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Geology of the
Mount Koonya area

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Summary

Several residents in the catchment of Cascade Rivulet, near Koonya on the Tasman Peninsula, utilise spring water that is derived from areas of State Forest at Mount Koonya and Mount Clark. Two geological reports (Sloane, 1987; Weldon, 1991) have dealt with the potential effects of forestry operations on the springs. These investigations related the common occurrence of seepages near the lower boundary of a sill or sheet of Jurassic dolerite where it intrudes a succession of Triassic sandstone and mudstone. Some seepages were noted to disappear downslope beneath dolerite talus deposits and reappear at lower elevations.

The current work has enabled a stratigraphic subdivision of the Triassic rocks that has assisted in the structural interpretation of the area. The oldest Upper Parmeener Supergroup rocks are of Early Triassic age and consist predominantly of cross-bedded quartz sandstone (Rqph) and subordinate beds and thin intervals of siltstone and mudstone, some of which are mappable (Rqpc) at Norfolk Bay. The sandstone is well exposed at coastal sections and extends inland to form the foothills of the Mount Koonya area.

The overlying unit (Rqm) consists predominantly of siltstone and mudstone with less and finer grained quartz sandstone compared to unit Rqph. The strata include a thin bed of characteristic silicified and strongly bioturbated fine-grained sandstone. Correlation with similar Early Triassic units north of Hobart is indicated. Contrasting with these predominantly fine-grained rocks is a unit of predominantly medium-grained to coarse-grained quartz sandstone (Rvvp) that usually contains quartz granules and, in some places, quartz pebbles. This unit is probably little more than three metres thick and has proved to be a useful marker horizon that has been observed discontinuously to wrap around Mount Koonya from the headwaters of Cascades Rivulet into the catchment of Newman Creek. The marker horizon is well exposed on the foreshore near Premaydena where its relationship to the next two overlying units can be observed, but at Mount Koonya all succeeding strata up to the dolerite base have been grouped together as one undifferentiated unit (Rvv). This unit consists of interbedded siltstone, mudstone and quartz-rich lithic sandstone with minor quartz sandstone near the base and common grey shale about 60 m above the base. A Middle Triassic age for the unit (Rvv) can be inferred based on correlation with rocks near Oatlands.

The Jurassic dolerite sheet that caps Mount Koonya intrudes transgressively within the unit Rvv. North of the study area, dolerite (probably part of a different sheet) extends inland from Shelly Beach and intrudes the older units (Rqph and Rqm). A layer of Upper Parmeener strata may separate the two sheets on the northern side of Mount Koonya, but further south the two sheets may intersect. In the valley of a tributary or branch of Newman Creek, Upper Parmeener Supergroup rocks are topographically higher than the dolerite which intrudes them. This may be due to an upward transgression of the lower sheet or a downward transgression of the Mount Koonya sheet. This ambiguity imposes limitations on the interpretation of dolerite structure in this area and most of the study area further south.

The distribution of the marker sandstone unit (Rvvp) indicates that equivalent stratigraphic horizons and the base of the Mount Koonya dolerite sheet are both considerably lower in the east compared to the west. This fall in elevation is equivalent to an average easterly dip of 5°, but is probably a result of both faulting and variable dip on different faulted blocks. The position of possible faults can be inferred, but the faults have not been accurately located. Although the base of the Mount Koonya sheet has been mapped on the escarpment slopes, the possibility of faults, steep transgressive segments and intersection of separate sheets limits the accuracy of predictions of the sheet base altitude beneath the dolerite plateau area.

The Koonya B spring system and similar springs on the western side of Mount Koonya, between the fire tower site and Kingstons Pinnacle, are probably fed by a combination of surface or near-surface water flow and fractured aquifer groundwater derived from local infiltration zones largely west, but in some cases slightly east, of the surface water divide between Cascades Rivulet and Newman Creek. Individual fracture zones, such as faults, could convey water to seepages on the western or northern side of Mount Koonya, possibly from infiltration areas east of the divide.

Based on the current limited information, the location of the springs, the concept of topographically driven flow cells, consideration of symmetry and potential preferred pathways probably provide the best means of crudely estimating the flow paths and the location of recharge areas for groups of springs within flow cells. The recharge areas for individual springs are more difficult to define.

In the vicinity of the Koonya divide the piezometric surface crest is probably east of the divide when the forest water yield is symmetric about the surface divide. Forestry operations have the potential to displace the piezometric crest and the boundaries between the inferred flow cells and hence alter the areas of recharge for individual springs.

Forestry operations within a recharge area may both increase and decrease water yield (precipitation less water loss by evapotranspiration) and spring base flow. Forestry operations immediately east of the existing G. Giblin operation are unlikely to have any detectable effect on the Koonya B spring system.

Forestry operations north of the Giblin coupe may have an effect on springs mostly north of the Koonya B spring system.

The spatial distribution of the hydraulic head and the hydraulic conductivity of the dolerite fractured aquifer are both very poorly known at Mount Koonya. The numerical relationships between forest water yield, recharge of the fractured aquifer, and spring base flow are also poorly known.

Water budget considerations for the entire area and over a long time interval based on frequently measured rainfall, stream and spring flow might bring less ambiguity to the interpretation. In particular the establishment of a means to frequently measure flow rate, or should that be difficult a proxy means such as frequent measurement of TDS and pH of the Koonya B system, might prove useful to determine interflow and base flow recession. Borehole information on the gradient of the piezometric surface and the hydraulic gradient, and more precise information regarding the location of faults and openness of fractures, are probably required to provide the necessary information on which to base firm hydrogeological conclusions.

Introduction

Mount Koonya (486 m above sea level; 565400 mE, 5 226 300 mN) lies west of the Arthur Highway near the centre of Tasman Peninsula and is fully encircled by the road system that links Taranna, Koonya, Nubeena and Port Arthur. Mount Koonya and the neighbouring Mount Clark (494 m) and Mount Tonga (360 m) occur in an area of State Forest largely underlain by Jurassic dolerite. Encircling the State Forest at mostly lower elevations is privately-owned land. Some of this land is also forested, some is residential land and some is farming country under pasture. Particularly in the north and west, the dolerite terrain passes downslope into land underlain by Triassic age sedimentary rocks.

The State Forest forms the source area for several streams and many of the residents use spring water, particularly in the catchment of Cascade Rivulet.

Sloane (1987) and Weldon (1991) reported on the potential effects of forestry operations on slope stability and springs in the Mount Clark–Mount Koonya area. Sloane (1987) noted that the spring seepages often appear close to the contact between dolerite and the underlying sandstone and mudstone. Sloane also noted that dolerite talus cover often masks the seepage origin and that the seepages may appear lower on the slopes.

Both reports (Sloane, 1987 and Weldon, 1991) considered the role of fractured-rock aquifers as a potential source for some spring water. Based on a study of stream and escarpment directions, Sloane (1987) deduced a NNE–SSW structural control with a secondary control at right angles. Sloane (1987) and Weldon (1991) suggested that joints and faults with these directions may play an important role in spring development

In particular Sloane (1987) considered that some of the spring water on the northern slopes of Mt Clark was derived by infiltration of rainwater south of the surface drainage divide. This water was considered to flow through the NNE-directed dominant joint system to the springs close to the dolerite basal contact on the northern side of Mount Clark.

More recently a working group, currently with representatives from the local residents, Tasman Council, Department of Primary Industries, Water and Environment (DPIWE), Mineral Resources Tasmania (MRT), Forest Practices Board and Forestry Tasmania (The Koonya Forests Group) was formed to address some water issues relating to forestry operations in the area. In a proposal put forward by the working group for a field investigation of part of the Mount Koonya area (McIntosh *et al.*, 2002) it was considered that the Sloane (1987) analysis of spring water origin was likely to be correct. Consequently the proposal for a Stage 1 investigation attached importance to the geometry of the interface between what was broadly considered to be essentially permeable dolerite overlying impermeable sedimentary rock as a major control of groundwater flow.

The major task of the geological mapping component of Stage 1 was to better define the structure of the basal dolerite intrusive margin and, where possible, to note the fracture pattern in the dolerite within the study area. Late in 2002 Mineral Resources Tasmania (MRT) agreed to undertake approximately five days geological mapping at Mount Koonya and MRT's representative on the working group was changed from A. Ezzy to S. Forsyth.

Acknowledgements

Geology

Introduction

As part of the geological mapping component of Stage 1 of the Mount Koonya Working Group Proposal (McIntosh *et al*., 2002), approximately five days fieldwork was undertaken in and near the defined Stage 1 area during December 2002. The writer has also made observations on some coastal sections on other occasions.

Following an introductory visit to the area with S. Davies, B. Haywood and P. McIntosh during the morning of 9 December, geological mapping commenced in the afternoon of the same day and continued until 13 December. A supplementary day of field investigations was spent on 19 December. During the first four days much of the geological fieldwork was undertaken in the company of S. Davies who provided GPS data to support the geological observations as well as undertaking his prime function to describe the associated soil profiles.

The study area can be accessed in the west from Fire Tower Road and in the east from a forestry road that extends through private property southwest from the end of Newman Creek Road. Communication towers near the old fire tower site on Mount Koonya can be reached by four-wheel drive vehicle from the forestry road or on foot, either along the old fire tower pack horse track (partly through private property) or by a more direct foot track though State Forest. Both these tracks and a further 4WD access track to property UPI 0031 commence from Fire Tower Road. Although outside the study area, the Clark Cliffs walking track and Mount Clark vehicular track provided convenient access to Plummers Creek and the base of the dolerite sheet on Mount Clark.

Most of the study area is clothed in wet to somewhat drier sclerophyll forest. Some parts have been clear-felled and are now are in the early stages of revegetation and other parts have been thinned. The forest understorey is generally relatively open and not difficult to walk through.

Previous geological maps and investigations

Only the northernmost part of Tasman Peninsula has been systematically geologically mapped at a scale of 1:50 000 (Gulline, 1982, 1984). South of latitude 43°S the sequence of broad-scale geological maps which have been produced over the last thirty years are essentially compilations of local detailed maps of limited lateral extent, and photo interpretation or reconnaissance maps to infill the intervening areas. Most of the Tasman Peninsula geology of the first Geological Survey 1:250 000 scale map (Farmer, 1975) is based on an earlier, predominantly photo-interpretative study (Geophoto Resources Consultants, 1966; more accessible as Barton and Brock, 1967).

A 1:25 000 scale map of the Port Arthur area, including Mount Tonga, was presented by Cromer *et al*. (1976) and the information included in a revised general map of Tasman Peninsula (Cromer *et al*., 1979). A significant discussion of the history of the Tasman Peninsula from 1798, and the results of geological observations, is presented by Banks *et al*. (1989). Banks *et al*. (1989) acknowledge the use of the Cromer map (Cromer *et al.*, 1979) with some additional ground and aerial surveys as the basis of their own map of the geology of Tasman Peninsula.

Subsequent to 1989 the area adjacent to the southern shore of Norfolk Bay was mapped as part of a University honours project (Edwards, 1990). The Edwards map was the first to depict Jurassic dolerite south of Shelly Beach near Koonya. Edwards (1990) correlated Triassic strata exposed on the coastline between Parkers Beach and Newman Beach with the Middle Triassic lithological unit Rsq described from the Oatlands area by Forsyth (1984). Unfortunately this correlation was incorrect, as most if not all strata exposed along this section of coast are closely comparable with an older Early Triassic rock unit.

Aspects of Edwards map, together with the other existing sources, were used in the second geological survey 1:250 000 (digital) compilation (Forsyth *et al*., 1995). Despite the gradual advances of geological information over the years the accuracy of the geological boundaries on this map range from the maximum achievable for the scale to inaccuracies of several kilometres.

Geological mapping specific to the Mount Clark–Mount Koonya area is rather limited.

Sloane (1987) spent a day investigating this area and produced a 1:25 000 scale geological sketch map of the Mount Koonya area as an adaptation from the Cromer map (Cromer *et al*., 1979).

Sloane (1987) and subsequently Weldon (1991) described the plateau areas of Mount Koonya and the adjacent Mount Clark as the eroded exposed remnant of a Jurassic-age dolerite sill or sheet that had intruded a sequence of Triassic sandstone and mudstone. Both authors drew attention to what is almost universally developed in such geological situations, namely a mantle of dolerite-derived slope deposits that extends downslope onto the underlying sedimentary rocks and commonly obscures the basal intrusive contact of the dolerite.

Prior to the commencement of fieldwork, existing maps, waterbore records and two sets of aerial photographs were studied. The March 1966 Forestry Tasman Project 1598 photo set revealed an extensive closed forest vegetation cover throughout much of the

area and very little ground detail could be discerned compared to the March 1946 Tasman set. The older photographs revealed considerably more cleared land and open forest of low height, such that fallen logs were readily apparent as were some master joints in dolerite, some bedding traces and cliff lines developed in Triassic rocks, and some minor drainage lines and surface drainage source areas. It was also evident that the forest cover had considerably masked the detailed form, and at places the location of the mapped drainage lines and land topographic form, on the aerial photos used to produce the DPIWE Port Arthur 1:25 000 scale topographic map.

This preliminary office-based study supported the existing interpretation of a sill or sheet form for the dolerite on the part of Mount Clark north of the summit, and for the west to northwest-facing slopes of Mount Koonya. Several features suggested possible structural complexity on the southern side of Mount Clark. These included:

☐ intersections of sandstone overlying dolerite reported from waterbores in the Highcroft area;

☐ an isolated area of Lower Parmeener Supergroup rocks near the Nubeena Road/Stormlea Road junction;

☐ a ridge, apparently of dolerite, that extends southwest from Mount Clark towards Nubeena Road; and

☐ a broad ridge of dolerite that extends southeast from Mount Clark towards the southern slopes of Mount Koonya and that descends near or to the bed of Plummers Creek.

These features could be interpreted to suggest the possible existence of a separate dolerite intrusion south of Mount Clark and/or a steeply transgressive sheet section along the southern side of Mount Clark. The presence of two dolerite sheets in the Mount Arthur area further south was commented upon by Cromer *et al*. (1976).

A second area of potential structural complexity was considered to exist on the eastern side of Mount Koonya and concerned the relationship of the Mount Koonya dolerite to the dolerite that forms Sympathy Hills. Unfortunately the geological maps of Tasman Peninsula are not sufficiently accurate to resolve the dolerite structure in all areas with any certainty. A regional knowledge of geological structure is often required to solve structural problems on a local scale and it was beyond the scope of the project to expand the regional knowledge except in areas immediately outside the study area.

A possibility that the distribution of Triassic rocks, as depicted on the 1:250 000 scale geological map inside the study area east of Mount Koonya, might provide vital clues was not borne out during the first few hours of mapping when the area was found to consist entirely of dolerite. As a consequence the mapping

area was broadened in an attempt to obtain more information about the dolerite intrusive contact along the northern side of Mount Koonya.

Stratigraphy

LOWER PARMEENER SUPERGROUP

Some aspects of the stratigraphy of Tasman Peninsula have been described by Banks *et al.* (1989). The oldest sedimentary rocks exposed on Tasman Peninsula belong to the glaciomarine Lower Parmeener Supergroup. Outcrops of the Lower Parmeener Supergroup are not widespread west of the Arthur Highway and none occur in the Mount Koonya study area or in the immediately adjacent areas. Following Cromer *et al.* (1976), Banks *et al.* (1989) referred the Lower Parmeener Supergroup rocks exposed at Point Puer, and all occurrences further west, to the Ferntree Formation, the uppermost formation of the Lower Parmeener Supergroup.

