaeozoic Intrusive and Extrusive Rocks

As noted above, none of the extrusive units of whatever rank in Carboniferous ignimbrite-dominated units of the Georgetown Region can confidently be carried across any but the most limited gap(s) in outcrop continuity. No correlations can be substantiated between the main current outcrop areas and groups of outcrop areas which, as a matter of practicality, form the basis for defining and delineating the limits of stratigraphic entities. This is the case even though all units, except for the Paddock Creek Formation and Butlers Volcanic Group, are underlain by some development of the Gilberton Formation, implying a rough synchroneity in initiation of extrusion, commonality of palaeotopographic base level, and at least the potential for lateral interfingering.

Judging from preserved relationships, the inability to recognise any sharing of units between major sequences in the Georgetown Region is due to a combination of factors which are reflected in the locally complex stratigraphies of the sequences involved. Many of the ignimbrites, as well as other rock types, in the sequences are not in themselves sufficiently distinctive to be useful as markers, while those rocks which are distinctive enough to be potentially useful either show marked lateral variations in characteristics, and/or are too thin and poorly exposed to be traced at any but the most detailed mapping scale, and/or are lensoidal and die out within relatively short strike distances.

Lateral variations in ignimbrites, and consequent difficulties of correlation, could be expected to increase as a direct function of degree of contemporaneous topographic relief, with or without associated structural disruption. Elsewhere, notable lateral variations are routinely ascribed to major caldera collapse (e.g. Lipman & others, 1973; Steven & Lipman, 1976; Lipman, 1984). Intracaldera ignimbrites differ, sometimes in spectacular fashion, from their cogenetic outflow equivalents in: thickness; abundance and size of crystal/pumice/lithic inclusions; welding/devitrification/recrystallisation; jointing; alteration; and even chemical characteristics. Some inferred intra-caldera ignimbrites are very crystal-rich, and resemble intrusive granitoids in overall aspect, especially in instances where groundmass material has undergone considerable recrystallisation.

Volumes of magma withdrawn suddenly from chambers during caldera-associated eruptions are taken to be typically several tens to hundreds of cubic kilometers (Smith, 1960). Conceptually, however, the interplay of variables which presumably influence caldera formation (such as volume and horizontal–vertical distribution of source magma chambers, and strength of chamber roof(s)) might be expected to cause smaller-than-expected ignimbrite volumes to be associated with calderas in one place (or at one time), whereas even the most voluminous eruptions elsewhere (or at another time) might not result in collapse.

Interstratified megaclastic breccias, interpreted as the products of landsliding from caldera walls, are regarded as particularly characteristic of collapse-associated ignimbrites (Lipman, 1976). While such rudites should be uniquely diagnostic of caldera-related units and sequences, their objective differentiation from coarse to very coarse clastic rocks formed by one or more of many other possible processes is likely to be exceedingly difficult, if not downright impossible, in reality.

Postulated intra-caldera ignimbrites are commonly overlain by post-collapse successions, dominated by lavas and fluviatile and/or lacustrine sedimentary rocks (Smith & Bailey, 1968).

The numerous discordances, and locally marked thickness variations, within the Carboniferous ignimbrite-dominated sequences of the Georgetown region are probably symptomatic of recurrent non-deposition and/or erosion of at least local extent. In turn, this presumably reflects structural instability, although not necessarily more than would be expected in any volcanic environment. Differential uplift and tilting, with shifting centres of extrusion and/or accumulation, appear most likely to have been responsible for many instances of such non-deposition/erosion. These movements might have been equivalent to the postcollapse stage of (structural) resurgence which forms part of the "classical" caldera cycle (Smith & Bailey, 1968; Steven & Lipman, 1976). On the other hand, some cases evidently involved displacements on high-angle faults, such as the Brodies Gap and Fiery Creek structures, penecontemporaneous with ignimbrite extrusion and accumulation.

Contrasts between Bousey Rhyolite in the southern lobe of the Newcastle Range and rocks assigned to the same formation in the central isthmus of the range suggest that the former occurrence could be of intra-caldera origin, with the latter representing its outflow sheet. Also, Jinker Creek Rhyolite in the southern lobe has the microgranitoid-like nature to be expected of a "typical" intra-caldera sheet, as does Shrimp Creek Rhyolite and parts of the Cumbana Rhyolite. The Mosaic Gully Rhyolite of the eastern lobe of the Newcastle Range must be considered as another strong contender for the title of intra-caldera unit because of its apparent great volume (cf. Smith, 1960). In fact, if volume alone was uncritically assumed to be uniquely diagnostic of an association with caldera collapse, several other ignimbrite sheets in the region would be implicated in such a process. On the other hand, a strong argument against the assumption that Carboniferous ignimbrites of "appropriate" volume in the Georgetown Region were associated with surficial collapse calderas is the almost complete lack of known rocks which can be attributed to slumping and other processes of caldera wall degradation with any degree of confidence. There is a single possible exception in the Cumberland Range Volcanic Group. However, most of the coarse volcaniclastic rudites known in the region, such as those in the Corkscrew, Kitchen Creek, and Brodies Gap rhyolites, and in the Ironhurst Formation, are better and quite adequately interpreted as either lag-fall or ground-lag deposits. Such rudites are commonly autoclastic; basement material is notably rare at all stratigraphic levels. This last feature is consistent with an essentially surficial flaring of source vents within the products of their own and immediately preceding activity, and continual recycling of clasts by gas-streaming (cf. Eichelberger & Koch, 1979). It is not consistent with slumping of steep caldera walls in which appreciable exposure of older extrusive and basement rocks would be expected, at least during early stages in the accumulation of a volcanic pile. This lack of slump-generated rudites is probably not simply an artefact of exposure; such rocks would be expected to occur preferentially in the lower parts of intra-caldera ignimbrites close to caldera walls. With the exceptions of Jinker Creek and Shrimp Creek rhyolites, the lower parts of Carboniferous ignimbrites in the Georgetown region are mostly adequately exposed adjacent to any structural boundaries which might represent caldera walls for manifestations of slumping to be detected if they were present.

In the Cumberland Range Volcanic Group, the overstepping of the 500 to 700 m-thick Scrubby Creek Rhyolite by Namul Dacite over a distance of less than 1 km locally suggests significant pre-Namul faulting close to the present southern and southeastern edges of the outcrop area of the group. This suggestion is supported by the coarse rudites containing angular clasts derived from Proterozoic Lane Creek and Townley Formations. Several such rudites are probably intercalated within the upper third of the Scrubby Creek Rhyolite, and might have originated by fault scarp (=caldera wall?) slumping. Other non-welded clastic rocks in the formation are predominantly epiclastic, and probably mainly of fluviatile and possibly lacustrine origin. These observations are consistent with trapdoor-style subsidence to the south and southwest to form an asymmetrical palaeotopographic caldera during accumulation of the upper part of the Scrubby Creek Rhyolite, even though none of the ignimbrite sheets in the formation is of "typical" large-volume intra-caldera aspect. In contrast, northwestwards subsidence is implied by thickness variations of ignimbrite sheets in the lower Scrubby Creek Rhyolite. According to the distribution of probable lag-fall Namul Dacite rudite, and of intrusive autoclastic and polymictic rocks cutting that formation, the source(s) of the Namul Dacite lay at the postulated Scrubby Creek Rhyolite caldera margin, although that margin was not active as a contemporaneous fault. The caldera margin might also have localised an east-trending dyke of unassigned andesite, which cuts Namul Dacite in the southern part of its outcrop area.