The Ferntree Formation can be readily distinguished from Upper Parmeener Supergroup rocks because of the formation's glaciomarine character. The rocks are composed dominantly of variable mixtures of poorly sorted sand, silt and clay size particles. Additional coarser particles as lonestones, rarely up to boulder size, are usually present. Intense bioturbation is common and beds with marine shell fossils may occasionally be present. The bedding style is more uniform and the beds more continuous than in the Upper Parmeener Supergroup rocks. Bedding is commonly defined by alternations of fissile and non-fissile siltstone. The rocks are commonly more indurated than Upper Parmeener rocks.

UPPER PARMEENER SUPERGROUP

The boundary between the Lower and Upper Parmeener Supergroup rocks reflects the change from a glaciomarine to fresh-water depositional environment. The Upper Parmeener rocks are usually well sorted and the sandstone commonly exhibits cross bedding and ripple depositional structures that are usually indicative of deposition from flowing water. Marine fossils are absent, but coal seams, fossil plants and vertebrates are known from some localities. Upper Parmeener Supergroup rocks are widespread west of the meridian of Port Arthur and occur within the Mount Koonya area.

Cygnet Coal Measures Correlate — Permian?

An isolated occurrence of the Ferntree Formation at Point Puer occurs on the foreshore east of Remarkable Cave, where the rocks are directly overlain by Upper Parmeener rocks. Cromer *et al*. (1976) suggested that these Upper Parmeener rocks could be equivalent to the Cygnet Coal Measures. If this correlation is correct it is likely that rocks equivalent to the Cygnet Coal Measures are more widespread on Tasman Peninsula than currently indicated. Possible occurrences could include a band of strata west of the Ferntree Formation

south of Port Arthur and the upper parts of coastal cliffs east of Mount Fortescue. Should the Ferntree Formation near the Nubeena Road and Stormlea Road intersection not be entirely isolated by faults or dolerite intrusions, then some of the nearby Upper Parmeener rocks, including strata on the south side of Mount Clark, may be equivalent to the Cygnet Coal Measures.

Dominantly quartz sandstone sequence (Rqph) — Early Triassic

A sequence dominantly of quartz sandstone (Rqph), including intervals with abundant cross-bedding and some overturned cross-bedding, is exposed at various places around the foreshore of Norfolk Bay including the section between Parkers Beach to east of Parkinsons Point, the western side of Koonya Beach and east of Shelly Beach. Included in the sequence are thinner intervals where the proportion of interbedded siltstone and mudstone is greater than that of sandstone. One such interval, with conspicuous red-maroon siltstone, crops out almost continuously on the foreshore and lower cliff section between Parkers Beach and Parkinsons Point. The dominantly quartz sandstone sequence is lithologically correlated with similar Early Triassic rocks found elsewhere throughout the Tasmania Basin (Lower sandstone-dominated interval of Unit 2 of Forsyth, 1989).

Banks *et al.* (1989) summarised the palaeontological evidence for Early Triassic strata at Lime Bay which probably belong to this sequence, and from Impression Bay north of Premaydena where quartz sandstone, carbonaceous siltstone and red siltstone may be part of the sequence or may occur directly above the sequence.

The dominantly quartz sandstone sequence has only been cursorily inspected during the current mapping, but is considered to extend up Fire Tower Road to between the 120 m and 130 m contours, just above prominent sandstone outcrops visible in adjacent fields and on aerial photographs. Upper Parmeener rocks exposed above this height on Fire Tower Road are predominantly siltstone or very fine-grained sandstone, and inspection of aerial photographs reveals a subdued topography without cliffs or sharp benches. Sandstone cliffs within the valley of Cascades Rivulet have been photo interpreted up to about the 160 m contour and additional bench features that may be sandstone outcrops occur near the 190 m and 200 m contours not far from the property access road near 565 500 mE, 5 227 500 mN.

A 'drive-by' inspection of Nubeena Back Road revealed many quartz sandstone outcrops, but no conspicuous siltstone or mudstone. Aerial photo interpretation supports the presence of the dominantly quartz sandstone sequence to the 150 m contour and possibly to the 170 m contour along this road. Slightly above these heights, especially in the area about the junction with MacDonalds Road, the aerial photo interpretation is less conclusive and a more detailed surface inspection would be required to determine the upper limit of the quartz sandstone sequence. The log of a nearby waterbore records a thick (10 m) surface interval of clay over sandstone, while a second bore to 76 m recorded both sandstone and mudstone (MRT BORIS database). The bores may be collared above the dominantly quartz sandstone unit (Rqph)

Interbedded siltstone, fine-grained sandstone and mudstone sequence (Rqm) — Early Triassic

Outcrops of Triassic rocks along Fire Tower Road, above the 140 m contour to the 300 m contour, and on the Mount Clark forestry road, consist predominantly of siltstone. Where sandstone outcrops occur they are generally of fine to very fine-grain size and commonly include interbedded siltstone. The main exception to this occurs between the 180 m and 190 m contours, where outcrops of sandstone, including one layer with pebbles and granules of milky quartz, span a vertical interval of several metres. This sandstone unit provides a convenient means of subdividing the strata into a lower and an upper unit. The lower unit (Rqm) is discussed under this heading.

Within the Mount Koonya study area outcrops of the lower unit (Rqm) are moderately to extremely weathered and exhibit pallid to ferruginous colours and a silty to muddy consistency. A four metre thick interval at 565 070 mE, 5 227 442 mN consists predominantly of siltstone, including pale grey and light olive green varieties with orange ferruginous films on numerous irregular fractures. Some of the less weathered outcrops include finely micaceous mudstone. Mudstone exposed at a house site has a maroon-grey colour [565 590 mE, 5 228 740 mN].

Road cuttings north of the study area expose less weathered rocks including micaceous fine-grained sandstone [565 640 mE, 5 229 430 mN] and a variety of siltstone types, including maroon siltstone [565 600 mE, 5 229 630 mN]. Of particular significance are occurrences of thinly bedded, partly silicified and intensely bioturbated very fine-grained sandstone north of the study area [566 250 mE, 5 229 540 mN and 566 980 mE, 5 230 010 mN], as this lithology appears to be restricted to a particular stratigraphic interval in the Midlands and southern Tasmania. The lithological characters strongly suggest correlation of the rocks at Mount Koonya with the Upper lutite-rich interval of Unit 2 of Forsyth (1989), including the muddy floodplain facies (Rm; Forsyth, 1984) and the more recently mapped unit (Rqm) on the Richmond 1:25 000 scale geological map (Forsyth, 2002). The thickness of unit Rqm at Mount Koonya is not tightly constrained, but appears to be in the range of 50–70 metres.

The best exposures of unit Rqm on the eastern side of Mount Koonya occur in road cuttings on a residence access road [567 890 mE, 5 229 260 mN]. Extensive outcrops of siltstone on the Nubeena Road south of Premaydena, from about 45 to 145 m elevation, could belong to this unit, but have not been inspected during the current mapping. Edwards (1990) correlated many

of the rocks west of Parkers Beach with the Oatlands muddy flood plain facies Rm. These include some strata on the western shore of Impression Bay that are equivalent to unit Rqm at Mount Koonya.

Quartz sandstone unit with granules (Rvvp) — Middle? Triassic

As noted above, this unit is exposed on Fire Tower Road where it was distinguished from the underlying and overlying rocks primarily by the presence of multiple beds of coarser-grained sandstone, including beds with quartz granules and pebbles. The sandstone beds are not uniformly coarse, but range from fine to coarse-grained. In most areas at least some layers are medium to coarse-grained with some quartz granules. Less commonly quartz pebbles to about 30 mm diameter are present.

From the roadside exposure it was possible to follow a line of sandstone boulders for about 100 m south on the lower side of the road until a small valley was crossed. A few boulders were found on the western side of the valley, but it was not clear if this was west of Cascades Rivulet or west of an unmapped tributary stream because the valley trend differed from that of Cascade Rivulet shown on the topographic map.

North from the roadside exposure the sandstone is buried beneath dolerite talus, but reappears on the Mount Koonya walking track. Northward from here a continuous bench, and in places a cliff, is visible on the 1946 aerial photographs and extends to a quartz sandstone outcrop on the access track to property UPI 0031. It is therefore concluded that the low sandstone cliff a few metres above the Koonya B spring is part of this sandstone unit. The cliff reveals an interval of three to four metres composed of medium to coarse-grained sandstone with several cross-bedded layers and some granule-bearing sandstone.

Boulders of quartz sandstone were noted beside the original fire tower pack track further north, but the next outcrop located was on a resident's access road where traces of quartz granules were found in some beds [565 640 mE, 5 228 000 mN]. Boulders of sandstone continue to occur southward onto the adjacent property while low sandstone cliffs continue to the north through pasture and are visible from Fire Tower Road. The cliff was not followed, but outcrops of the sandstone unit were again located near the boundary with the next property [565 900 mE, 5 229 150 mN]. From here some loose sandstone boulders were found to the east along the property boundary fence line to a small creek, but not beyond this point. Some of these boulders may have been placed into position to make the fence more secure or to prevent erosion near the creek, consequently they cannot be entirely relied upon to infer the natural rock distribution.

The next outcrop located was significantly lower (see Figure 1) and from here scattered outcrops and boulders extend to a small shelf, south of a large farm dam, where the sandstone is particularly pebbly [566 650 mE, 5 229 740 mN]. Further discontinuous boulders and outcrops of sandstone and pebbly sandstone occur along a forested slope east of a creek. To the northeast they become increasingly obscured by dolerite slope deposits, but are well exposed in a road cut at 567 070 mE, 5 229 950 mN. Loose sandstone boulders are common near the property boundary not far to the north, but dolerite slope deposits occur east of the fence and creek intersection [567 170 mE, 5 230 000 mN].

Quartz sandstone with granules also occurs below the access track to land parcel 0036 [567 550 mE, 5 228 690 mN]. The western limit of this occurrence is not known, but it is possible that dolerite talus obscures the sandstone to the west. The sandstone crosses the access road to the northeast, but was not followed beyond this point. Two isolated occurrences of quartz sandstone were found in the forest to the north, but neither could be mapped accurately. The northernmost occurrence includes granule sandstone layers [567 670 mE, 5 229 230 mN]. The southern occurrence consists of a collection of medium-grained sandstone boulders, some possibly forming the foundations of a building ruin, but others appeared to be natural and have been depicted as the unit Rvvp on the map (fig. 1) [567 730 mE, 5 229 030 mN].

Another occurrence of boulders of granule-bearing sandstone near a house in Newman Creek Road [568 080 mE, 5 229 200 mN] has not been depicted on Figure 1.

Edwards (1990) correlated pebbly sandstone at several localities with the basal coarse beds of the Oatlands unit Rsq. Only two of these localities have been re-inspected. The pebbly bed at a locality east of Parkers Beach is stratigraphically lower than unit Rvvp and is part of the Early Triassic unit Rqph. Steeply-dipping beds exposed on the western shore of Impression Bay, about 600 m north of the Saltwater River Road junction with Nubeena Road, include pebbly sandstone equivalent to unit Rvvp.

At the latter locality the pebbly sandstone ranges from about one metre to two metres thick. An unmeasured interval, possibly about 20 m thick, that consists of siltstone and quartz-rich lithic sandstone, separates the pebbly sandstone from an overlying quartz sandstone unit a few metres thick. Both immediately beneath the pebbly sandstone and a few metres stratigraphically above the pebbly sandstone occur siltstone layers with numerous short cylindrical sand-filled burrows about two millimetres in diameter. In the Austins Ferry to Richmond area north of Hobart these types of burrows appear to be similarly confined to the bed immediately below unit Rvvp and the dominantly siltstone interval (Rvvr) immediately above it up to a thin overlying quartz sandstone unit (Rvvs). The excellently exposed Impression Bay rocks enable a strong correlation to be made with the Hobart

area and give some support to the independent correlation of the Mount Koonya succession.

Undifferentiated quartz-rich lithic sandstone, quartz sandstone and mudstone (Rvv) — Middle Triassic

The beds above the quartz sandstone unit (Rvvp) consist of interbedded mudstone, siltstone and sandstone.

Medium to coarse-grained quartz- rich lithic or arkosic sandstone is present at a few localities within the lowest interval of about 20 m thickness, occasionally passing up into a thin layer of laminated quartz sandstone [564 970 mE, 5 227 070 mN; 566 690 mE, 5 229 560 mN]. No quartz sandstone was found above this interval. The presence of laminated quartz sandstone low in the succession resembles similar occurrences in the Hobart and southern Midlands areas (unit Rsq, Forsyth, 1984; and Rvvs, Forsyth, 2002). The laminated quartz sandstone is not as persistent or prominent in the Mount Koonya area and the unit has not been differentiated on the map. Where weathered, the associated siltstone and mudstone is difficult to distinguish from weathered rocks from the older unit Rqm. Where less weathered, the fine-grained rocks are mostly cream to light buff in colour and contain a higher proportion of mudstone or claystone.

The most characteristic and best exposed rocks found above the quartz sandstone unit (Rvvp) occur on the access track to the G. Giblin block (UPI 0031) about 45 to 55 m above the quartz sandstone. These rocks consist of interbedded buff to brown-coloured quartz-rich lithic sandstone and siltstone. Mica and abundant carbonaceous fragmentary plant fossils occur on some sandstone laminae. The rock types are sufficiently characteristic to indicate lithological correlation with the 'Interval with lithic sandstone and lutite' of Unit 3 of Forsyth (1989) and the unit Rvvl of the 1:25 000 scale MRT digital geological maps. Carbonaceous siltstone overlain by quartz-rich lithic sandstone is exposed in a three metre high cliff at a similar topographic height about 50 to 100 m south from the exposure on the track.

Higher on the same track, about 60–70 m above the quartz sandstone unit (Rvvp), dark grey mudstone is prominent and resembles similar occurrences at this stratigraphic level on South Bruny Island south of Mangana Bluff (Farmer and Forsyth, 1993). Elsewhere in the Tasmania Basin this part of the succession passes up into the 'Younger interval with quartz sandstone' of Unit 3 of Forsyth (1989) and rocks of this association occur on Tasman Peninsula at Prices Bay. No equivalent quartz sandstone was found beneath the dolerite sheet at Mount Koonya.

QUATERNARY DEPOSITS

Slope deposits

As noted by Sloane (1987) and Weldon (1991), dolerite slope deposits mantle much of the escarpment slopes around Mount Clark and Mount Koonya. Observations on these deposits were made at a number of locations but no specific attempt was made to map their distribution. The boundaries shown are therefore commonly of inferred status. The deposits have been grouped under the umbrella term 'talus', used in the sense of poorly-sorted, sub-angular to sub-rounded clasts set in a matrix of finer grain size.

The slope deposits are quite varied and range from accumulations where the dolerite clasts are locally dominantly of cobble size, to deposits where boulders about one metre in diameter are dominant. In some areas boulders in excess of six metres long are present [565 760 mE, 5 228 230 mN]. Some of the slope deposits with more angular cobble-size clasts are derived from eroded platy dolerite in which parallel joints are closely spaced. The matrix ranges from silty, sandy gravel to gravely plastic clay. In some places where the slope deposits have moved over the Triassic rocks, matrix and sedimentary rock clasts have been incorporated into the deposits.

A variety of processes may have contributed to the formation of the slope deposits, including cold climate solifluction and ice wedging, land sliding including debris flows, rock falls resulting in the formation of talus cones or sheets, creep and general colluviation. Some deposits, including those on the shelf above the Koonya B spring, may be partly of alluvial origin and form alluvial fans.

The lower intrusive contact of dolerite sheets is commonly susceptible to instability on slopes, particularly if it is underlain by weathered sedimentary rocks which in turn may provide a clayey slip plane that promotes downslope movement of collapsed debris. The area slightly downslope from the lower dolerite contact is therefore often a locus of thick talus deposits. Thick deposits may also form over dolerite where slopes are steep and/or structural defects are abundant.

On the eastern side of Mount Koonya, talus with slightly weathered dolerite clasts in a silty clay matrix was found to vary significantly in thickness from <0.5 m to >2 m in a lateral distance of less than one metre over an irregular surface of very to extremely weathered dolerite.

Two boulder-strewn scarps, separated by a shelf with either a backward tilt or a contour-parallel drainage line, are depicted on Figure 1 [565 740 mE, 5 228 320 mN]. These features could be related to large scale rotational landslides at the dolerite contact. Rare siltstone fragments occur within the higher scarp. The

presence of only dolerite talus rather than Triassic rocks along the section of Fire Tower Road below this area suggests that a continuous lobe of talus may extend downslope from the scarp features.

A smaller landslide feature with an internal drainage depression occurs further south and is crossed by the access track on land parcel UPI0031 (G. Giblin block) [565 470 mE, 5 227 675 mN]. A photo interpreted erosion scar, visible on the 1946 aerial photographs [565 320 mE, 5 227 330 mN], may be a very small landslide.

In a few areas, very to extremely weathered dolerite debris was found beneath the less weathered surface mantle of talus. The exposures were too poor to determine if the weathered debris was part of an older slope deposit or disrupted bedrock.

Although largely outside of the study area, aerial photo inspection revealed bedding traces and close spaced short drainage courses on parts of land parcel UPI0027, such as may be expected over mudstone or siltstone bedrock. Adjacent areas show a finely hummocky surface morphology that may be a talus mantle or an unusual erosion form on mudstone. An inspection of the access road on land parcel UPI0029 revealed talus, including boulder-size dolerite, which may extend downslope from Mount Clark to Cascades Rivulet or to the parallel tributary slightly further west. To the north on neighbouring properties, dolerite talus mantles the ridge between the tributary and Cascades Rivulet. Minor amounts of maroon, grey and tan-coloured siltstone and quartz-rich lithic sandstone that were found in road cuttings on this ridge appear to be components of the talus deposit, but may be partly locally derived.

Other Quaternary deposits

Various other alluvial, coastal and sandy deposits have been depicted on Figure 1. Many of these deposits have been photo interpreted, particularly those depicted as undifferentiated Quaternary deposits.

Broad tidal flats occupy the sheltered bays. The exposed deposits are mostly of fine-grained sand that is formed into beach ridges and silt with some rotting wood. The sediments support large crab populations. Flat areas occur inland of some of the beach deposits. These areas probably include alluvial deposits, but as they have not been inspected the possibility that they include marine or lagoonal deposits has not been ruled out and these flat areas have been depicted as undifferentiated Quaternary. Some photo interpreted ridges between the east side of Newman Beach and Nubeena Road could be forested sand dunes.

Meandering stream and abandoned stream courses are visible further inland on the aerial photographs, and the deposits have generally been depicted as undifferentiated Quaternary alluvium. Some subtle terraces are developed on some alluvium, but attempts have generally not been made to distinguish alluvial terraces of different ages, except locally for some Holocene alluvium.

Several small areas of undifferentiated Quaternary deposits at much higher elevations on Mount Koonya have been depicted on Figure 1. These are two dimensional or one dimensional, approximately flat bottomed areas that probably contain swamps or alluvial deposits. A much larger area at Benjafields Marsh, crossed by the Port Arthur to Nubeena road, has been depicted as alluvium, whereas adjacent slightly-raised areas that are depicted as undifferentiated Quaternary may include aeolian sand deposits. Unmapped thin and patchy deposits of sand over Jurassic dolerite were observed nearby.

Igneous rocks

JURASSIC DOLERITE

Dolerite intrudes the Triassic rocks in the Koonya area as one or more thick sheets. It is the most common rock type within the actual study area where, on the western and northern sides of Mount Koonya at least, it is approximately sill-like in form. Dolerite is also widespread outside the study area and similarly forms a sheet capping the northern parts of nearby Mount Clark to the west, and forms almost continuous dolerite terrain to the east and south. A more detailed discussion of the dolerite structure is presented under the *Structural Geology* heading.

Extensive continuous exposures of dolerite occur in several quarries, along some road cuttings, on some of the high ridge crests, and as cliffs where the main east-flowing branch of Newman Creek descends steeply from Mount Koonya. Less extensive rocky outcrops also occur, mostly in well-flowing streams, some road cuttings, and scattered infrequently on steep slopes or as subdued projections in areas of low slope.

More commonly, potential outcrops were found to be about one metre in diameter and a subjective appraisal was required to decide whether the rock was *in situ*, dislodged without significant transport, or merely clasts in a talus deposit. Such appraisals can be based on joint orientations and the similarity with surrounding debris, but may at places be in error. The causes of poor outcrop conditions are probably a combination of the talus cover and the degree of weathering. The latter may be manifested firstly by very to extremely-weathered dolerite that is too soft to form natural outcrops and that may be hidden even beneath very thin soil or talus cover, or secondly by partly weathered dolerite where fresh dolerite boulder sized cores are separated by residual clay. These boulders may gradually topple from the clay or be extracted out by the roots of falling trees, or the clay may be removed from around them.

The features recorded at outcrops mostly relate to the grainsize, texture and colour of the rock, jointing style and direction, and degree of weathering. The aims of

mapping dolerite areas were to establish more accurately the distribution of the dolerite and its contact with underlying Triassic rocks, and to collect data that might indicate the flow direction of groundwater through the dolerite fractured aquifer.

Grainsize and texture were investigated at a reconnaissance standard in an attempt to detect any extreme variations detectable in the field that might quickly lead to clues to the dolerite structure.

The following grainsize classification and textural/composition symbols appear on the map.

Grainsize (mm)

Jdvf	0–0.7
Jdf	0.7–1.5
Jdm	1.5–3
Jdc	>3
Jdvc	>6
Jdo	Dolerite with orthopyroxene microphenocrysts
Jdg	Granophyre and pegmatite

Very fine-grained dolerite with small orthopyroxene microphenocrysts was found at four localities. These include rock exposed in a small farm dam east of the quarries at the southern end of Newman Road. Here the very fine-grained dolerite is in contact with brown silty clay that could be soil or extremely weathered coarse-grained dolerite with the igneous texture completely obliterated. No sedimentary rocks occur in the spoil dug from the dam. Relatively fine-grained dolerite occurs around the nose of the spur towards the quarries and extends to the north-flowing branch of Newman Creek. A further occurrence comprising loose pieces of dolerite with orthopyroxene microphenocrysts occurs at a second farm dam about 200 m east of the first-mentioned dam. On the northwest side of the ridge between the two dams, concentrations of fine-grained dolerite pieces were found a short distance above mudstone and the geological boundary has been interpreted as an intrusion base, although other interpretations are possible.

The third location with 'quenched' dolerite is on the forestry road south of Newman Creek and just south of the study area [567 240 mE, 5 226 920 mN]. Neither the extent of this occurrence nor the relationship of the outcrop to surrounding rocks is known. The 'quenched' dolerite may be a minor dyke within the main dolerite intrusion or a major intrusive boundary against another dolerite intrusion or against sedimentary rocks. A few hundred metres further south patches of granophyre occur in coarse-grained dolerite near the first bend on a spur road to the east.

Orthopyroxene microporphyritic dolerite grading into equigranular fine-grained dolerite occurs near the basal contact of the sheet on the northwest side of Mount Koonya [565 815 mE, 5 228 820 mN]. Loose pieces of fine-grained or fine to medium-grained dolerite occur in the talus near the intrusion edge along the northern side of Mount Koonya to the east of

Kingstons Pinnacle. One piece of exceptionally fine-grained dolerite, or perhaps slightly crystalline hornfels, was found at a farm dam [566 290 mE, 5 229 220 mN] and suggests that the intrusive contact lies south of the waterhole. Fine-grained dolerite was found at a vertical intrusive contact with Triassic rocks to the east at a small quarry. The intrusive contact trends about 25° east of north and extends over a vertical distance in excess of three metres. Other outcrops to the southwest of the quarry are also fine-grained [567 040 mE, 5 229 910 mN].

Crystals of 3 mm length appear in the dolerite quite close to the basal intrusive boundary. These crystals may be thin and acicular or the average grainsize may be less than 3 mm. Because of incomplete exposure this transitional zone and the contact rocks are usually not found. Much of the dolerite found nearest the contact zone at Mount Koonya or along the Mount Koonya forestry road west of the locked gate is of coarse grainsize with average crystal lengths of 3 to 6 mm. This dolerite is of uniform grey appearance and outcrops and detached boulders commonly have a prismatic appearance. Outcrops at 566 320 mE, 5 227 820 mN show dolerite of different grainsize occurring in close proximity.

The dolerite within the lower quarry at the end of Newman Creek Road is of less uniform appearance and some shows a texture suggestive of a tendency towards a granophyric composition. This is more pronounced in the upper quarry, where the textures suggest that some of the dolerite is borderline granophyre. The joints appear to be less regular, particularly in the lower quarry, with many inclined and intersecting joints resulting in non-prismatic small blocks of dolerite.

A third quarry, situated further north beside Newman Creek Road, contains highly-weathered borderline granophyre similar to that in the upper quarry to the south. Some nearby outcrops have a pegmatitic texture with crystals to 20 mm length. A separate area of dolerite further west is mostly of coarse to fine-medium grainsize, but contains some small patches of granophyric dolerite.

An unusual orb of granophyre was found embedded in a large boulder or outcrop of coarse-grained dolerite at 567 645 mE, 5 228 865 mN.

Granophyre forms late in the crystallisation sequence when the residual magma has evolved from the original composition by the preferential removal of some elements into the earlier formed crystal phases. Typically granophyre occurs in the upper third of major sheets or in very broad dykes emanating from the sheets or from feeder structures where the volume of magma is great and the cooling period prolonged. (McDougall, 1962; Leaman, 1975).

Metamorphic effects of the dolerite

The Upper Parmeener Supergroup rocks appear to be thermally hardened near some dolerite contacts [e.g.

567 135 mE, 5 228 710 mN, 567 695 mE, 5 230 045 mN, 567 175 mE, 5 229 915 mN].

More intense metamorphism, associated with the basal contact of the Mount Koonya dolerite sheet, was noted north of Kingstons Pinnacle [565 875 mE, 5 229 085 mN] and as hornfels clasts in talus south of the Mount Koonya walking track.

Structure

ATTITUDE OF UPPER PARMEENER SUPERGROUP

With negligible dip and strike readings available for the Upper Parmeener Supergroup rocks at Mount Koonya, the thin quartz sandstone unit (Rvvp) forms a convenient horizon to study the attitude of these strata. Assuming that all isolated occurrences of this unit have been correctly correlated, it is apparent that this horizon is significantly higher in the Fire Tower Road area than near Newman Creek. A uniform dip of 5° to the east applied over a distance of about two kilometres could account for this difference. Alternatively, and most probably, the unit could be faulted.

The quartz sandstone unit with granules (Rvvp) has been depicted discontinuously on the geological map (fig. 1) partly because the unit is obscured by slope deposits and partly because the intervening areas have not been mapped. The apparent dip required to link the discontinuous segments has been compared to the apparent dip in the same direction of the mapped segments. An apparent dip of about 2° is required to link the two main segments mapped near Fire Tower Road; this is greater than the equivalent apparent dip of ≤0.5° of the mapped sections. To link the northernmost of these segments to the segment located to the northeast requires an apparent dip of about 6°, compared to an average apparent dip of 2.5° on the northeast segment. It is concluded that the dips are either greater between the depicted segments or that the segments are separated by faults.

A potential location for such a fault is approximately coincident with an aerial photo interpreted lineament trending towards 330° immediately northeast of Kingstons Pinnacle. A possible fault, perhaps of similar trend, could pass through the saddle between Kingstons Pinnacle and Mount Koonya.

A single measured dip of 3.5° to 8° east of north for rocks near a large farm dam is not considered to be entirely indicative of the structural dip of the strata because of the lenticular nature of the bedding surfaces. The rock distribution at the farm dam suggests a somewhat more easterly dip, although the measured dip seems compatible with the distribution of the Rvvp unit on the ridge to the south.

A steeper dip of 25° to 125° was measured a few metres northwest of a quarry (near 567 090 mE; 5 229 950 mN) that displays a near-vertical contact (trending 25°)

between dolerite and Upper Parmeener rocks that appear to be more or less flat-lying nearby to the southeast. The dipping strata could suggest a post-dolerite fault trending parallel to the strike of the strata, but is more likely to be related to deformation during intrusion.

Edwards (1990) measured dips on the Upper Parmeener Supergroup rocks exposed on the foreshore of Cascades Bay. These dips show considerable variation and range from easterly-directed, through south to almost westerly-directed, with the declination ranging from 1° to 16°. From Shelly Beach to Newman Beach the dips are more consistent in direction and, with a few exceptions, are mostly directed towards the ESE and range in declination from 3° to 16° degrees.

Some of the local variations of dip are caused by original lenticular bedding surfaces, some are related to soft-sediment deformation, and some changes are local steepening of dip near small and larger faults and bedding warps. The average regional dip between Parkers Beach and the eastern side of Parkinsons Point is about one degree in an approximately southerly direction, with the oldest strata present at the tip of Parkinsons Point. This is indicated by the continuous presence along the coastline at sea level, to a maximum elevation of 7–10 m ASL, of an interval with red siltstone beneath a major quartz sandstone depositional cycle. The low-angle average regional dip may continue to Koonya and may equate inland to what is suspected to be an area of regionally sub-horizontal strata near Mount Clark.

East of the dolerite at Shelly Beach the strata were measured to dip ESE at up to 20°, but this dip lessens irregularly towards Newman Beach. East of a cartographic projection of the eastern dolerite boundary exposed on Nubeena Road, the coastal rocks may in places be almost flat lying or alternatively strike parallel to the shore and dip south, although outcrop is limited. Closer to Newman Creek and near a fault the dip is easterly.

If the coastal structure is at all indicative of the inland structure at Mount Koonya, it is possible that zones with increased dip and fault displacements may be present at Mount Koonya. Areas with sub-horizontal strata may be present, but both dip directions and magnitudes may vary from place to place. Northeast to southeast may be the most common directions of dip where the dip magnitude is moderate and the bedding strike may be parallel to local faults. It is not known if the area of steeper dip east of Shelly Beach is genetically related to intrusive or pre-intrusive tilting, or whether these types of effects are present at Mount Koonya.

DOLERITE STRUCTURE

The quartz sandstone unit (Rvvp) also provides a datum to assess the structure of the dolerite intrusion at Mount Koonya. In the absence of pre-dolerite faults

the base of a sill-like dolerite sheet could be expected to show the same structural form as unit Rvvp. The maximum separation between unit Rvvp and the sheet base is about 80 m in the G. Giblin block. This separation falls to <40 m near Kingstons Pinnacle and to about 20 m further north. Near Newmans Creek Road the separation could be less, but the possible presence of separate dolerite intrusions complicates the interpretation.

The dolerite that forms the ridge that extends northeast from Kingstons Pinnacle descends to about the 140 m contour and is separated from a topographically lower area of dolerite outcrop by a band of Upper Parmeener strata. The distribution of the lower dolerite is limited in the northeast by a northwesterly trending (320°) low scarp, towards which the dolerite shows a decrease in grain size. The scarp is interpreted as marking a steep igneous contact with inferred Upper Parmeener strata. Two water bore logs northeast of the low scarp record sandstone beneath clay and sand.