Thickness distributions in small-volume Shamrock and Corkscrew rhyolite welded ignimbrites suggests simple downwarping in their main areas of development in the central isthmus of the Newcastle Range. The situation in the northern part of the isthmus, and in the northern lobe, is more complex. Twin Dams and Dagworth andesites are thickest in the western part of the northern lobe, within and immediately north of the Brodies Gap Fault Zone. Associated tongues of Shamrock and Corkscrew rhyolite ignimbrites suggest that this thickening resulted from downwarping, rather than from the construction of a topographically positive lava pile from which pyroclastic flows would tend to be diverted. However, Corkscrew Rhyolite lava in the east does not extend north across the fault zone, suggesting uplift in that part of the northern lobe. Thickness distributions in different parts of the Brodies Gap Rhyolite are not well understood in detail, but they do not unambiguously indicate significant differential movement between the central isthmus and northern lobe of the range across the Brodies Gap Fault Zone contemporaneous with accumulation of the unit. Depositional centres evidently changed position and form through time, and did not necessarily coincide with the currently-preserved structurally-defined features. The local limestone, well within the Brodies Gap Rhyolite outcrop area of the northern lobe, suggests the presence of at least transitory negative palaeotopography. Areas underlain by Routh Dacite and Corkscrew Rhyolite lavas in the central isthmus of the Newcastle Range could have been palaeotopographically positive, although at least local overall subsidence and neutral to negative palaeotopographic expression are suggested by associated ignimbrites and volcaniclastic intervals.

Yellow Jacket and Beril Peak rhyolites appartently die out beneath Mosaic Gully Rhyolite on the western side of the eastern lobe of the Newcastle Range, across a zone now occupied by Caterpillar Microgranite. Again, this suggests a shift of depositional centres within the overall structural and depositional feature marked by the lobe. Kitchen Creek Rhyolite and Routh Dacite in the central isthmus of the Newcastle Range thin northwards across the Gulf Highway Fault Zone, while Corkscrew Rhyolite lava thickens. Rocks assigned to the Shamrock Rhyolite are not known to occur south of the fault zone. The Thornborough Andesite Member of the Routh Dacite crops out only adjacent to the northern edge of the zone. Similarly, Bousey Rhyolite thins abruptly across the Spear Creek Fault Zone.

The west-northwest-trending Fiery Creek Fault Zone forms the northern edge of the Maureen basinal structure, and has undergone cumulative south-side-down movement. This is the same as the sense of movement on the Brodies Gap Fault Zone of the northern Newcastle Range, with which the Fiery Creek Fault Zone is aligned. The Fiery Creek Fault Zone shows a gross coincidence with a locally expanded sequence of Gilberton Formation, with maximum vertical and lateral variations in the Ironhurst Formation, and with probable lag-fall rudite in the lower Puranga Rhyolite. It also contains the greatest concentration of intrusive rocks of various kinds associated with the Maureen basin.

The nature and distribution of the Paddock Creek Formation suggest that the rocks were erupted from a series of originally semi-connected sources within a roughly north-trending belt extending at least from the type area of the unit to Wire Yard Mountain, a distance of slightly more than 20 km. In addition, the distribution of different parts of the formation implies that the central area of the Bagstower structure was slightly positive relative to peripheral areas at the time that at least the lower and middle subdivisions of the sequence accumulated. The minimum relief was presumably in the order of the 250 m combined thickness of the lower and middle parts of the Paddock Creek Formation at their maximum development; this relief presumably largely reflected early doming at the site of the Bagstowe structure.

On the whole, available stratigraphic data are most suggestive of a pattern of differential and perhaps episodic downwarping in most areas, probably at a late evolutionary stage. There are indications of slight shifts in the locations of structural centres through time, probably accompanied by changes in the forms of the evolving structures. An asymmetrical collapse caldera might have occurred in the Cumberland Range area at the time that Scrubby Creek Rhyolite was extruded, even though that unit (and the others in the Cumberland Range Volcanic Group) are not notably voluminous or of intra-caldera aspect.

In the Newcastle Range, if collapse calderas developed at all, they were probably restricted in space and time; they would most likely have been associated with Shrimp Creek and Jinker Creek rhyolites, and possibly some other units high in sequences as preserved, which are of intra-caldera aspect. However, many available data are more consistent with synvolcanic palaeotopographies being neutral to positive (constructional). There was no clearly systematic coincidence between detectable high-angle faulting during ignimbrite activity in the Newcastle Range and the present structural–stratigraphic boundaries of sequences.

Geochemistry and Petrogenesis

In terms of the classification developed and refined by Chappell & White (e.g. 1974), late Palaeozoic igneous rocks in the Georgetown Region were originally considered to be all of variably fractionated I-type character (cf. Richards, 1980; Oversby & others, 1980; Mackenzie, 1987a). However, a systematic re-evaluation of geochemical data from the whole of northeastern Queensland undertaken by Champion & Heinemann (1993, 1994) shows that, while the I-type characterisation is still mainly accurate for the Georgetown Region, A-type rocks are also present in and adjacent to the Newcastle Range (Fig. 1). Extrusive A-type units are Routh Dacite and Corkscrew Rhyolite (Kungaree Volcanic Subgroup, and Brodies Gap Rhyolite (Namarrong subgroup), in the upper preserved part of the Newcastle Range Volcanic Group sequence. Intrusive A-type units are Caterpillar Microgranite (Eveleigh Cauldron) and MacCallor Microgranodioirite (Wirra Cauldron and southern Kungaree Trough). Outside the Georgetown Region, in comparison, A-type rocks evidently dominate Scardons Volcanics, north to northeast of the Newcastle Range, and the upper Featherbed Volcanic Group farther to the northeast. By contrast, no late Palaeozoic S-type igneous rocks are known closer to the Georgetown Region than the present coastal area, and these are intrusive only (Fig. 1).

The most obvious apparent difference between Carboniferous and Permian igneous rocks in the Georgetown Region and immediately to the west (eastern Croydon area—Mackenzie, 1987a) is the considerably larger volume of dominantly felsic ignimbrites in Carboniferous sequences, and a greater proportion of more mafic lithologies in the Premian associations, at Georgetown.

Major-element compositions of the Carboniferous and Permian rocks are broadly similar; however, there are several significant differences at a detailed level. Most of the intermediate to silicic Carboniferous rocks are lower in Al_2O_3 and higher in total Fe than equivalent Permian lithologies. Among these Carboniferous rocks, a group of intermediate-SiO_2 (61 to 67%) types which are also characterised by moderately high K_2O, appears to be genetically related via crystal fractionation (on a basis of linear trends on K_2O, Rb, Y, and especially Zr Harker plots) to lower-SiO_2 (53 to 59%) rocks (Mackenzie, 1987a, Fig. 5). The Zr Harker plot also highlights differences in the less silicic (50 to 60% SiO_2) types suggesting that Carboniferous and Permian rocks are not genetically related; equivalent differences are shown by P_2O_5, Ba, and Sr (Mackenzie, 1987, Table 2).