This dolerite is thought to merge with a broad ridge of dolerite exposed on Nubeena Road near the Shelly Beach Road junction and indicated by Edwards (1990) to have parallel boundaries trending slightly west of south. Edwards considered that the eastern boundary of the dolerite exposed on Nubeena Road was an intrusive contact in a fault gouge. The dolerite may extend further north than shown on the map (fig. 1) and narrower dyke-like masses could extend continuously to outcrops at Shelly Beach and nearby.

During the current mapping, dolerite considered to be a southern extension of the dolerite from Nubeena Road was mapped south to the 110 m contour where the boundary with Early Triassic sandstone was obscured by sand. The upper limit of this dolerite from here to Newman Creek Road is ill-defined because it is commonly obscured by sandy deposits, colluvium or soil. Some of the dolerite near this boundary is fine to medium-grained and occasionally forms pavement-like outcrops similar to exposures of sheet tops. The dolerite ranges up to coarse grained and includes some granophyre.

The continuous distribution of outcrops of this dolerite terminates at Kingstons Road and is separated from the dolerite exposed in the I. Kingston quarry by an area of fine-grained, matrix-rich quartz sandstone. The boundary between the sandstone and dolerite exposed in the quarry is of north–south orientation and its location at the time of mapping was well-defined in a temporary trench. Red and brown clay, possibly derived from dolerite, occurred in the boundary zone and obscured the nature of the boundary. The sandstone was too weathered near the boundary to reveal possible metamorphic effects and none were observed in less-weathered sandstone several metres to the west. Near the boundary the dolerite was finer grained than in the quarry, but maintained a crystal size of 2–3 mm within five metres of the boundary.

The presence of some granophyre in the dolerite that extends from Shelly Beach Road to Newman Creek Road indicates that it is not a further simple occurrence of the sheet base from Mount Koonya. The possibility that the lower dolerite is a steeply transgressive segment of the Mount Koonya sheet is considered unlikely. This is because a stronger positive relief would be expected along the transgressive segment and if the segment did not remain vertical through the crust strongly contrasting differential uplift caused by the intrusion would be revealed in the surrounding strata.

The most likely interpretation of this dolerite is that it is an intrusion of different age to the Mount Koonya sheet and that it passes beneath both Mount Koonya and the Triassic rock exposed around Norfolk Bay. This explanation does not require marked differences in differential uplift and accounts for the pavement-style exposures consistent with a sheet top.

Some support for an underlying intrusion comes from the occurrence of dolerite at and southeast of Shelly Beach, including a small dolerite island noted by Edwards (1990), a small, segmented dyke in the bay west of Parkinsons Point (Banks *et al.*, 1989), and a further dyke in the bay east of Parkinsons Point.

The north-trending boundary west of the dolerite at the I. Kingston quarry suggests that the dolerite at this quarry may be part of the Sympathy Hills intrusion. Should the north-trending boundary be a fault then the sense of throw would indicate if the Sympathy Hills dolerite is more likely to be part of the Mount Koonya sheet or part of the inferred lower Koonya sheet.

The recognition of two separate surface areas of dolerite, and most likely two separate intrusions, in the Mount Koonya–Shelly Beach area is facilitated by the presence of intervening sedimentary rocks. Should local or regional irregularities in the intrusive form had led to either sheet intruding the other, then the clues provided by the sedimentary rocks would no longer be present. If such a situation existed detailed mapping of the dolerite texture, and possibly the joint patterns, may have enabled the boundary between the inferred two intrusions to be located.

The relative ages of the two dolerite intrusions is not known. Leaman (1975) reasoned, from a hydrostatic approach, that the addition of major dolerite sheets into the Parmeener Supergroup could result in younger sheets intruding younger stratigraphic horizons. Should the Mount Koonya intrusion be younger, then any intersection of the two sheets would result in parts of the Shelly Beach sheet having a reversed lower/upper ordering and to be found above the Mount Koonya sheet. Where two intrusive sheets intersect and where the lower sheet is younger, the lower intrusion is likely to cause some fracturing of the upper sheet and some of the fractures may be intruded by dolerite dykes. The distribution of the 'quenched' dolerite on the Mount Koonya forestry road could provide significant structural information.

The dolerite occurring in quarries at the southern end of Newman Creek Road is exposed in the east-flowing branch of Newman Creek and extends a short distance up the northern valley side, where in two areas it is replaced by Upper Parmeener rocks at higher elevations.

At the western of these two areas, coarse-grained dolerite exposed in the creek (creek location incorrect on the 1:25 000 scale Tasmap) grades into very fine-grained dolerite about 10–20 m higher on the northern bank [567 135 mE; 5 228 710 mN]. The local rock distribution suggests that thermally metamorphosed Upper Parmeener siltstone overlies this dolerite. If this relationship is correctly interpreted it suggests that the lower dolerite sheet may rise steeply towards the south and may crop out in the dolerite quarries. This interpretation of the dolerite structure is depicted in the north–south and east–west cross sections (fig. 2, 3, 6). Alternatively the upper sheet could descend steeply in a southerly direction.

The Upper Parmeener rocks are overlain by dolerite boulders at the eastern of the two areas, but further north the boulders may be locally dislodged from outcrop. One coarse-grained boulder was found that contained an orb of granophyre. This suggests that the boulder was not derived from near a sheet base and supports the possibility that the Shelly Beach sheet may crop out in this area.

The dolerite exposed in the lower quarry to the south is rather fractured in appearance and probably at least half of the joints are inclined at 30° or more away from the vertical (fig. 8). This contrasts with the more or less vertical prismatic appearance of outcrops elsewhere and is in keeping with a locally transgressive sheet rather than a horizontal concordant form.

Several other cross sections depict the inferred geological structure (fig. 4–6; see fig. 7 for location of sections). The section depicted in Figure 5 has been selected to pass through or near well-located surface geological boundaries to minimise the degree of extrapolation required to predict the subsurface boundaries. In general subsurface boundaries, especially those below dolerite, are poorly controlled. This is particularly so for the lower dolerite sheet depicted in the cross sections.

Unfortunately too little is known of the regional dolerite structure to aid the resolution of the local structure. Generally the investigation of the form of major dolerite intrusions is facilitated by the presence of detailed geological and geophysical information over a large area. On the Tasman Peninsula the existing 1:250 000 scale geological map is inadequate for this purpose and the following interpretation should be regarded as speculative.

It seems likely that the westerly dipping Lower Parmeener Supergroup rocks from Point Puer to Remarkable Cave are underlain by a dolerite sheet. This relationship is suggested by thermally metamorphosed Lower Parmeener Supergroup rocks reported by Cromer et al. (1976) and Leaman (2002) at the dolerite-surrounded Crescent Bay and the ascent of the upper surface of the dolerite through rocks of the possible Cygnet Coal Measures correlate at Remarkable Cave. Banks et al. (1989) noted that the dolerite ascends in a southwest direction through the Upper Parmeener Supergroup rocks north of Kelp Bay. At Cape Raoul dolerite forms the full height (>220 m) of coastal cliffs, but further west the lower surface of the sheet is exposed within cliffs formed of Upper Parmeener Supergroup rocks.

West of Point Puer dolerite occurs at considerable elevation at Mount Arthur (447 m) (and the high ground to the south). The 1:250 000 scale geological map depicts this dolerite as virtually completely surrounded by Upper Parmeener Supergroup rocks. Cromer et al. (1976) regarded the dolerite at Mount Arthur to be a separate intrusion. If this dolerite is not a separate intrusion from the inferred Point Puer–Cape Raoul dolerite sheet then many of its contacts with the Upper Parmeener strata must be steeply discordant.

The logs of waterbores near Highcroft indicate errors in the 1:250 000 scale digital geological map (Forsyth et al., 1995). Some waterbores depicted as collared in dolerite instead record sandstone or sandstone boulders overlying dolerite and others logs of bores that plot in sandstone terrain instead record dolerite and clay without sandstone. Unmapped dolerite extends further east than that depicted on Nubeena Road east of the Highcroft Road junction and further north to include Prices Hill. This dolerite may underlie (based on photo interpretation) sandstone about 800 m WNW from Prices Hill, but the relationship of this strata to the dolerite that forms the crest of Mount Clark is uncertain.

There is some suggestion that the dolerite sheet inferred to underlie the Lower Parmeener Supergroup strata at Point Puer could rise to the northwest along northeast-trending structures. A candidate for the location of an intrusive riser/step is suggested by the alignment of the dolerite points — Commandants, Frying Pan, Garden and possibly Evandons — in the vicinity of the Port Arthur township.

A second riser could be located near the western shores of Long Bay and Stingaree Bay, where Cromer et al. (1976) indicated that the boundaries between dolerite and Upper Parmeener Supergroup rocks were of an intrusive nature. The corresponding step could occur south of Mount Tonga where Cromer et al. (1976) mapped small patches of sandstone apparently overlying dolerite, and further south recorded a southerly-dipping dolerite contact with overlying sandstone in a quarry near Nubeena Road. Cromer et al. (1976) regarded the Mount Tonga–Mount Koonya massif as a single dolerite sheet, but may not have considered the possibility that if two sheets were present then the sheets would not necessarily be separated by sedimentary rocks.
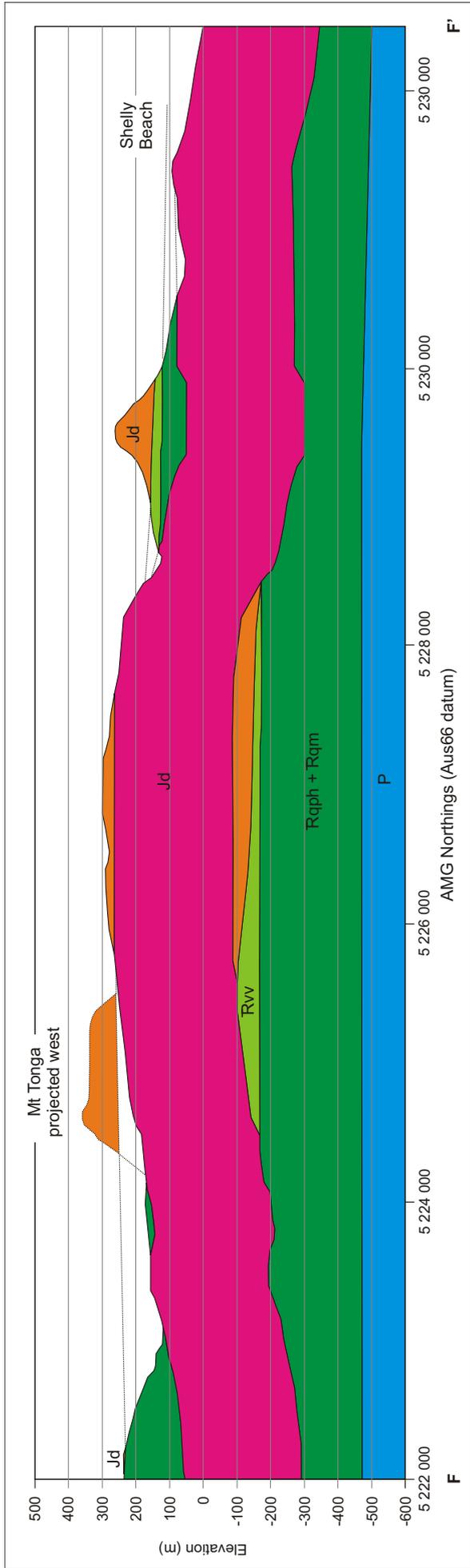
Figure 2

South–north geological cross section showing inferred geological structure along AMG grid line 567 140 mE (Aus66 datum)

Figure 3

West–east geological cross section showing inferred geological structure along AMG grid line 5 227 870 mN (Aus66 datum)

Figure 4

Approximate south–north (NNE trending) geological cross section showing inferred geological structure from Mount Koonya through Kingstons Pinnacle

Figure 5

Approximate southwest–northeast geological cross section showing inferred geological structure from Plummers Creek to Heywoods Road
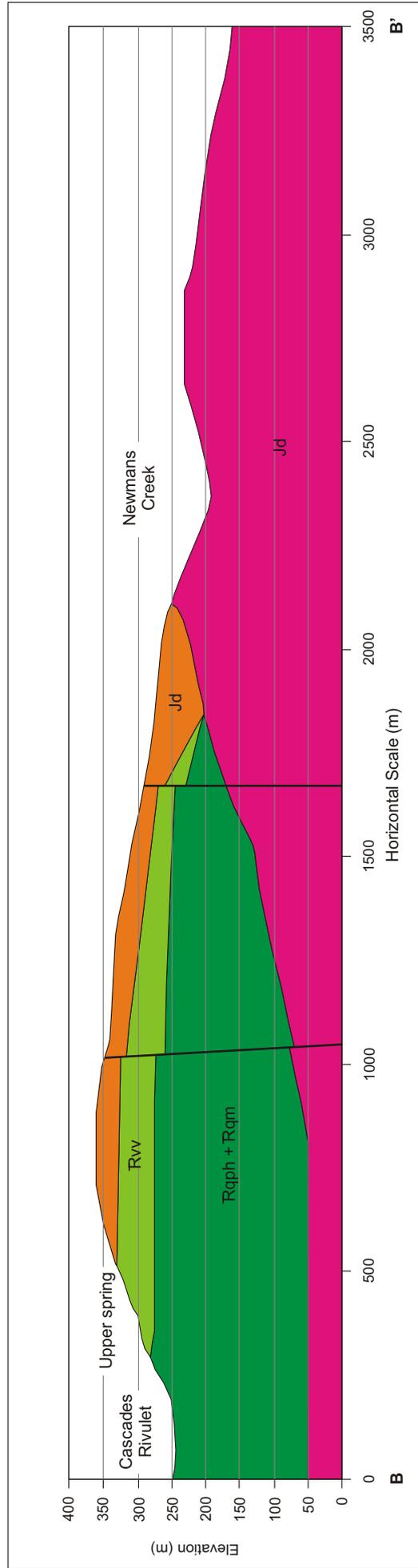
Figure 6

West–east geological cross section showing inferred geological structure along AMG grid line 5 228 725 mN (Aus 66 datum)
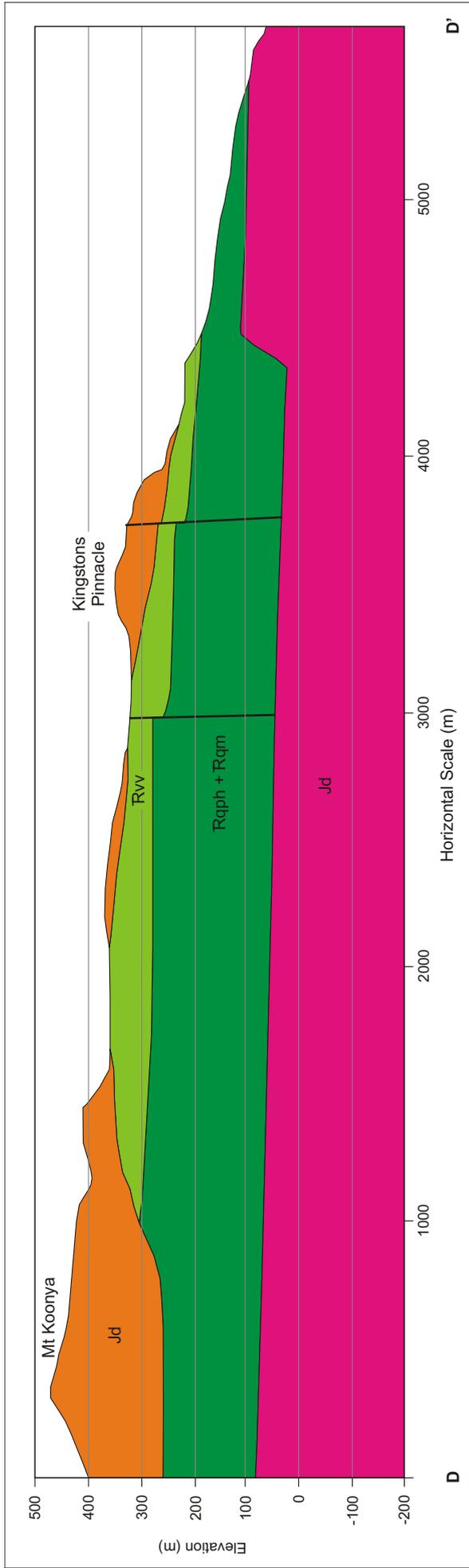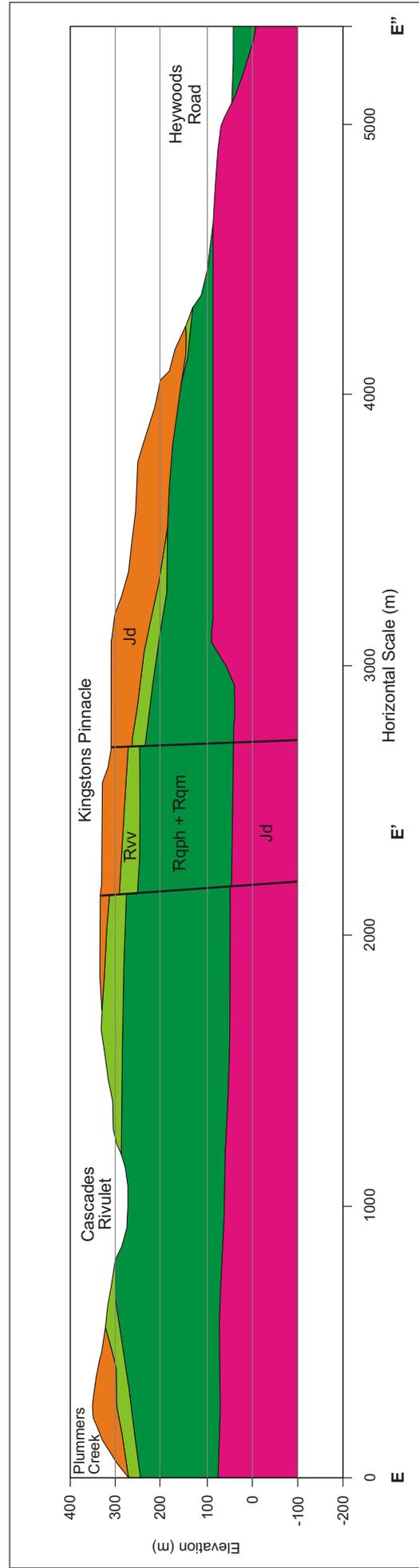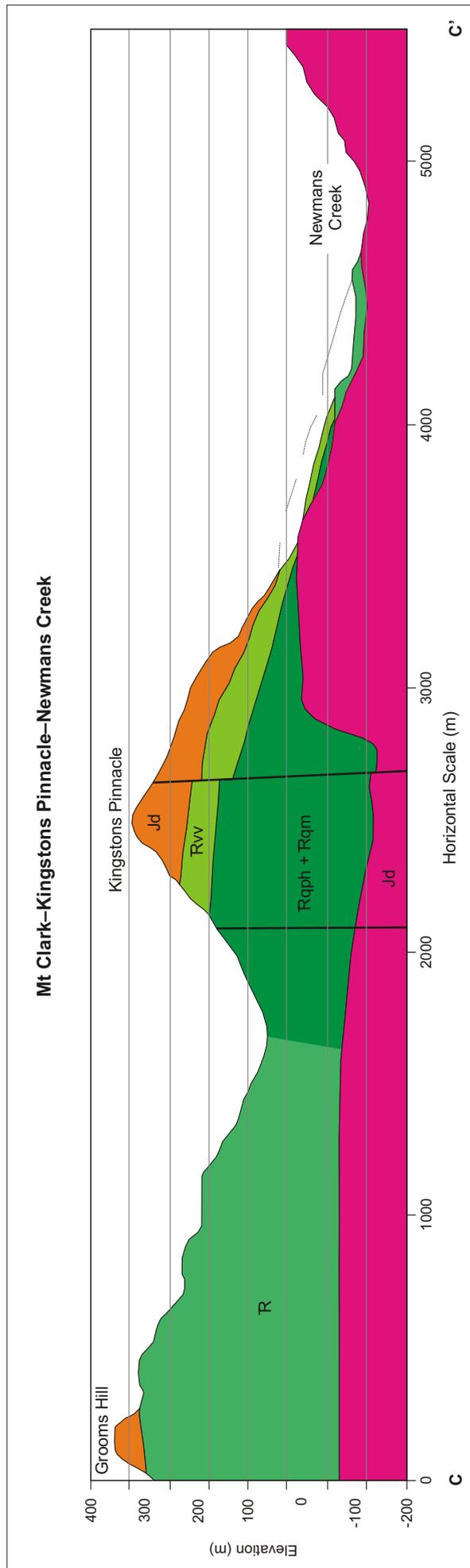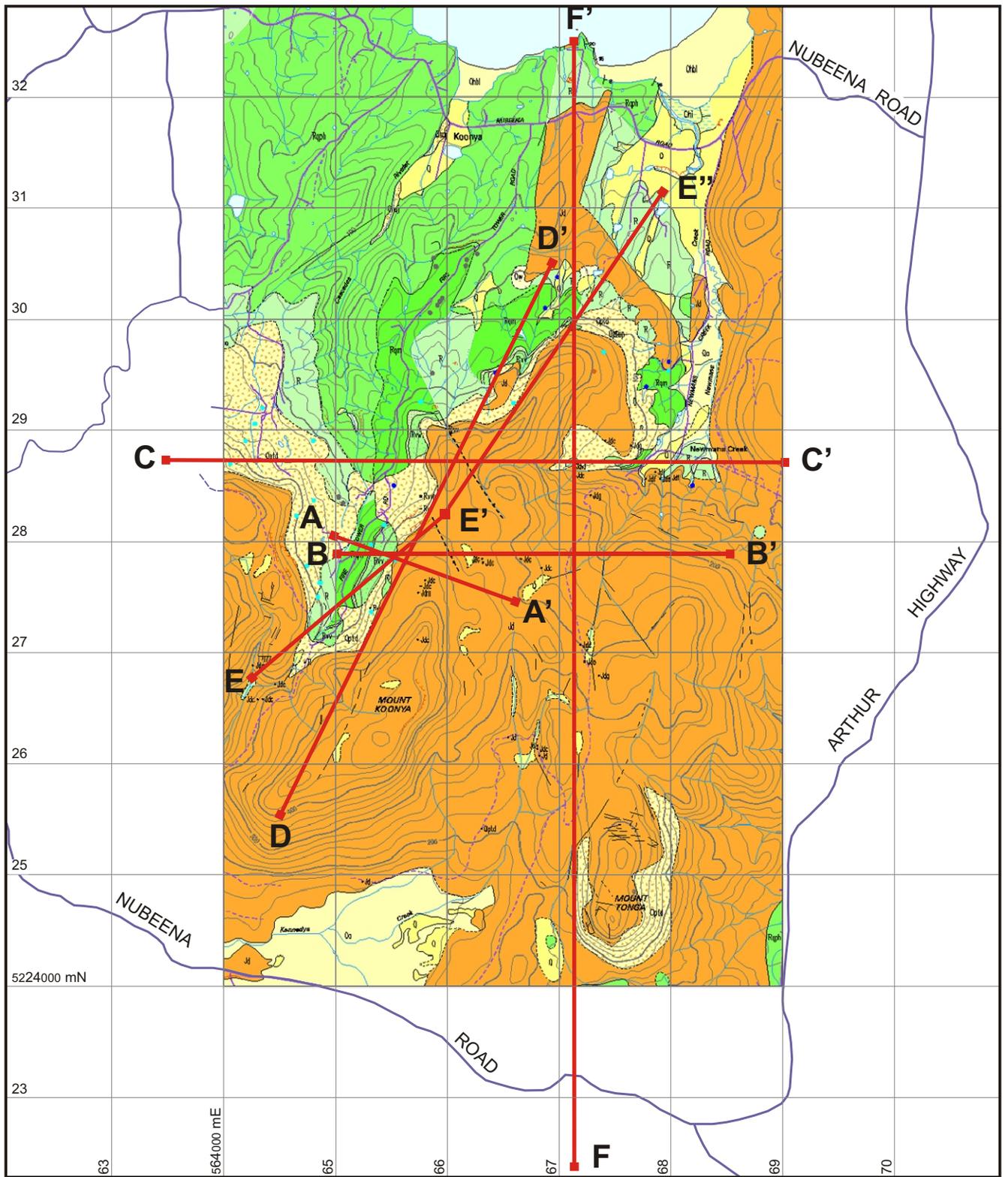
Figure 7
Location of section lines in Figures 2 to 6

Photo interpretation suggests that a northwest-trending structural feature, possibly associated with unmapped sedimentary rocks, may separate the Mount Tonga area from Sympathy Hills between the northern end of Long Bay and the southern end of Newman Creek Road.

Banks *et al*. (1989) drew attention to the morphology of Fortescue Plains, but it remains unclear whether the plain and associated bosse-like protrusions of Crescent Mount and Simmonds Hill are related solely to erosion or at least partly to dolerite structure. The bosses are not dissimilar in form to Mount Tonga and suggest another possible origin for some of the mountain forms, i.e. upward projecting intrusive bosses that could retain a protected skirt of sedimentary rock and mimic dual sheets.

FAULTS

The changes in the attitude of the quartz sandstone marker unit (Rvvp) suggest the presence of faults that either delimit areas of different dip and/or cause displacement of the strata. Although neither the location nor trend of these faults have been well defined, a northwesterly trend has been suggested for a possible fault near Kingstons Pinnacle based on photo interpreted lineaments. This direction lies within the trend range of a collection of faults that are better defined along the coastal sections (fig. 11). A second possible fault of similar trend has been inferred south of Kingston Pinnacle, although this fault is more poorly defined. Other possible trends for faults are suggested by the nature of some photo lineaments, particularly those that trend approximately north–south or within a few tens of degrees east of north–south. This trend is shared by the dolerite intruded fault gouge exposed on Nubeena Road (Edwards, 1990).

JOINTS

Leaman (1999) demonstrated that the columnar appearance of coastal and inland dolerite cliffs resulted from true thermal cooling columns. He also noted that tabular joints perpendicular to the columns, and mirroring the concordant contacts, are in some areas the most common joint type near the tops and bases of intrusions. Leaman (1999) cautioned workers about inferring the existence of regionally penetrative joint systems based on alignment of topographical features.

Sub-parallel lineament features are visible on aerial photographs in the area studied by Leaman (1999) at Cape Hauy. Cliff edges appear to show an alignment with these features. The lineaments are commonly an estimated 20 to 40 m apart, although other better defined lineaments, commonly many hundreds of metres long, are up to several hundred metres apart. Although on an outcrop scale these apparent fractures could bend around the cooling columns it seems feasible that the cliff alignments are initially controlled

by true penetrative fractures. Subsequent erosional cliff retreat could then remove the penetrative fracture zones. Elsewhere gulches in dolerite at sea level are usually associated with sub-parallel closely-spaced penetrative fractures. Some of the photo lineament directions appear to be discernible in the measured joint directions presented by Leaman (1999), particularly in the rosette diagram of all joints, but for other photo-lineaments the azimuths are slightly different to that of the dominant joint trends.

Measured joints and fractures

Penetrative joint trends and inclinations have been measured at several locations, particularly in quarries and other excavations where the rocks are well exposed. Clearly dominant joint sets were not recognised at most localities, although they may exist. The collected data (fig. 9) are of limited use as the sampling has been non-random and too little data has been collected for meaningful statistical analysis.

Joint inclinations ranged from near-vertical to sub-horizontal, but particularly in the quarries south of Newmans Creek Road many (~75%) joints were inclined away from vertical by 20° to 70° (fig. 8). A narrow, moist, highly weathered zone of closely fractured rock extends the full height of the lower quarry and has a trend of about 30°. In the lower quarry there are crudely defined sub-horizontal and near-vertical zones that are more intensely fractured.

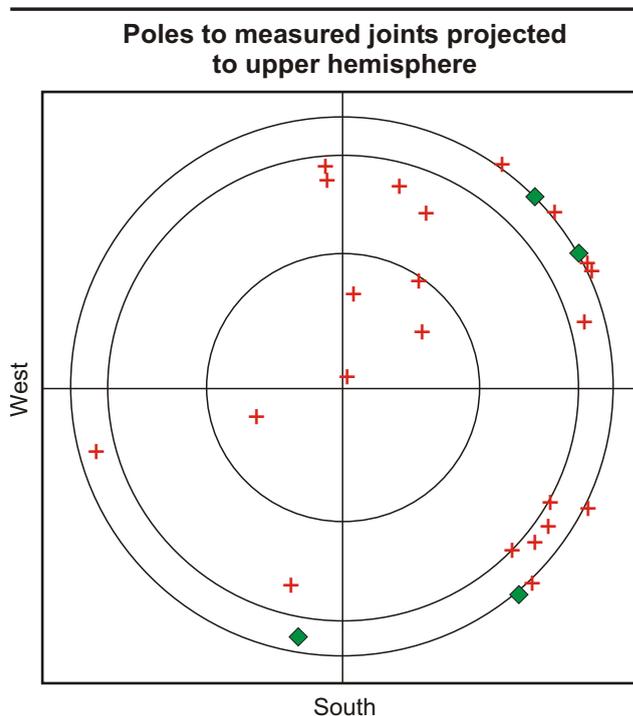**Poles to measured joints projected to upper hemisphere**

Figure 8

Poles to measured joints in dolerite (crosses) mostly from the Newmans Creek Road southern quarries and Upper Parmeener Supergroup rocks (diamonds). Vertical joints plot on the outer circle, joints of 60° inclination plot on the intermediate circle, and joints of 30° inclination plot on the inner circle.
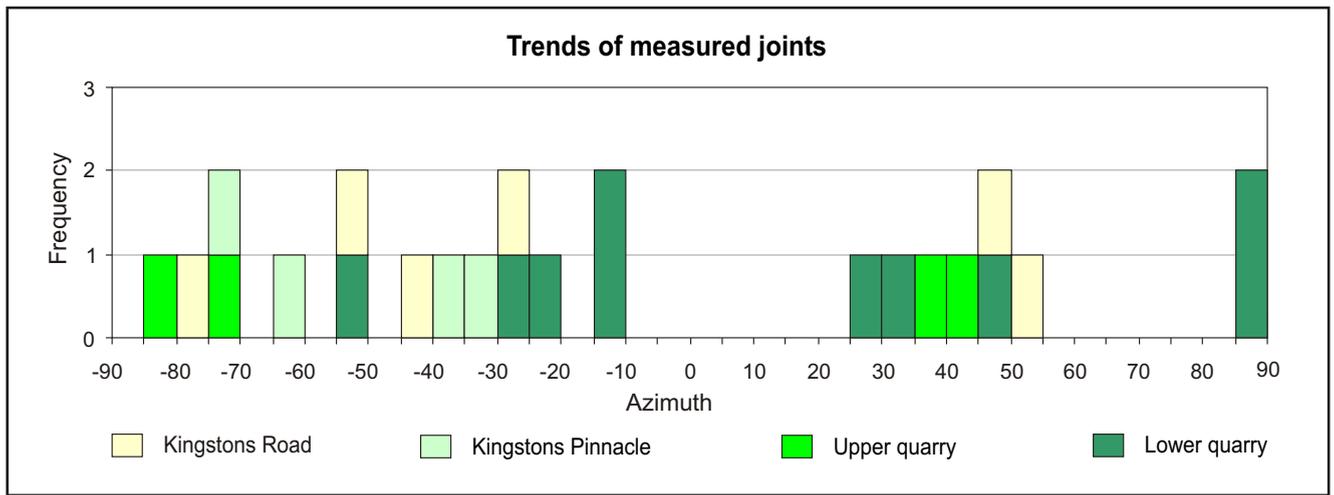
Figure 9