The most felsic Carboniferous rocks (SiO_2 >71%) are poorer in K_2O, Rb, and Zr (and richer in CaO) than they would be had they fractionated from precursors similar to the more mafic Carboniferous rock types.

Intrusive rocks from the Cumberland Range area (including ones assigned to Mount Sircom and Mount Darcy microgranodiorites) plot on the Zr-SiO_2 and most other variation diagrams close to known Permian granodiorites from the eastern Croydon area, and well separated from typical Carboniferous counterparts (Mackenzie, 1987a). These geochemical indications of a Permian age are consistent with geochronological data, even though the closely associated Cumberland Range Volcanic Group appears to be Carboniferous.

Initial $^{87}Sr/^{86}Sr$ ratios of Carboniferous and Permian silicic to intermediate rocks suggest that both age groups were derived mainly or entirely from highly evolved ("old") sialic crust (Mackenzie, 1987a); Carboniferous and Permian mafic rocks probably represent mantle-derived magmas, possibly from an "old" lithospheric source, although variably modified by crustal contamination. Such mantle-derived magmas may have invaded the sialic lower crust of the region recurrently during both Carboniferous and Permian times, and provided the heat source for partial melting of a variety of crustal rocktypes.

All available analyses have been entered into the AGSO "ROCKCHEM" database.

Regional tectonic setting of Late Palaeozoic Magmatism

The preferred interpretation of the tectonic setting of the site of northeastern Queensland during late Palaeozoic time envisages the region as a moderately extensional passive continental margin of upper-plate type (Lister & others, 1986). Apparent compressional (transpressional?) folding and faulting in areas, such as the Bundock and Clarke River basins, and possible strike-slip movement on components of the Palmerville Fault system, are believed to reflect extreme though only local and transient/intermittent uppermost crustal stress perturbations within the regime of overall extension. The semi-continuous batholiths and volcanics defining the Townsville–Mornington Island Igneous Belt (Wellman & others, 1994), which trends west-northwest immediately north of the Newcastle Range (Fig. 1), may represent a major extensional transfer structure related ultimately to membrane tectonics (Oversby, in preparation). Late Palaeozoic igneous features in the Georgetown Region with a trend subparallel to this igneous belt (notably the elongate basinal structure of Agate Creek volcanics, and associated dykes, but also including, e.g. the Brodies Gap–Dagworth Bore Fault Zone in the Newcastle Range, and Fiery Creek Fault Zone farther west) are now seen as possible secondary accommodation zones formed throughout late Palaeozoic time, rather than as manifestations of a discrete Early Permian stress field with roughly northeast to southwest extension, as believed previously (e.g.. Oversby, 1983). Some major structures of pre-late Palaeozoic origin, including precursors of the present Gilberton, Buredekin River, and Clarke River faults probably also behaved as accommodation structures.

Late Palaeozoic magmatism defining the northeastern Queensland Coastal Ranges Igneous Province overprinted several previously cratonised tectonic elements. By themselves, geochemical data from the igneous rocks apparently do not (and probably should not be expected to) unambiguously discriminate between possible tectonic settings because of ubiquitous sialic crustal contamination signatures. The best that can be inferred from available data is that most, if not all, silicic to intermediate rocks were derived from highly evolved sialic crust; the mafic rocks could represent lithospheric mantle-derived magmas variably modified by crustal contamination.

Trends of late Palaeozoic extensional features in northeastern Queensland, especially dyke swarms and composite subsidence structures, are subparallel to the present coastline and continental margin. They would be subparallel to the trend of a subduction zone if any such had existed contemporaneously. In the compressional part(s) of an active convergent regime, extensional features should tend to be perpendicular to the subduction zone. These relationships, taken in conjunction with the inferred lack of appreciable crustal thickening, do not support an interpretation of the tectonic setting as having been an intra-Andean-type arc.

Location in an extending back-arc environment, or in and on an oversteepened lithosphere wedge above a shallowing subduction zone (cf. Platt, 1986; Krueger & Jones, 1989), are likewise not supported because of complete lack of evidence for any other subduction-related elements of appropriate age within or east of the region. However, in this context it should be noted that a good case can be made for late Palaeozoic subduction in the New England Fold Belt farther south, and this scenario can possibly be extended as far north as the Broad Sound–Rockhampton area (cf. Murray & others, 1987). However, rather than postulating some contrived relationship between subduction and the late Palaeozoic magmatism of northeastern Queensland, an alternative tectonic scenario is tentatively offered here.

During the Carboniferous and Permian, Australia and its present offshore continental extensions lay at the trailing edge of Gondwanaland as it changed longitude rapidly towards and over the South rotational and magnetic poles. Margins of the supercontinent would have been subjected to tensional stresses as part of an adjustment to decreased surficial curvature of a non-spherical Earth at high latitudes. While such stresses need not have had any major consequences in their own right, they would at the least introduce an element of inherent instability and tendency to extensional "membrane tectonics" (Oxburgh & Turcotte, 1974 cf. Oversby 1988, in prep) which might either have initiated or been exacerbated (or a combination of both) by ascent of thermal and asthenospheric plumes into the lower crust. Such "hotspots" are believed to have been responsible for the observed active type (as distinct from passive—e.g. Sengor & Burke, 1978; Turcotte & Emerman, 1983) subsidence structures which mostly propogated northwards, consistent with the southward movement of Gondwanaland.

As suggested by Mackenzie (1987a), the extensive and voluminous Carboniferous magmatism of northeastern Queensland probably reflected a large input of mantle-derived mafic magma into (or underplating of) the lower crust. The concomitant thermal input might have led to extensive melting and ductile deformation in the lower crust, and a marked structural decoupling from brittle upper crust with little opportunity for mafic magmas to reach high levels. The high thermal flux might also have caused partial melting of high-level hydrous rocks, unlikely to have been significantly depleted in low-melting temperature fraction by preceding events, resulting in predominantly explosive extrusive activity. High-level silicic magma chambers were capable of attaining large size, with associated fracture/intrusion systems being extensive, but commonly rather diffuse. In comparison, Permian mantle input in the Georgetown Region at least was possibly less voluminous than that of the Carboniferous, but more readily transmitted to high crustal levels via well-defined brittle fracture systems, which could have penetrated to deep levels because of supression or elimination of a marked brittle-ductile transition (cf. Mackenzie, 1987a). There would have been limited opportunity for crustal melting relative to the Carboniferous phase, and possibly decreased availability of hydrous low-melting point upper crustal component from which volatile-rich anatectic magmas could be generated. Alternatively, Permian underplating may have ocurred at deeper levels and partially melted higher-grade, inherently relatively anhydrous (e.g. granulitic) rocks.