Frequency plot of the horizontal azimuths of joint surfaces in dolerite from various areas including the upper and lower quarries at the southern end of Newmans Creek Road, various exposures close to Kingstons Road and from a house site near Kingstons Pinnacle.
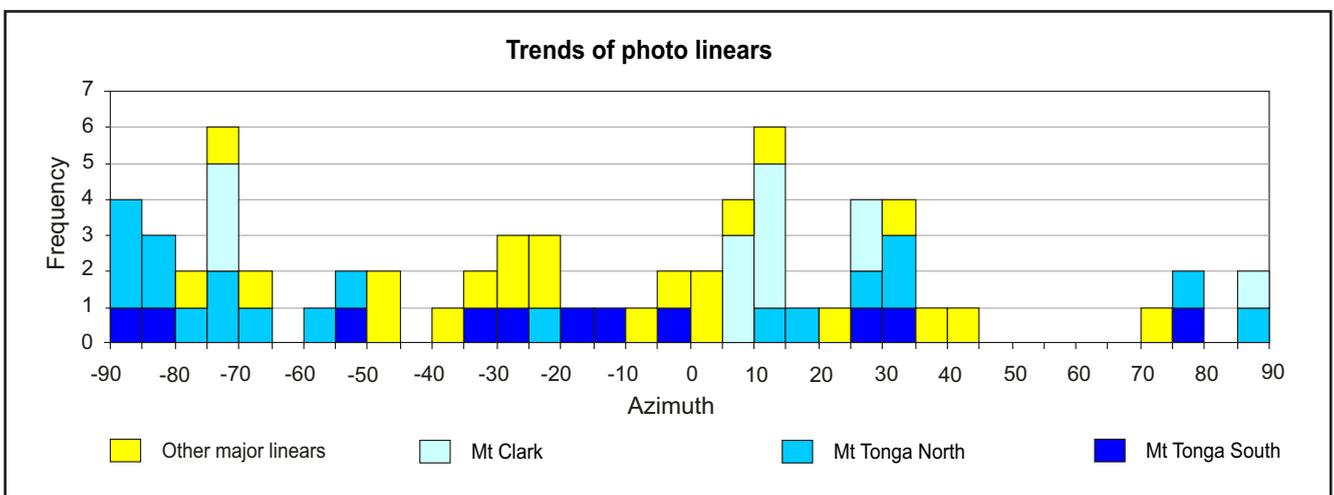
Figure 10

Frequency plot of photo interpreted photo lineaments in dolerite terrain from various areas, including individual lineaments of sub-parallel lineament groups from the northern and southern parts of Mount Tonga, and parts of Mount Clark near Plummers Creek. Individual long lineaments depicted separately as other major lineaments.

In the less fractured zones the joints are generally about 150 mm apart and seldom more than 400 mm apart. In the more fractured zones the joints are about 30 mm apart.

Sloane (1987) reported dominant subvertical joints with a spacing of 300 to 1000 mm in dolerite from near the Mount Clark vehicular access track, whereas from sections of the then proposed Mount Koonya forestry road route Weldon (1991) reported joints with a spacings from 50 to >1000 mm.

PHOTO LINEAMENTS

The trends of photo-interpreted lineaments were studied, including parallel sets of lineaments a few tens of metres apart and individual lineaments that could include fault traces (fig. 10).

When plotted with the measured joint directions (fig. 11), a wide but uneven distribution of azimuths is noted. Because of the non-random collection of data it may be more meaningful to note directions for which no features were noted, i.e. between 55° and 70°.

COMPARISON OF STRUCTURAL TRENDS

Eight faults of various scales and eight dyke segments or intrusive margins were observed (fig. 11), mostly in the adjacent coastal areas to the north. The faults were primarily of trend 305° to 0°, with only one fault outside this trend range (near 60°). Contrasting to this distribution, the dolerite margins (mainly dykes) range predominantly from 350° to 85°, with most trends more easterly than 5°.

The gap in joint and dolerite photo lineament trends between 55° and 70° is instead a direction of dolerite margins, with four of the eight margins measured trending between 50° and 80°.

Figure 11

Frequency plot of the trends of various mapped and photo interpreted features, including photo lineaments, joints, discordant dolerite dykes and exposed faults. Note the limited overlap in tr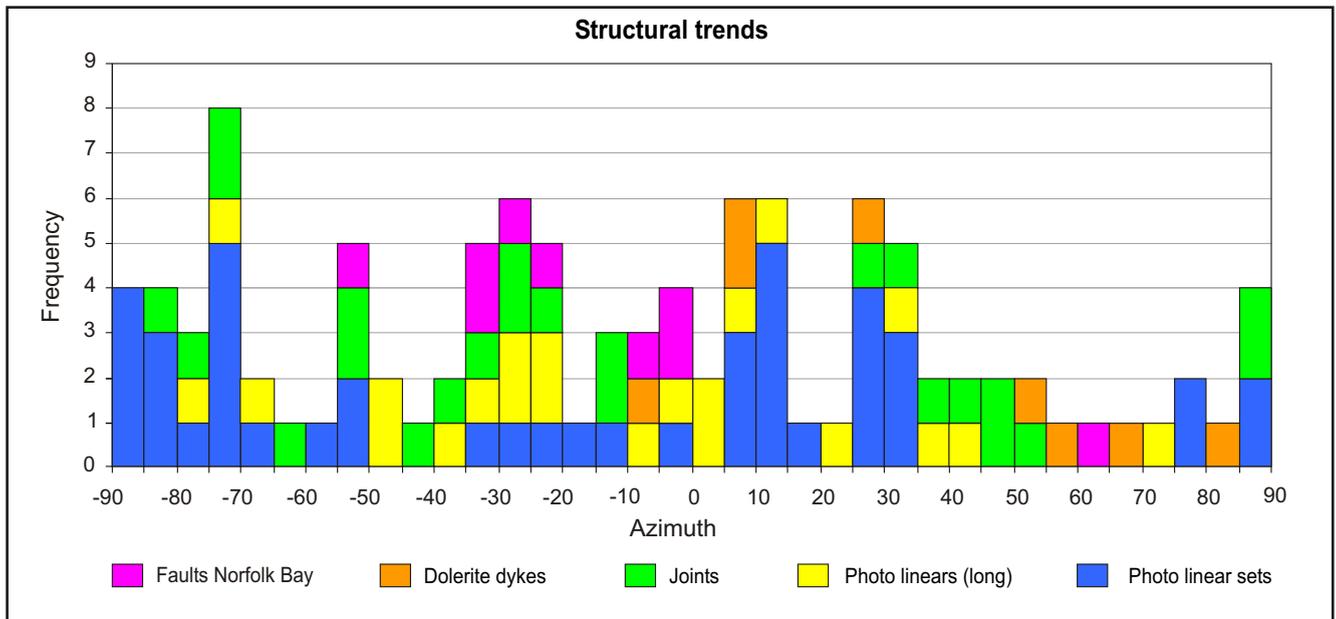ends of dolerite dykes and faults at Norfolk Bay. The uneven distributions of the trends of joints and photo lineament sets may indicate some preferred trends, but could be caused by insufficient data.

Comments on Hydrogeology

There are no water bores in the dolerite at Mount Clark and Mount Koonya to define the piezometric surface. Consequently past workers have relied on the distribution of springs and generalised models of the dolerite fractured aquifer and near-surface talus or soil layers to interpret the hydrogeology (Sloane, 1987; Weldon, 1991; McIntosh *et al.*, 2002). Although the movement of water through talus or at the bedrock and talus/soil interface, or through near-surface open fractures in bedrock, is conceptually simple and highly probable, the possibility of storage and slow release from these environments is more difficult to estimate.

A fractured rock aquifer such as dolerite derives its secondary porosity from the presence of open cracks in the rock, even though the primary porosity of the dolerite is usually low. The permeability of a fractured rock aquifer is a function of the interconnectivity of the fractures. The fractures in dolerite may arise from cooling contraction, tectonic or other intrusive events or from stress release (Leaman, 2002). Weathering and erosion may subsequently enlarge the fractures, providing the weathering products are at least partly removed. Open fractures may later be filled by mineral precipitates or clay. Hale and Spry (1964) suggested that large cavities in dolerite could be produced by dissolution of zeolitised zones. A fractured rock aquifer is capable of storing a large volume of water with a slow release rate.

Modelling a fractured rock aquifer is difficult, as different types of fractures may induce the permeability and the depth to which each fracture type remains open or permeable may vary. Leaman (2002) considered that subhorizontal joints may be open at considerable depth whereas column joints may not be.

The depth to which the fractures of a particular type may remain open also may vary related to surface topography. Adjacent to slopes where the lateral confining forces are less, and where gravitationally induced instability may have been or still is active, fractures would tend to be more open and perhaps markedly so. These effects are expected to be more pronounced where the erosional remnant of the sheet is thin. Observations during construction of the Poatina Power Scheme indicated that the dolerite was impermeable at depth below the Central Plateau, but deep permeable fractures were encountered in altered zones for a lateral distance of 0.5 km inward from the escarpment (G. E. A. Hale, pers. comm., 2003). The plateau margin fractures extend to a much greater depth near Poatina than suggested for Mount Koonya. It is likely that the depth of open fractures is directly related to the scale of the associated escarpment. Alternating dry and wet zones were encountered during construction of the Tungatinah Tunnel (G. E. A. Hale, pers. comm.).

Leaman (1999) demonstrated that the columnar appearance of cliffs of major sub-horizontal dolerite intrusions is caused by the presence of thermal cooling columns rather than epeirogenic joint patterns. Further, Leaman (1999) considered joints perpendicular to the columns and parallel to the sheet boundaries were the most common type of joint near

the upper and lower contacts of dolerite intrusions. If these joints are open near the sheet lower contact in the study area then the local permeability is expected to be directionally isotropic in a zone parallel to the sheet base.

The origin and nature of other sub-parallel lineament features commonly observable on aerial photographs of dolerite is unclear. The lineaments that are commonly about 20 to 40 m apart and locally sub-parallel tend to vary in direction or prominence over broader areas. These features may be master joints and it is likely that Leaman's (1999) observations, such as near Cape Hauy, are primarily on the dolerite masses between the lineaments and not observations on the lineaments themselves.

Elsewhere other photo lineaments, approximately one hundred metres apart and many hundred metres long in places, are parallel to the more closely spaced lineaments, but other widely spaced photo lineaments appear to be significantly oblique. The larger lineaments, and particularly the latter, may be faults. The presence in the Mount Clark–Mount Koonya area of inferred faults, photo lineaments that may be faults, and other photolineaments that may be master joints indicates other potential features that may affect the movement of groundwater. In particular any brecciated or more intensely-jointed areas in fault zones may contain open fractures to a different depth compared to the thermal joints. There is potential for fault zones to provide deeper and directed groundwater flow. Conversely, clay in fault zones may impede groundwater flow across the fault. This situation may arise where extreme weathering has penetrated deeply in fault zones and the clay weathering products have not been removed.

Shallowly to moderately inclined joints have been observed in the area and Leaman (2002) considers relaxation joints of similar attitudes to be important ground water conduits. Relaxation joints may facilitate local groundwater flow from the plateau edges to the escarpments.

Information from waterbores and seismic surveys provide further information regarding the depth of open fractures in dolerite. Leaman (2002) notes that seismic survey results suggest that the majority of fractures in dolerite are closed below 50 metres. The statewide results of water bores suggest 70 m as a general limit for effective permeability in dolerite (M. Latinovich, pers. comm., 2002), although some significant exceptions are known. This figure is based on dolerite sheets in general and may not be indicative for specific situations such as sheet basal contacts or fault zones.

Water bores in Upper Parmeener Supergroup rocks and dolerite on the Tasman Peninsula have similar success rates of about 55% (Matthews, 1989). This suggests similar permeabilities for these rock types, although on a statewide basis bores in Upper Parmeener rocks have a higher success rate (>75%,

Matthews, 1989). This higher success rate is probably related to a much higher primary porosity of the sandstone beds in the Upper Parmeener Supergroup. When individual horizons within the Upper Parmeener Supergroup are considered, those with a high proportion of mudstone or siltstone (and in particular the stratigraphic interval to which rocks underlying the dolerite at Mount Koonya belong) have been found to be poor aquifers, implying that they have low permeability. At Mount Koonya, this structural relationship potentially creates a situation where water accumulated in the dolerite aquifer can discharge as springs near the dolerite lower contact. Bore water yield is also strongly linked to rainfall, so the comparative success rates of bores in different types of aquifers are considerably influenced by the rainfall factor.

Recharge

Except in areas of exposed rock, rain or other atmospheric water must first pass through the soil layers before it enters the unsaturated or saturated zones of the dolerite or regolith to recharge the groundwater. When the soil moisture exceeds the field capacity it becomes possible for gravitational flow of water to commence, enabling interflow or recharge of the aquifer. Where unsaturated soil contains extensive fissures or macropores classical hydrogeology concepts suggest air gaps in the fissures restrict water flow. Although some conceptual models suggest that water flow will tend to remain in the matrix if the vertical water flux is less than the saturated hydraulic conductivity of the matrix, field studies have shown fracture water flow commences at a minimum matrix moisture content less than saturation (Domenico and Schwartz, 1998).

A more recent conceptual model derived from the study of chemical pollution of groundwater in an arid area has indicated that water passes through the unsaturated zone predominantly through fissures. "Thus to a large degree most of the matrix water moves slowly and appears not to play an active role in the short-time scale hydrology, short time again referring to significant precipitation events. The larger the storm event or sequence of events, the more water will enter the fracture and penetrate to greater depths. During small precipitation events, significant fracture flow does not occur, and infiltration takes place slowly through the matrix. This conceptual model is more in tune with observations made in tunnels and underground mines following precipitation events." (Domenico and Schwartz, 1998).

This conceptual model is also considered to apply to fissured clayey soil during significant rainfall events when the rainfall rate exceeds the infiltration rate of the surface soil matrix. Saturation of the low permeability clay matrix enables water to flow to the nearest fissure or macropore where similarly the fissure walls become saturated and fissure flow results.

Thus one view of the recharge at Mount Koonya is that infiltration of significant summer rainfall events rapidly accesses the aquifer through desiccation cracks in the soil on north-facing slopes. Such a process is facilitated by dry periods before the rainfall events and steep slopes that facilitate rapid overland or shallow subsurface flow. Water is considered to rapidly arrive at and enter the cracks to maximise input before the clay component of the soil swells to close the cracks. Another mechanism may operate during prolonged wet periods when the water may infiltrate the soil and aquifer slowly. In this case recharge is maximised by prolonged precipitation and areas of low gradient that retain moisture. Infiltration through root hollows, worm or other animal burrows, and soil tunnels might apply in either situation.

Providing that the rate at which water reaches the regolith/rock boundary does not exceed the rate that water can infiltrate the rock fracture system, then the water will pass through the unsaturated part of the fractured aquifer into the saturated zone. If instead the aquifer infiltration rate is exceeded, water may flow laterally, especially if macropores such as soil tunnels exist at the regolith/rock boundary. Alternatively the water may saturate the lower soil zone, resulting in a perched aquifer. Small streams draining dolerite on the Tasman Peninsula show a relatively short delayed response to high rainfall events (measured in hours) and a significant decline over several days, indicating fairly rapid interflow, but limited storage in the shallow regolith. Locally, where the regolith is thicker and where the internal stratigraphy and drainage of the regolith has been disrupted by mass movement, storage could be greater.

The total amount of recharge of the fractured aquifer may be increased if the period of recharge is lengthened after a rainfall event. This may occur if perched water tables continue to recharge the deeper aquifer or if any greater volume of soil moisture is able to move under gravity to the aquifer. If logging results in improved near-surface lateral drainage (for example by the decay of the previous vegetation root system) then the period of recharge could be decreased because of greater interflow. If water availability for potential recharge exceeds the flow capacity for recharge then the recharge may be partly buffered against the effect of decreasing soil moisture caused by greater transpiration during vigorous regeneration.

Where there is no soil the recharge may be more or less direct from rainfall, or be prolonged indefinitely in an upland stream.

In contrast to flowing streams, where the dolerite may be relatively fresh and fractures open, in other potential infiltration areas the dolerite may be more weathered or clay-rich soil may impede the infiltration process. Exposures of dolerite on the plateau area north of the communication towers at Mount Koonya indicate that the fresh dolerite outcrops are commonly separated by extremely weathered dolerite that has

retained traces of the igneous texture and joint surfaces. Where the weathered dolerite is moist the joints appear to be closed and it is likely that the permeability of the dolerite in this stage of weathering is low compared to dolerite that is entirely fresh or only moderately weathered.

In some areas of low gradient, swamps or alluvial deposits have been inferred based on aerial photo interpretation. Surface water may have a longer retention time in these areas, but the nature of the deposit/rock interface and the likelihood on water infiltration is not known.

A longer retention time for water at the soil interface is probably required for water to infiltrate joints that are extremely weathered near the surface. It is expected that the openness of dolerite joints would be greater in proximity to the plateau or ridge edges and that overlying dolerite clay seals are more likely to have been eroded from these areas.

Overall recharge is expected to be diffuse, the most likely possible exception to this in the plateau area is in the headwaters of Newmans Creek. Because the areas with higher rates of infiltration into the soil do not always correspond to the areas with greater recharge potential within the fractured aquifer, there may be additional spatial variability of recharge rates at Mount Koonya.

The direction of change to recharge caused by forestry operations could vary from place to place. A decreased loss of water to evapotranspiration may increase recharge from upland streams and in areas where slow infiltration occurs through the soil, but would have a neutral effect on recharge in areas of exposed rock and may decrease infiltration through desiccation cracks.

Forestry operations within a recharge area may both increase and decrease water yield (the nett difference between precipitation and evapotranspiration). The result will be partly dependant on the type and age distribution of the pre-existing forest, the age distribution and type of subsequent regrowth, and the percentage of the recharge area effected by logging.

Many other factors may affect the local recharge outcome after forestry operations, including the magnitude and duration of a particular rainfall event, the preceding weather, the thickness and properties of the soil and how they relate to the mechanism of infiltration, and the properties of the dolerite aquifer. Without data from other comparative areas or site specific information for the Mount Koonya area, the direction and magnitude of changes to the recharge caused by these factors are clearly difficult to predict.

As the rain falls predominantly in the cooler months and transpiration is the factor most influencing soil moisture changes, it is assumed that variations in recharge rates expected from forestry activities are more likely to follow the directions of annual water yield change described by Vertessy *et al.* (1998). In areas of slow recharge, prolonged periods of high soil

moisture content, such as may occur in the first few years after logging, will generally increase recharge, but decreased soil moisture during vigorous growth will decrease recharge.

Comments related to previous aquifer concepts

The groundwater concepts previously applied to the Mount Clark area (Sloane, 1987; McIntosh, 2002) appear to be based on an inferred sill or sheet form of the intrusion and the inferred locations of the dolerite contacts. The nature of the dolerite contact, particularly on the southern side of Mount Clark, requires further investigation to confirm a sill-like form, and elsewhere in general to better define the position of the contact. During the current study the base of the dolerite was found to be 40–50 m lower in the headwaters of Plummers Creek than its location less than 700 m to the northeast on the Mount Clark access track. Locally at least, the sense of dip of the basal dolerite contact is opposed to that applied in the McIntosh *et al.* (2002) groundwater sketch. Should the piezometric surface fall approximately northward this dolerite geometry would not prevent groundwater flowing to the northern side of Mount Clark as suggested by Sloane (1987) and McIntosh *et al.* (2002). The asymmetry of the known distribution of spring locations at Mount Clark (Sloane, 1987) may be partly contributed to by the need to locate water close to residences or farms. The apparent lack of springs in the forested valley of Plummer Creek, between Mount Koonya and Mount Clark, may merely indicate a lack of exploration for springs. Fewer springs may also be recorded where alternative water sources are

available, such as where Plummers Creek passes through farmed country.

Generalised concept of the dolerite fractured aquifer

It seems likely that both the piezometric surface and the base of the water-bearing zone in the fractured aquifer are upwardly convex in and near the study area, with a general convergence of the two surfaces where the sheet base intersects the land surface. This configuration is depicted in cartoon form in Figure 12. The lower surface of the water-bearing zone may lie above the basal dolerite contact if the fractures are closed where the sheet is thick. The surfaces are more likely to be down-warped near faults unless clay seals (no flow boundaries) act to partly dam the groundwater. The permeability contrast at the dolerite sheet bases may vary where the sheet is more transgressive and the nature of the underlying strata changes. The gradient direction of the piezometric surface may differ from that of the base of the water-bearing zone.

Comments on the Koonya B spring system

The main springs on the western side of Mount Koonya lie along a drainage line or small creek visible on the 1946 aerial photographs. Both springs occur near cliff lines of Upper Parmeener Supergroup rocks where the water that flows along the rock–soil interface becomes more apparent. Upslope from both springs the shallow water flow is partly concealed by a cover of soil or dolerite talus. Several very small
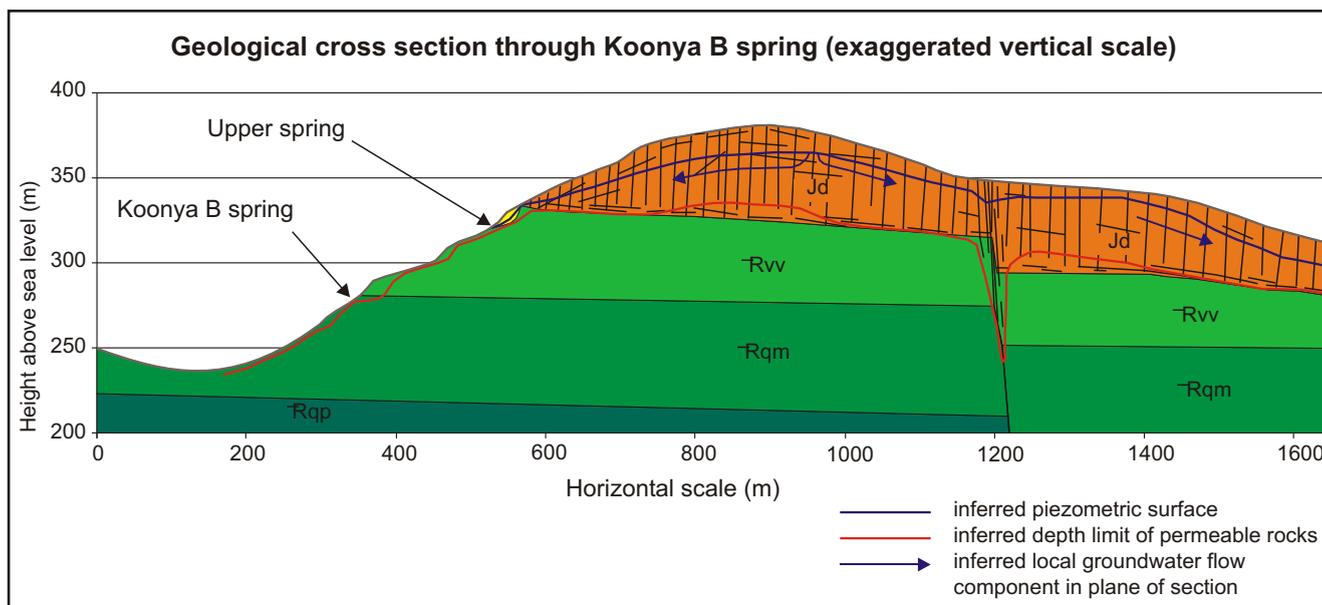
Figure 12

Geological cross section along line trending approximately 110° east of north and passing through the Koonya B spring. The fault location and positions of subsurface geological boundaries are diagrammatic only as they are inferred by extrapolation over considerable distances. Fractures in dolerite are similarly diagrammatic only. The direction of local groundwater flow component in the plane of the section, depth limit of permeable rocks and piezometric surface are entirely inferential.

tributaries concentrate the water flow near the top spring, but a drainage line is still evident in the dolerite talus on the shelf above. Part of the water may seep from a fractured rock aquifer as concluded by Sloane (1987) at Mount Clark, but an entirely surface drainage course origin for a component of the water cannot be ruled out in this area. It is possible that the fractured rock aquifer component may be concentrated by major defects rather than accumulating in response to the geometry of the dolerite sheet base.

Fluctuations through time of the total dissolved solids (TDS) and pH of the Koonya B water (McIntosh and Haywood, 2003) suggest that more saline and more alkaline ground water is diluted by increased overland flow or near-surface groundwater following rainfall events. The TDS values reported from the Koonya B spring range from 225 mg/L to 305 mg/L. Sloane (1987) reported salinities of 150 mg/L and 250 mg/L from two seepages on nearby Mount Clark.

Ezzy (pers. comm.) noted that the TDS of groundwater from zones of shallow, weathered, very fractured dolerite exposed in highway cuttings close to Longley, near Hobart, ranged from ~60 mg/L to ~85 mg/L within 48 hours of a major rainfall event. The flow rate in the weathered zone decayed rapidly over a period of a few days, whereas slower seepages from deeper, less weathered dolerite were maintained. The total recharge area for this flow may be 25 hectares, although the recharge area for the shallow flow is probably more local and only a few hectares in size. These observations suggest that the Koonya B base flow may have a longer retention time in the aquifer.

Regionally the land surface intersection of the dolerite sheet base is close to its highest point (>360 m ASL) within a few hundred metres of the surface drainage line that feeds the Koonya B spring, but locally the basal dolerite contact has a northward falling component towards the drainage line. Local irregularities of the dolerite sheet base appear to be of greater magnitude than variations in dip of the underlying strata. Unfortunately only apparent dip components are easily recognised in the outcrop pattern of the sedimentary rocks. The true dips are most likely to be in the range of towards ESE through east to north. On a broad scale the dolerite basal contact is approximately concordant with the strata on the northwest and northern sides of Mount Koonya. The overall fall of the sheet base appears to be greatest towards the east, but this is probably contributed to by faults with a similar sense of downthrow and the dips of the blocks between the faults may be in different directions.

Flow direction

The direction of groundwater flow is controlled by the hydraulic gradient and the orientation of the actual conduits available for flow. In an homogenous porous media aquifer the orientation of the conduits are numerous at scales several times the grainsize, so only

the hydraulic gradient need be considered. This statement could also be considered to apply to homogeneous fractured aquifers at a scale several times the fracture spacing. By boring holes to install piezometers the hydraulic head can be measured at point localities through a groundwater system. This information can then be contoured to obtain lines or surfaces of equipotential. In one or more homogeneous aquifers, knowledge of the geological boundaries that separate the different aquifers can reduce the number of piezometers required to adequately describe the hydraulic head for the purpose required.

In the dolerite fractured aquifer at Mount Koonya the hydraulic conductivity is likely to be quite variable because of the variations in fracture types and properties already noted, but the hydraulic conductivity may be relatively uniform within some zones. For example, on average the hydraulic conductivity in the horizontal plane is likely to decrease with depth, but discontinuities could be expected in passing from the surface weathered zone to unweathered dolerite. In general the vertical hydraulic conductivity may differ from the horizontal hydraulic conductivity because of the preponderance of vertical fractures, although the relative difference in these vectors for any given depth could also differ. The more fractured zone at the base of the dolerite sheet is considered to have a higher hydraulic conductivity than the dolerite immediately above it, but the absolute value probably varies according to depth.

Fractures of tectonic origin within parts of the dolerite intrusion probably result in a degree of anisotropy in the horizontal plane because, locally at least, they will probably belong to one of several sets of distinct azimuth. Similarly, relaxation joints may contribute to anisotropic hydraulic conductivity. On a broad enough scale the average anisotropic hydraulic conductivity could be determined and applied over the larger volume of the aquifer scale, providing the geological conditions remain constant. This determination could probably be achieved by a combination of drilling, geophysical surveys and more detailed geological surveys. Some field techniques and their limitations are discussed by Cook (2003).

Beyond this scale there probably exist fault lines (some already inferred at Mount Koonya and others as yet undetected) and possible intrusive boundaries within the dolerite where the hydraulic conductivity could be sufficiently different from that of the surrounding rock mass to require individual consideration as discrete flow pathways. This difference will distort the lines of equipotential from their more uniform form and direct some flow lines into surfaces parallel to the structural features.

Near the escarpments the direction of flow in the fault zones is probably towards the escarpment. Elsewhere there may be divergences of flow into opposite directions depending on the hydraulic gradient. The effect of clay barriers in fault zones is likely to similarly

direct water flow laterally along the adjacent fractures of the fault zone, although the hydraulic conductance would be less, and to reduce the height of the piezometric surface on the other side of the fault. In these cases the orientation of the adjacent fracture zone is considered to have a greater control on flow direction than the hydraulic gradient across the fault. The possible northwest-trending fault immediately northeast of Kingstons Pinnacle may intercept a component of the surface water flowing in a tributary of Newmans Creek and deliver seepage to a spring north of Kingstons Pinnacle. This spring water is utilised on the Clark and Campbell farms (Marcus Clark, pers. comm., 2002).

Whereas it may be possible to indicate the relative difference in hydraulic conductivity between some adjacent parts of the dolerite intrusion there is insufficient information available to indicate the magnitude of those differences, or in many cases the relative difference of the hydraulic conductivity in non-adjacent parts of the intrusion.

The variable magnitude and direction of the hydraulic conductivity vector through the dolerite will cause the lines of equipotential to be distributed differently to that expected if the hydraulic head was determined by depth within the groundwater and topographic height alone.

Flow directions of near-surface groundwater through the soil layers, talus or very shallow fractures and weathered zones of the dolerite can be expected to be similar to what might be expected for overland flow, that is, down the maximum topographic gradient with some departures that might cause translation of some flow laterally along slopes. Because of scale and other factors, the 10 m contour topographic map does not consistently indicate the maximum local land gradient and some drainage lines up to 300 m long were noted that were only slightly oblique to the contour lines.

Deeper flow directions in the dolerite intrusion cannot be indicated reliably because of the absence of detailed information. The azimuths of the flow lines in any one area may also vary according to depth. A first order approximation of the flow vectors can be attempted based on classical concepts of topographically-driven groundwater flow and consideration of the asymmetry/symmetry.