The late Palaeozoic magmatism of northeastern Queensland may have been the principal expression of extensional activity, which progressively intensified and focussed eastwards through Mesozoic time, although stopping short of rifting. However, a climax was reached during the early Tertiary with initiation of seafloor spreading in what was to expand into the Coral Sea. The rather enigmatic high-grade Barnard Metamorphics in the easternmost Hodgkinson Province might represent a metamorphic core complex which was uplifted and exposed, along with late Palaeozoic batholiths in immediately adjacent areas whose extrusive superstructures have been removed, as extensional tectonism moved towards its Tertiary climax.

Assuming the fundamental validity of a subduction model for the late Palaeozoic of the New England Fold Belt, the scenario developed above implies separation of the site of northeastern Queensland from the remainder of eastern Australia by a major transform zone.

Mineral Deposits

Known and probable late Palaeozoic mineral deposits in the Georgetown Region (Bain & Withnall, 1984) have most recently been discussed briefly as part of a review by Bain & others (1990).

A number of non-geological factors (mainly "floating" of the price of gold, development of the Ranger uranium deposit in the Northern Territory, and collapse of the international tin market), have combined to result in gold currently having the greatest economic potential of the several commodities ocurring in the Georgetown region (cf. Champion & Mackenzie, 1994). The significant breccia pipe gold deposit at Kidston lies within the diffuse northern periphery of the Lochaber centred igneous structure. Main-stage brecciation and gold minerlisation were preceded by stockwork molybdenum mineralisation, suggesting an affinity with porphyry-type copper–molybdenum deposits. The currently subeconomic Christmas Hill deposit, adjacent to the northern periphery of the Bagstowe Centred Igneous Structure, is probably broadly similar.

The subeconomic Phyllis May (southern Dismal Creek area) and Mount Turner porphyry-type copper–molybdenum deposits occur in extensive areas of hydrothermally altered Proterozoic granitoids cut by irregular small plutons of Mount Darcy Microgranodiorite, dykes and plugs of rhyolite, and pipes of intrusive rudite. Mineralisation consists of disseminated and fracture-filling chalcopyrite, molybdenite, and pyrite; the Mount Turner occurrence has a presumably related system of radiating galena (argentiferous)–sphalerite veins peripheral to it.

Many small uranium–fluorine–molybdenum deposits are known in the Georgetown region, but only occurrences associated with the eastern Maureen and northwestern Newcastle Range Volcanic Groups have any potential significance. The deposits are stratabound concentrations, most commonly in Gilberton Formation subjacent to the extrusive sequences, and void (including breccia interstices) fillings within fault zones marginal and adjacent to extrusive sequences. The Maureen deposit contains colourless to purple fluorite, iron oxides/hydroxides, hydrated molybdenum oxides, and uranium phosphates, oxides, arsenates, and sulphates.

Minor vein-greisen deposits with variable proportions of tin, tungsten, copper, molybdenum, and bismuth minerals occur in or close to the Elizabeth Creek, Purkin, and Lochaber granites, Yataga Granodiorite, and Eva Creek Microgranite. Alluvial–colluvial cassiterite derived from Elizabeth Creek granite and associates has been extensively exploited only in the extreme northeastern Georgetown Region as part of an extensive field centred to the north of Mount Surprise.

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Appendix: Derivations of names, and locations of type and/or other sections, for new and revised Late Palaeozoic stratigraphic units of the Georgetown region discussed in this report

See main text for discussions of lithologies, thicknesses, and other details.

The **Gilberton Formation** was named by White (1959a) from "Gilberton" homestead (7659–809675). By definition, rocks assigned to the formation contain only subsidiary and/or impersistant volcaniclastic material.

The holostratotype area of the Gilberton Formation (White, 1959a) lies south of the Gilbert River opposite "Gilberton". A lectostratotype section between the Percy River and Granite Creek extends from the base of the formation (on Cobbold Metadolerite in Daniel Creek Formation) at 7659–811779 to its preserved top (beneath Agate Creek Volcanic Group) at 7659–835807.

A thickness of 875 m in the lectostratotype area has been derived by taking the average dip to be uniformly 15° northeast, and making allowance for some apparent repetition by faults near the top of the section. The dip is realistic, but the thickness seems excessive in view of the size of the outcrop area and proximity of what seem to be upper parts of the unit to its northern outcrop limit. It is suspected that structure along the the section is more intricate than apparent from outcrop data.

Primary volcanic components of the Gilberton Formation occur mainly in two members. Both of these are made up of sparsely porphyritic (and extensively altered) greenish-grey andesites. The **Mamberra** Andesite Member is named from the Parish of Mamberra, County of Gilbert; it occurs in Gilberton Formation beneath the eastern Wirra Volcanic Subgroup (Newcastle Range Volcanic Group). Mamberra Andesite's type section occurs to the east of Chinaman Creek 9 km northeast of "Beverly Hills", between 7660–127267 and 7660–126267. The **Spyglass Andesite Member** is named from Spyglass Creek, a southern tributary of Clark Creek which it joins at 7561–453907, 4.8 km northwest of "Mount Turner" homestead; this member occurs in the formation subjacent to eastern Dismal Creek Dacite. The member's type section extends from 7561–411831 to 7561–406837, approximately 3 km north-northeast of Mount Darcy.

Newcastle Range Volcanic Group replaces the previous Newcastle Range Volcanics (formation) of White (1959a), Branch (1966), and others. The name derives from the Newcastle Range.

The **Wirra Volcanic Subgroup** is named from "Wirra Wirra" homestead, 15 km east-southeast of Forsayth.

The **Bousey Rhyolite** is named from Mount Bousey, slightly more than 25 km southeast of Forsayth.

Branch (1966) correlated rocks now assigned to Bousey Rhyolite with his "middle composite member".

The holostratotype section of Bousey Rhyolite is unavoidably composite because of structural complications. The lower part of the section extends from a transitional lower contact with Gilberton Formation at 7660–873266 to a probable minor fault at 7660–877275. The section continues from the fault to 7660–873281. The upper part of the holostratotype section extends upstream along the Robertson River from 7660–942306, believed to be at an equivalent stratigraphic level to 7660–873281, to a sharply discordant upper contact with Jinker Creek Rhyolite at 7660–983303. A hypostratotype section in lower Bousey Rhyolite extends upstream along the Robertson River from 7660–881265 to 7660–903290, then from 7660–914297 to 7660–942306.

The thickness of Bousey Rhyolite in its holostratotype area is 900 m.

The **Jinker Creek Rhyolite** is named from Jinker Creek, a northern tributary of the Robertson River which it joins at 7660–922302. Branch (1966) correlated Jinker Creek Rhyolite with his "upper welded tuff member".

The holostratotype section of Jinker Creek Rhyolite extends from its sharply discordant lower contact with Bousey Rhyolite at 7660–983303 upstream along the Robertson River to the core of the basinal structure which it occupies, and its upper limit of exposure, at 7660–021326. A more accessible hypostratotype section extends from the northern exposures of the formation at 7660–006379 to 7660–042344, then from 7660–039322 to 7660–021314. The original top of the formation is not preserved.

The **Kungaree Volcanic Subgroup** is named from the Parish of Kungaree.

The **Shamrock Rhyolite** is named from Shamrock No. 1 Pastoral Block, which lies 15 km northeast of Georgetown. Branch (1966) correlated stratigraphically low rocks in the central isthmus of the Newcastle Range with his "middle composite member", although he evidently (personal communication via field notes) did not encounter Shamrock Rhyolite as such.

The holostratotype section of Shamrock Rhyolite is placed in the western occurrence of the formation, despite a moderate degree of structural complexity. The section extends from a faulted contact with uppermost Daniel Creek Formation (Etheridge Group) at 7661–802917, to a sharp and apparently concordant upper contact with volcaniclastic rocks in Corkscrew Rhyolite at 7661–811910. Much of the Shamrock Rhyolite appears to be repeated by a high-angle fault and dyke zone at 7661–807913. The section also contains numerous concordant sheets of intrusive rhyolite, especially in its higher part, as well as sporadic tongues of Dagworth Andesite. A parastratotype section in the unfaulted eastern part of Shamrock Rhyolite extends upstream along a western tributary of Duckholes Creek, from a lower contact with Gilberton Formation at 7661–953841 to an upper contact with Corkscrew Rhyolite at 7661–951842.

The thickness of Shamrock Rhyolite in its holostratotype section is 250 m.

The **Routh Dacite** is named from Routh Creek, which joins Thornborough Creek at 7661–871756, 18 km east of Georgetown. Branch (1966) equated rocks now assigned to Routh Dacite with his "middle composite member".

The holostratotype section of the Routh Dacite lies on the western side of the central isthmus about 4 km north of the Gulf Developmental Road. The section extends from a sharp and probably concordant contact with Shamrock Rhyolite at 7661–844812 to a sharp, steep, and discordant, but apparently unfaulted, contact with Corkscrew rhyolite at 7661–861803. Hypostratotype sections, in which the lower parts of the formation are obscured by faulting, extend from 7661–846767 to Corkscrew Rhyolite at 7661–848762, and from 7661–865750 to Kitchen Creek Rhyolite at 7661–865747.

The thickness of Routh Dacite in its holostratotype section is 1000 m.

The **Corkscrew Rhyolite** is named from Corkscrew Ridge, which occurs on the western side of the central Newcastle Range isthmus, 10 km south of the Gulf Developmental Road. Branch (1966) assigned the Corkscrew Rhyolite cropping out in the Gulf Developmental Road area to his "middle composite member".

The holostratotype section of the Corkscrew Rhyolite occurs on the western side of the central isthmus about 20 km north of the Gulf Developmental Road, and extends from a sharply concordant lower contact with Shamrock Rhyolite at 7661–826986 to a sharp but slightly discordant upper contact with Brodies Gap Rhyolite at 7661–858983. Hypostratotype sections extend from 7661–839687 to 7661–849689, and from 7661–888755 to 7661–889757. The latter hypostratotype section makes up the type **Thornborough Andesite Member**; this member is named from Thornborough Waterhole (7661–830746), at the debouchement of Thornborough Creek from the western side of the central Newcastle Range isthmus, 2 km south of the Gulf Developmental Road 14 km east of Georgetown.

The **Kitchen Creek Rhyolite** is named from Kitchen Creek, which joins Thornborough Creek at 7661–815738, 12 km east of Georgetown. Rocks assigned to the formation occur in an area of 43 km^2 in the central part of the Newcastle Range isthmus south of the Gulf Developmental Road. They also occur in fault blocks totalling 7 km^2 in the vicinity of the road, on the the western side of the isthmus.

Branch (1966) equated rocks now assigned to Kitchen Creek Rhyoltie to both his "middle composite member"and "upper welded tuff member".

The holostratotype section of the Kitchen Creek Rhyolite extends from a sharp and apparently concordant lower contact with Corkscrew Rhyolite lava at 7661–906726 to the axis of the trough-like structure which it occupies, and its upper limit of exposure, at 7661–882705. The original top of the Formation is not preserved.

The **Namarrong Volcanic Subgroup** is named from Namarrong Pastoral Holding.

The **Twin Dams Andesite** is named from the two interconnected stock water dams at 7662–854089 and 7662–854090, 40 km north-northeast of Georgetown.

The holostratotypes section of the formation extends from a sharp and apparently concordant lower contact with Gilberton Formation at 7662–852098 to a near-concordant upper contact with a local lens of volcaniclastic arenite in the lowermost Shamrock Rhyolite at 7662–859098.

The **Dagworth Andesite** is named from Dagworth Creek, which enters Cattle Creek at 7661–840233, 2 km north-northeast of the confluence of the latter with the Einasleigh River.

The holostratotype section of the Dagworth Andesite extends from a sharp and probably concordant lower contact with welded rhyolitic ignimbrite assigned to the Shamrock Rhyolite at 7661– 865098 to an upper contact with Corkscrew Rhyolite welded ignimbrite at 7662–877098. This upper contact also appears to be sharp and concordant. Sporadic intrusive rhyolites in the section probably mark zones of dilation, but not otherwise appreciable structural disruption.

Brodies Gap Rhyolite is named from Brodies Gap, a pass through the Newcastle Range in the area of transition between the central isthmus and northern lobe, about 35 km north-northeast of Georgetown.

The holostratotype section of the Brodies Gap Rhyolite is located in the central isthmus of the range. It extends from a locally sharp but slightly discordant lower contact with volcaniclastic rocks in Corkscrew Rhyolite at 7661–841020, to the limit of exposure of the formation in the core of the trough-like structure at 7661–890027. A parastratotype section occurs between a sharp near-concordant base on Dagworth Andesite at 7662–060117 to the local limit of exposure at 7662–028110. Hypostratotype sections extend from 7661–961010 to 7661–959012, then from 7661–953016 to 7661–907023, and also from 7661–930122 to 7661–942084.

Cumbana Rhyolite is named from the now-abandoned "Cumbana" homestead (7761–857042), about 60 km northeast of Georgetown. The name is a modification of "Cumbana Rhyolite Porphyry" (White, 1959b).

The holostratotype area of the Cumbana Rhyolite is located about 3 km ("2 miles") southwest of "Cumbana" (White, 1959b), in a structurally rather complex area. A lectostratotype section of the formation extends from 7661–122015, at the edge of Cainozoic soil and colluvium overlying a fault and dyke zone, to the upper limit of exposure at 7661–143025. The section probably crosses a fault at 7661–124018, which may cut out part of the sequence.

The **Eveleigh Volcanic Subgroup** is named from "Eveleigh" homestead (7661–139825), 45 km east-northeast of Georgetown.

The **Yellow Jacket Rhyolite** is named from Yellow Jacket Creek, which enters the Einasleigh River at 7761–908669. The formation makes up the bulk of Branch's (1966) "middle composite member".

The holostrototype section of Yellow Jacket Rhyolite extends along Yellow Jacket Creek and an unnamed southwestern tributory from the base of the formation at 7761–887364 to its top at 7761–875642. In this section, the formation lies with slight angular discordance on Gilberton Formation. The upper contact with Beril Peak Rhyolite is sharp, and appears to be concordant. A hypostratotype of Yellow Jacket Rhyolite occurs along Pint Pot Creek from 7761–885668 to 7761–852674. This section is interrupted by a concordant sheet of intrusive microgranite between 7761–884666 and 7761–880665. The upper part of the section includes a minor development of the **Pint Pot Andesite Member** between 7761–861673 and 7761–860673 (named from Pint Pot Creek), which is not seen in the holostratotype section.

The main development, and type section, of Pint Pot andesite extends from 7661–092747 to 7661–101746 in the northwestern part of the eastern lobe of the Newcastle Range.

The **Beril Peak Rhyolite** is named from Beril Peak, whose summit is at 7761–848693 in the central-eastern part of the eastern lobe of the Newcastle Range. The formation was included in the "upper welded tuff member" of Branch (1966).

The holostratotype section of the Beril Peak Rhyolite carries on from that of the Yellow Jacket Rhyolite along an un-named southern tributary of Yellow Jacket Creek. The base of the Beril Peak Rhyolite lies sharply and apparently concordantly on Yellow Jacket Rhyolite at 7761–875642. The top of the formation is at 7761–870638. Beril Peak Rhyolite is overlain, generally sharply and concordantly, by Mosaic Gully Rhyolite, although locally the contact is gradational. In such cases, the contact is placed at the level where quartz and feldspar crystals averaging up to 3 mm in maximum dimension become and remain ubiquitous in the rock.

The **Mosaic Gully Rhyolite** is named from Mosaic Gully, which enters the Einasleigh River at 7761–899682. Mosaic Gully Rhyolite formed part of the "upper welded tuff member" of Branch (1966).

The holostrototype section of the Mosaic Gully Rhyolite extends along Shrimp Creek and one of its un-named western tributaries. It extends from a sharp and apparently concordant lower contact with Beril Peak Rhyolite at 7761–862607 to a slightly discordant upper contact with overlying Shrimp Creek Rhyolite at 7661–164612.

The **Canyon Dacite** is named from Canyon Pastoral Holding. The holostratotype section of Canyon Dacite is in two parts, both of which are along un-named tributaries of McMillan Creek. The section in the lower part of the formation extends from a sharp and apparently concordant contact with Mosaic Gully Rhyolite at 7661–059652 to 7661–065651. From this point, the section is offset for 2.2 km southwest along the contact to 7661–050635. The section embracing the upper part of the formation extends from here, across a syncline, to the base of a 30 m thick intrusive microgranodiorite sheet at 7661–054625. The microgranodiorite has been inserted at the discordant upper contact of the Canyon Dacite with Shrimp Creek Rhyolite.

The **Shrimp Creek Rhyolite** is named from Shrimp Creek, which joins the Einasleigh River at 7761–905632. Branch (1966) assigned the formation to his "upper welded tuff member".

The holostratotype section of Shrimp Creek Rhyolite continues on from that of the Mosaic Gully Rhyolite. The section extends along an un-named western tributary of Shrimp Creek from a slightly discordant lower contact with Mosaic Gully Rhyolite at 7661–164612, to the unconformable base of Mesozoic cover rocks (Jurassic to Lower Cretaceous Coffin Hill Member of the Gilbert River Formation) at 7661–136607. A hypostratotype of the formation occurs between 7661–054624 and 7661–070595.

Tenavute Microgranite is named from "Tenavute" homestead (7660–859453), about 12 km east-northeast of Forsayth.

The holostratotype section of the Tenavute Microgranite extends from a faulted contact with the lower welded rhyolitic ignimbrite sheet of the Bousey Rhyolite at 7660–907474 to the limit of exposure at 7660–952427. There is a gap in the section, occupied by MacCallor Microgranodiorite, between 7660–943452 and 7660–949441. By definition, Tenavute Microgranite is restricted to the southern lobe of the Newcastle Range.

Mount Departure Microgranite is named from Mount Departure (7662–024155), in the northeastern part of the northern lobe of the Newcastle Range, 50 km northeast of Georgetown. Branch (1966) did not distinguish the unit in its own right.

The holostratotype of Mount Departure Microgranite lies on the southwestern bank of Eight Mile Waterhole (Einasleigh River, about 50 km northeast of Georgetown), between 7662–987201 and 7662–988200.

Talaroo Microgranite is named from Talaroo Pastoral Holding. Branch (1966) did not differentiate Talaroo Microgranite as a distinct unit.

The holostratotype section of Talaroo Microgranite lies between 7661–819879 and 7661–832878, in the eastern one of two outcrop areas of the unit.

Caterpillar Microgranite is named from the Caterpillar Hills (or Range). These hills make up an undulating narrow range extending from the eastern side of the Einasleigh River opposite the Einasleigh copper mine for 8 km north to Mount "Alder" (Adler), and then for 3 km west-northwest to rejoin the river. Branch (1966) did not differentiate Caterpillar Microgranite as a distinct unit.

The holostratotype section of the Caterpillar Microgranite crosses the highest part of the Caterpillar Hills between 7761–942550 and 7761–951545.

MacCallor Microgranodiorite is named from the Parish of MacCallor. Branch (1966) did not differentiate the unit.

The holostratotype section of MacCallor Microgranodiorite extends along the northern bank of the Robertson River from a discordant intrusive contact with the middle welded ignimbrite sheet in the Bousey Rhyolite (Wirra subgroup of the Newcastle Range Volcanic Group) at 7660–901289 to a faulted contact with the lower sheet of the same formation at 7660–913301.

Mopata Microgranite is named from Mopata Pastoral Holding. Branch (1966) did not differentiate Mopata Microgranite as a distinct unit.

The holostratotype area of Mopata Microgranite occurs between the edge of an outcrop area of the unit at 7660–040327, and the centre of the area about 70 m to the north. A hypostratotype section, embracing disconnected outcrop areas separated by Jinker Creek Rhyolite (Wirra subgroup of the Newcastle Range Volcanic Group), extends along the northern bank of the Robertson River from 7660–043320, downstream (west) to 7660–020326.

Lubrina Granite is named from Lubrina Pastoral Blocks. Branch (1966) did not differentiate Lubrina Granite as a distinct unit.

The holostratotype section of the Lubrina Granite extends from 7662–865142 to 7662–858133.

Elizabeth Creek Granite was originally named from the Elizabeth Creek in the Georgetown Region which joins an anabranch of the Einasleigh River at 7662–043156, 55 km northeast of Georgetown (White, 1959b).

The holostratotype section of this Elizabeth Creek Granite *sensu stricto* occurs "along Elizabeth Creek near Cumbana homestead" (White, 1959c, p. 26). This is 3 km east of the boundary of the Georgetown 1:250 000 Sheet area. A hypostatotype herein defined in the Mount Noble Stock extends along the Einasleigh River from 7661–066036 to 7662–072093.

Elsewhere in northeastern Queensland, the name Elizabeth Creek Granite should be regarded as informal, to be progressively replaced by properly constituted local units.

The **Maureen Volcanic Group** was named (originally as a unit of formation rank, and including sporadically underlying Gilberton Formation as now defined) by Mackenzie (1980) from the Maureen uranium prospect, at the southeastern edge of the unit's outcrop area and 35 km north-northwest of Georgetown. Previously, the group (along with the local Gilberton Formation) was included in the Galloway Volcanics (Branch, 1966; Smart & Bain, 1977).

The name of the **Ironhurst Formation** is taken from Ironhurst Pastoral Holding.

The holostratotype section of the formation is in the Maureen prospect area. It extends along Fiery Creek from a sharp, but concordant, lower contact with Gilberton Formation at 7561–566080, to a similar upper contact with Puranga Rhyolite at 7562–532117. There is a gap in the section, occupied by intrusive volcaniclastic rudite, between 7562–557086 and 7562–556086. The **Ant Hill Andesite Member** is named from Ant Hill Creek, which joins the Etheridge River at 7561–408991. In the holostratotype of the Ironhurst Formation, the Ant Hill Andesite occupies the interval between 7561–557074 and 7561–555076. The **Wombleaila Rhyolite Member** is named from Wombleaila Pastoral Block. In the holostratotype of the Ironhurst Formation, the interval from 7561–515353 to 7562–545082 is occupied by the Wombleaila member.

Puranga Rhyolite is named from the County of Puranga.

The holostratotype section of the lower part of the formation extends from 7562–544084 to 7562–534082, while that of the upper part lies between 7561–507065 and 7561–475082.

The **Dismal Creek Dacite** is named from Dismal Creek, in the upper reaches of which the formation crops out. Previously, the Dismal Creek Dacite (along with underlying Gilberton Formation) was assigned to the Galloway Volcanics (Branch, 1966). Mackenzie (1980) named the entire sequence in the area, including rocks now assigned to the Gilberton formation, the "Dismal Creek Volcanics". Although of limited thickness and extent as preserved, and thus only given formation ranking, Dismal Creek Dacite is regarded as a self-contained stratigraphic entity, occurring in a small ignimbrite-related structure of its own. Accordingly, the formation is not assigned to either of the nearby Maureen or Cumberland Range groups.

The holostratotype section of the Dismal Creek Dacite is in two parts: from 7561–414857 to 7561–412856, and from 7561–403849 to 7561–397847. A hypostratotype section extends from the base of the unit at 7561–387889 to the upper limit of exposure at 7561–379886. The **Huonfels Rhyolite Member** is named from Huonfels Pastoral Holding. In the hypostratotype section of the Dismal Creek Dacite, the Huonfels Rhyolite Member extends from the base at 7561–387889 to 7561–385889.

The **Cumberland Range Volcanic Group** has been named from the Cumberland Range, which lies 20 km southwest of Georgetown. The group name replaces the previous Cumberland Range Volcanics of White (1959a) and Branch (1966).

The **Scrubby Creek Rhyolite** is named from Scrubby Creek, which enters the Gilbert River at 7561–428591.

The holostratotype section of the formation extends from 7561–452683 to 7561–462640, and then to 7561–495621. A gap between 7561–488625 and 7561–492623 is occupied by brecciated Proterozoic basement rocks (Lane Creek Formation). A hypostratotype of the Scrubby Creek Rhyolite lies between 7561–511657 and 7561–526650.

The name of the **Namul Dacite** derives from Namul Pastoral Holding.

The holostratotype of the Namual Dacite extends from 7561–526650 to 7561–532649, via 7561–530651. A hypostratotype section lies between 7561–490608 and 7561–506610.

Marquis Rhyolite is named from Marquis Hill (7660–657448), 11 km southeast of the outcrops of the unit. This is because there are no closer geographic localities with available names for stratigraphic use. Branch (1966) did not differentiate the Marquis Rhyolite as a unit in its own right.

The holostratotype of the Marquis Rhyolite is in two parts. That part embracing the un-named rhyolitic ignimbrite subunit (Cv_1) extends from 7560–582517 to 7560–581513. The section in the lava (Cv_2) extends from 7560–568527 to 7560–572525.

The **Butlers Volcanic Group** derives its name from Butlers Knob (7759–895949), which lies 50 km northeast of Gilberton and 60 km south-southwest of Einasleigh. The group name replaces the previous Butlers Igneous Complex of White (1959b) and Butlers Volcanics of Branch (1966).

The **Ballynure Rhyolite** is named from "Ballynure" homestead (7659–155894), 8 km southwest of Butlers Knob.

The holostratotype section of the Ballynure Rhyolite extends from the base of the formation at 7659–152907, via 7659–154920, to 7659–156919.

The **Edmonds Creek Rhyolite** is named from Edmonds Creek, which joins the Oak River at 7759–888168.

The holostratotype section of the formation extends from its base at 7759–842926 to its contact with McLennons Creek Rhyolite at 7759–849936. A hypostratotype extends along Sues Creek between 7760–902975 and 7760–900975.

McLennons Creek Rhyolite is named from McLennons Creek which joins the Copperfield River at 7760–954031. McLennons Creek Rhyolite was the main constituent of Branch's (1966) representative section of his Butlers Volcanics.

The holostratotype section of the McLennons Creek Rhyolite extends from its base at 7760–858999 to the local limit of exposure at 7760–861993. A hypostratotype section extends up Sues Creek from the base of the formation on Edmonds Creek Rhyolite at 7760–900975 to a probably locally near-concordant upper contact with intrusive Sues Creek Microgranite at 7760–

888973. This hypostratotype section embraces only the lower part of the formation.

The **Paddock Creek Formation** is named from Paddock Creek, which joins the Styx River at 7659–124772. Branch (1966) considered the northern outcrop area of the formation, as well as the rocks now assigned to it adjacent to the Mount Rous dyke, to mainly represent "volcanic necks". He also considered that rocks now included in the Paddock Creek Formation in the central part of the Bagstowe structure were intrusive ignimbrites in a series of partial ring-dykes (his "Grey Ring Dykes").

The holostratotype of the Paddock Creek Formation extends from the base of the unit lying unconformably on basement rocks at 7659–133798 to the local limit of exposure at 7659–108792. The section crosses an andesite dyke at 7659–115794, but no appreciable displacement is involved.

A hypostratotype section occurs in the central part of the Bagstowe structure.

Culba Granodiorite has been named from the Parish of Culba, County of Percy (Withnall & Bain, 1980).

The holostratotype of the Culba Granodiorite occurs in the southern part of the main occurrence of the unit, along Pinnacle Creek and up one of its western tributaries (Withnall & Bain, 1980, p. 25). A hypostratotype to the southeast is here nominated to extend from 7759–951691 to 7759–945696.

Cook Microgranite is named from the Pastoral District of Cook. Even though the unit makes up the Castle Hill Dyke (Branch, 1966), the name "Castle Hill" has not been applied because of its use in the Townsville area.

The holostratotype section of the Cook Microgranite extends across Castle Hill from 7659–144610 to 7659–145611. A more accessible hypostratotype is located where the unit is crossed by the "Glenmore" to Gilbert River track between 7659–136626 and 7659–135623.

Mount Rous Microgranodiorite is named from Mount Rous (7659–055598), 13 km south west of "Glenmore".

The holostratotype section of Mount Rous Microgranodiorite is along the Gilbert River, between 7659–025658 and 7659–026659. A hypostratotype section extends upstream (north-northeast) along the river from 7659–092601 to 7659–100612.

Cranky Creek Granodiorite is named from Cranky Creek, a southern tributary of Yarraman Creek which it joins at 7759–981675.

The holostratotype section of the Cranky Creek Granodiorite extends from 7759–945696 into the central area of the Four Mile Creek Stock at 7759–927704, and then to 7759–917725. The southernmost 0.7 km of the section is interrupted by at least one dyke of Conical Knob Microgranite.

Conical Knob Microgranite is named from Conical Knob or Conical Hill (7659–062716), 8 km west-northwest of "Glenmore".

The holostratotype section of the Conical Knob Microgranite lies across its northwestern outcrop area, along the Styx River from 7659–144765 to 7659–132770. A hypostratotype section extends across the southeastern area from 7759–890659 to 7759–885665.

Old Man Rhyolite is named from Old Man Creek, which joins Castle Hill Creek at 7659–117689, 2.5 km west-southwest of "Glenmore".

The holostratotype section of Old Man Rhyolite is subparallel to the northeastern bank of an eastern tributary of Castle Hill Creek, between 7759–857653 and 7759–855661. A discontinuous hypostratotype section extends along Castle Hill Creek from 7659–145651 to 7659–142658.

Black Cap Diorite is named from Black Cap, a hill at 7659–128624, 7.5 km south-southwest of "Glenmore".

The holostratotype of the Black Cap Diorite lies along House Creek, a southern tributary of the Styx River, from 7659–149752 to 7659–152752, and then up a gully to 7759–847753.

The **Bagstowe Granite** is named from "Bagstowe" homestead (7659–154746), 5 km north-northeast of "Glenmore".

The holostratotype section of the granite occurs in its main outcrop area. The section extends along Gorge Creek from 7759–849737 to 7759–862739, and then along a northern tributary to 7759–886736. A more accessible hypostratotype section crosses the western apophyse of the unit between 7659–151706 and 7759–848713, along the "Glenmore" to "Bagstowe" track.

Eastdale Granite is named from the Parish of Eastdale, County of Lyndhurst.

The holostratotype section of the Eastdale Granite extends from 7759–917725 to 7759–902733. A more accessible, but discontinuous, hypostratotype section extends along the Copperfield River between 7759–027860 and 7759–010876.

The name of the **Lochaber Granite** is derived from Lochaber (wolfram) Mine (White, 1959b; Branch, 1966), at 7759–005894, 20 km south-southwest of Kidston.

The holostratotype area of the Lochaber Granite is "in the Copperfield River south of the Lochaber Mine" (White, 1959b, p. 27). This area is now in the upper reaches of Kidston Gold Mine's water supply reservoir. A neostratotype is thus nominated as being on the banks of the reservoir opposite the submerged holostratotype.

Sues Creek Microgranite is named from Sues Creek, which joins Christmas Hill Creek at 7760–937982, 15 km southwest of Kidston.

The holostratotype section of Sues Creek Microgranite extends along a western tributary of Sues Creek from 7760–888973 to 7760–898973. A discontinuous hypostratotype section extends along the Copperfield River between 7759–024865 and 7759–010876.

Noel Micromonzonite is named from Noel Pastoral Holding.

The holostratotype section of the Noel Micromonzonite extends from 7760–861979 to 7760–870979.

The **Agate Creek Volcanic Group** is named from Agate Creek, which drains the main Agate Pocket outcrop area, and flows into the Robertson River at 7560–558156. It was originally defined as Agate Creek Volcanics (formation) by White (1959b) and Branch (1966).

Big Surprise Tuff is named from Big Surprise silver-lead prospect at 7659–758961, about 700 m northeast of the northeastern edge of the main outcrop area of the Agate Creek Volcanic Group sequence.

The holostratotype section of Big Surprise Tuff extends from a lower contact with Robin Hood Granodiorite at 7660–724979 to the formation's slightly discordant upper contact with Thunder Egg Rhyolite at 7660–723977. Hypostratotype sections of Big Surprise Tuff occur between the Percy River and Granite Creek (7659–850806 to 7659–854814), and in the outcrop area 15 km northeast of Agate Pocket (7660–642132 to 7660–635130).

Talaveras Rhyolite is named from Talaveras (or Talavera, or Garden) Spring, which lies at 7659–794744, 7 km north-northwest of "Gilberton" homestead.

The holostratotype section of the Talaveras Rhyolite extends from a probably near-concordant lower contact with a thin development of Big Surprise Tuff at 7659–837811 to the base of discordantly overlying Black Soil Andesite at 7659–837814.

Black Soil Andesite is named from Black Soil agate fossicking area in Agate Pocket.

The holostratotype section of the Black Soil Andesite extends from a lower contact with Robin Hood Granodiorite at 7659–700931 to the edge of Cainozoic alluvium on the southwestern bank of Agate Creek at 7659–704942, and then from the northeastern limit of the alluvium at 7659–713946 to the current level of erosion on the summit of Crystal Hill (7659–732944). The original stratigraphic top of the formation is nowhere preserved in Agate Pocket, and there are no uninterrupted sections from the base of the unit to its limit of exposure. However, a hypostratotype section of Black Soil Andesite in the northeasternmost part of the main outcrop area extends from a slightly discordant lower contact with Big Surprise Tuff at 7659–764941 to a similar upper contact with Thunder Egg Rhyolite at 7659–763940.

Thunder Egg Rhyolite is named for its content of "thunder eggs"—large spherulites containing the chalcedony and/or agate in fillings of crudely stellate syneresis cavities.

The holostratotype section of Thunder Egg Rhyolite extends from a lower slightly discordant contact with a thin development of Black Soil Andesite at 7659–727969 to a faulted contact with the same formation at 7659–724963. Thunder Egg Rhyolite probably includes some undifferentiated very high level intrusive rocks.

Connie May Dolerite is named from the former Connie May agate prospect, located at 7659–771907 about 1.5 km east of outcrops of the dolerite. Connie May Dolerite was not differentiated by Branch (1966).

The holostratotype section of Connie May Dolerite extends from 7659–748912 to 7659–751907.

Purkin Granite was named from the Parish of Purkin, County of Percy (Withnall & Bain, 1980). Branch (1966) used the name Elizabeth Creek Granite for the rocks. Smart (1973) used the name Purkin Igneous Complex for the outer part of the western stock.

The holostratotype section of the Purkin Granite occurs along the Gilbert River (Withnall & Bain, 1980, p. 26) in the eastern outcrop area of the unit. A hypostratotype section in the western outcrop area is here nominated to extend along Fish Hole Creek between 7659–876462 and 7659–879420.

The **Yataga Granodiorite** has been named from the Parish of Yataga, County of Einasleigh (Withnall & others, 1976).

The holostratotype section of the Yataga Granodiorite (Withnall & others, 1976, p. 3) is entirely within subunit Pgy_2. A hypostratotype section embracing this and the other subunits is here nominated to extend along Fiery and Dixon creeks from 7661–712022 to 7661–743029. In this section, Pgy_2 occurs between 7661–712022 and 7661–731019, and again between 7661–733021 and 7661–736027; Pgy_1 occurs between 7661–731019 and 7661–733021; Pgy_3 occurs between 7661–736027 and 7661–737928; and Pgy_4 occurs between 7661–737928 and 7661–743029.