In the absence of other information, the piezometric surface (corresponding to the top of the saturated zone in an unconfined aquifer) can be regarded in shape as a subdued version of the land surface topography. Typically the piezometric surface is deeper at topographic highs and shallower (or may intersect the land surface) in the intervening valleys. Flow directions are directed downward on the ridges and these areas are conceptually regarded as the prime recharge areas, whereas in the valleys flow directions may be orientated upwards and discharge of groundwater may take place. The valleys and ridges in a symmetrical situation thus partition the groundwater flow into a series of flow cells where each ridge separates two cells in which the groundwater initially moves downward then outwards from the ridge.

If the detailed spatial distribution of the aquifer properties is unknown, but is symmetrical, some indication of flow direction can be obtained based on the topographically-driven flow cell concept. Alternatively some indication of the effects of asymmetry in one variable can be indicated, providing other variables remain symmetrically distributed. These variables can include topography, hydraulic conductivity (including the presence and orientation of preferred pathways for water flow), recharge and discharge rates, and location.

A consideration of asymmetry has been used (below) to determine the approximate flow directions along the Koonya divide to estimate the likely recharge area of the deeper fractured aquifer component of the Koonya B spring system. A consideration of symmetry also suggests that the piezometric surface crest is probably situated east of the surface divide along parts of the Koonya divide when recharge rates are symmetrically distributed. Thus the partitioning of the flow cell boundaries is considered to result in the recharge area for the western flow cell to lie east of the surface divide along parts of the Koonya divide.

The location of the piezometric surface is not static and fluctuates through time according to the water balance of recharge and discharge. The fluctuations are expected to be greatest near the piezometric surface crest and be largely in response to rainfall. Piezometric surface fluctuations tend to be larger in a fractured aquifer (because of the small fracture porosity) compared to that of a porous medium aquifer.

A second form of fluctuation may result from the effects of forestry operations, when increased water yield after harvest may lead to a relative rise in the piezometric surface beneath a cleared area. During vigorous regrowth decreased water yield may lead to a corresponding fall in the piezometric surface. Local rises and falls of the piezometric surface will induce outflow and inflow from these areas. Near crests in the piezometric surface, where the surface approaches and becomes horizontal, such fluctuations have the potential to alter the gradient direction of the piezometric surface and the location of the boundaries between flow cells. Therefore forestry operations near these crests have the potential to alter flow directions and the locations of the boundaries between the recharge areas of the different flow cells. The likelihood and magnitude of such changes cannot be adequately estimated based on current information.

Further away from crests, where the topographic slope increases, the size of these fluctuations are expected to be small with respect to the topographically-induced variation down the slope. Any inflow or outflow induced by forestry operations remote from the crest is

considered to have significantly less effect on piezometric surface gradients near the crest.

Flow directions near the Koonya divide in the vicinity of the Koonya B spring system

The dolerite basal contact is about 330–340 m ASL above the Koonya B spring/upper spring water system. The geometry of the dolerite fractured aquifer is such that the recharge area for this spring system is contained within the map area of Mount Koonya above the 330 m contour, an area of approximately four square kilometres.

For much of this area south of the G. Giblin coupe the more-or-less symmetrical ridge of Mount Koonya probably partitions the groundwater into two approximately equal flow cells. The southeast cell is considered to direct water into the catchment of Kennedy Creek. The surface water divide is considered to approximately correspond to the crest of the piezometric surface, although it is possible that relaxation joints could enable groundwater to locally cross the surface divide along the ridge. For most of the ridge the inferred base of the dolerite is considered to be 70 to 200 m below the land surface. This is considered to further limit basal contact flow as the fractures at these depths are expected to be closed or significantly less open than for shallower depths. The inferred geometry of the basal dolerite contact, based on the known surface exposures, is expected to have a neutral or enhancing effect on any basal contact flow direction as suggested for the groundwater cells.

In considering the northwest cell in more detail a further partitioning of groundwater flow is expected, approximately coinciding with the Plummers Creek–Cascades Rivulet surface catchment divide. Recharge south of this divide is expected to flow towards Plummers Creek.

North of this divide a potential dolerite aquifer recharge area of about 65 hectares occurs west of the Mount Koonya–Kingstons Pinnacle divide. Above the 400 m contour this divide is a narrow and moderately steep-sided ridge; a profile determined from the contour map indicates a lateral fall of 70 m with gradient of 23°. Further north, and approximately corresponding to the G. Giblin coupe, the crest of the divide falls below the 400 m contour and the ridge is broadly rounded over a lateral width of about 300 metres. Here the initial 10 m lateral fall from the crest has gradients of 2.5° to 5°. These gradients steepen downslope to mostly about 13.5° to 17° above the Cascades Rivulet in the west, and to about 6° to 13.5° degrees in the east.

This asymmetry, and the presence of several discharge seepages from the aquifer on the western side of the divide, is considered to result in a lower piezometric surface west of the divide compared to the eastern side. The potential for the aquifer fractures to be more open nearer the escarpment may facilitate westerly draining of the fractures, but this may be balanced to some extent by the potential for draining near the inferred fault between Kingstons Pinnacle and Mount Koonya. Before logging, the crest of the piezometric surface therefore is considered to have been east of the surface divide. No piezometers existed before logging or currently exist to test this retrospective prediction and the dynamics of the piezometric surface shape and depth are unknown.

The extent to which the piezometric surface crest lies east of the surface drainage divide near the Koonya B system determines the extent to which the recharge area east of the divide contributes to the recharge of the western groundwater cell. No reliable estimate can be made for this potential recharge area east of the divide based on the existing information, but a cautious approach would be to include an area of around 20 hectares. The eastern boundary of this area approximately corresponds to a line drawn 15 m below the crest of the surface water divide.

Inclusion of this additional potential recharge area increases the potential recharge area for the springs between the fire tower and Kingstons Pinnacle to about 85 hectares.

Partitioning the contribution from the recharge area to individual springs within the western cell adds a further level of uncertainty. Three springs from 300 m to 500 m apart are known and of these the Koonya B spring probably has the largest flow. One of these springs flows through talus deposits, or at the base of these deposits, and was not located until it was revealed by road construction. It seems likely that further hidden flows may extend from the dolerite aquifer through the talus lobes to enter Cascades Rivulet.

In the absence of detailed information, significance is attached to the number of springs and their proximity to potential recharge areas to estimate the recharge area per spring. A reasonable estimate for the recharge area of the Koonya B spring is perhaps 30 hectares, although this figure might under or over estimate the area by ten or more hectares. It seems unlikely that groundwater from the G. Giblin coupe recharge area could flow to the spring near the walking track to the Mount Koonya Fire Tower, but the coupe may be part of the Koonya B recharge area.

It is apparent from the presence of the springs that at least the groundwater flux near these discharge points is non-uniform. This variable character of the aquifer may be restricted to the discharge areas or may be more widespread and influence general water transmission and recharge.

Conclusions

The base flow of springs in the Mount Koonya area is probably derived from a fractured dolerite aquifer. Spring peak flow is probably a combination of discharge from the deeper dolerite fractured aquifer, the regolith aquifer, and possibly overland flow mostly directed by drainage lines.

Based on the current limited information, the location of the springs, the concept of topographically-driven flow cells, consideration of symmetry and potential preferred pathways probably provides the best means of crudely estimating the flow paths and the location of recharge areas for groups of springs within flow cells. The recharge areas for individual springs are more difficult to define.

The depth and position of the piezometric surface crest in the vicinity of the Koonya divide are unknown, but in some areas the piezometric surface crest probably is east of the divide when the forest water yield is symmetric about the surface divide.

It appears likely that before logging the water that reached the Koonya B spring above Fire Tower Road was derived from local infiltration zones largely west of the Mount Koonya–Kingstons Pinnacle surface divide. A smaller, but significant proportion of subsurface water was probably derived from infiltration east of the surface divide.

The potential existence of faults of northwest trend and other fracture zones could facilitate the subsurface flow of ground water to the Fire Tower Road area from east of the surface divide. Such an effect may be more likely north of Kingstons Pinnacle, but becomes increasingly less likely in an easterly direction as the piezometric surface must eventually fall towards the valleys of Newmans Creek and Kennedy Creek.

Forestry operations have the potential to displace the piezometric crest and the boundaries between the inferred flow cells, and hence alter the areas of recharge for individual springs.

Forestry operations east of the inferred piezometric crest near the Koonya divide are less likely to alter the base flow of springs west of the divide than operations west of the piezometric crest.

Forestry operations within a recharge area may both increase and decrease water yield and inferentially spring base flow. The result will be partly dependant on the type and age distribution of the pre-existing forest, the age distribution and type of subsequent regrowth, the percentage of the recharge area affected by logging and any changes to recharge area boundaries caused by migration of flow cell boundaries.

The spatial distribution of the hydraulic head and the hydraulic conductivity of the fractured dolerite aquifer are both very poorly quantitatively defined at Mount Koonya.

The numerical relationships between precipitation less evapotranspiration, recharge of the fractured aquifer and spring base flow are not known. The recharge rate probably varies spatially and temporally because of the likely presence of preferred recharge pathways, variations in soil depth, surface gradient and seasonal changes of rainfall, and of soil transmissivity caused by desiccation cracking.

Water budget considerations of the entire area and over a long time interval, based on frequently measured rainfall, stream and spring flow, might bring less ambiguity to the interpretation. In particular the establishment of a means to frequently measure flow rate, or should that be difficult a proxy means such as frequent measurement of TDS and pH of the Koonya B system, might prove useful to determine interflow and base flow recession. Borehole information on the gradient of the piezometric surface and the hydraulic gradient of the shallow and deep aquifers, and more precise information regarding the location of faults and openness of fractures, is probably required to provide the necessary information on which to base firm conclusions about the hydrogeology.

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[12 November 2003]

APPENDIX 1

Some properties of dolerite and dolerite talus aquifers from various sources

Source	Latinovich *et al.* (2003)	Ezzy (2000)	Leaman (2002)					
Rock type	Dolerite	Dolerite	Dolerite	Fine-grained jointed dolerite	Med.-grained jointed dolerite	Massive dolerite	Dolerite talus	Clay, soil B
Hydraulic conductivity (m/day)	0.1–1	0.022–0.296 (0.106)	0.0003+–1.83	>0.025	0.4–1.83+	0.0003–0.8 (0.004)	>0.02–0.04 >(0.03)	0.0001– 0.000001
Aquifer transmissivity (m²/day)	5–100	1.1–2.62 (1.83)	0.001–4	1+	0.1–0.4+	0.001–4	>0.1–2 (>0.15 est.)	
Specific yield (%)	1							
Groundwater salinity (dS/m)	0.14–10.5							
Storativity				0.000000001	0.5–2.5		negligible	

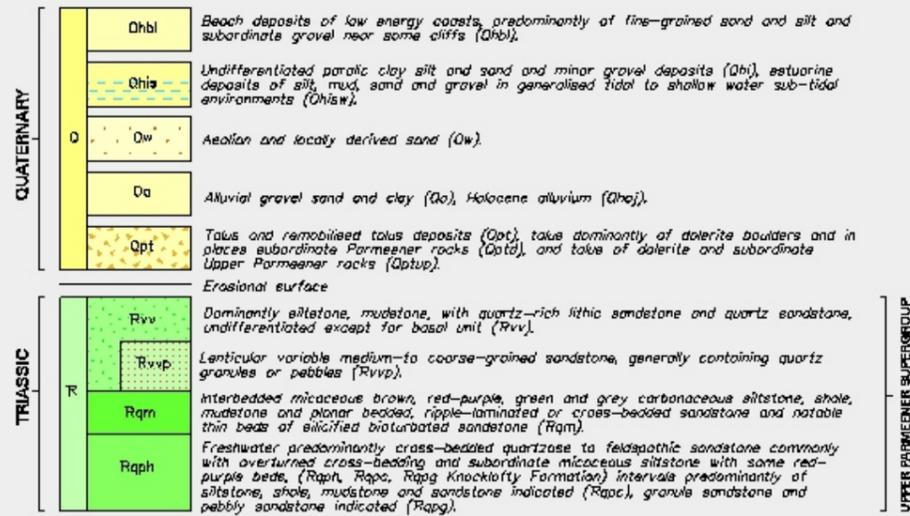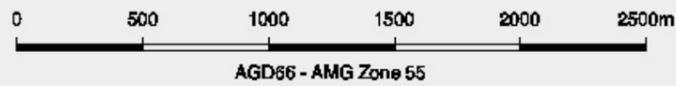Average values shown in brackets

Salinity values (total dissolved solids TDS) for local flow systems in high-relief Jurassic dolerite (Latinovich et al., 2003).

Salinity range (mg/L)	Percentage of available salinity data in range
105–1000	48
1000–2000	37
2000–11200	15

Figure 1
*(printed 1:25 000 scale maps
are available from Mineral
Resources Tasmania)*

MINERAL RESOURCES
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Tasmania

DEPARTMENT of INFRASTRUCTURE
ENERGY and RESOURCES

GEOLOGY OF THE KOONYA AREA
Geology by S.M. Forsyth B.Sc.

0   500   1000   1500   2000   2500m

AGD66 - AMG Zone 55

QUATERNARY

Q

Qhbl — Beach deposits of low energy coasts, predominantly of fine–grained sand and silt and subordinate gravel near some cliffs (Qhbl).

Qhis — Undifferentiated paralic clay silt and sand and minor gravel deposits (Qhi), estuarine deposits of silt, mud, sand and gravel in generalised tidal to shallow water sub–tidal environments (Qhisw).

Qw — Aeolian and locally derived sand (Qw).

Qa — Alluvial gravel sand and clay (Qa), Holocene alluvium (Qhaj).

Qpt — Talus and remobilised talus deposits (Qpt), talus dominantly of dolerite boulders and in places subordinate Parmeener rocks (Qptd), and talus of dolerite and subordinate Upper Parmeener rocks (Qptup).

Erosional surface

TRIASSIC

R

Rvv — Dominantly siltstone, mudstone, with quartz–rich lithic sandstone and quartz sandstone, undifferentiated except for basal unit (Rvv).

Rvvp — Lenticular variable medium–to coarse–grained sandstone, generally containing quartz granules or pebbles (Rvvp).

Rqm — Interbedded micaceous brown, red–purple, green and grey carbonaceous siltstone, shale, mudstone and planar bedded, ripple–laminated or cross–bedded sandstone and notable thin beds of silicified bioturbated sandstone (Rqm).

Rqph — Freshwater predominantly cross–bedded quartzose to feldspathic sandstone commonly with overturned cross–bedding and subordinate micaceous siltstone with some red–purple beds, (Rqph, Rqpc, Rqpg Knocklofty Formation) intervals predominantly of siltstone, shale, mudstone and sandstone indicated (Rqpc), granule sandstone and pebbly sandstone indicated (Rqpg).

UPPER PARMEENER SUPERGROUP

IGNEOUS ROCKS

JURASSIC

Jd — Dolerite (Jd), with orthopyroxene (o), granophyre and pegmatite indicated (g). Dolerite of grainsize 0 – 0.7mm (vf); 0.7 – 1.5mm (f); 1.5 – 3mm (m); >3mm (c); >8mm (vc) indicated.

— Geological boundary – position accurate or approximate.

---- Geological boundary – inferred.

Slope break.

Scarp.

----- Bedding trace interpreted from aerial photographs.

— Photo lineament.

(white line) — Limit of mapping of sub–unit within undifferentiated rock unit.

— — Fault – position accurate or approx.

— — — t — Fault – inferred, downthrow side indicated.

• Small outcrop or lag occurence.

● Spring – captured and uncaptured.

■ Seepage – diffuse.

● Possible spring – photo interpreted.

● Possible spring – other.

RESPONSIBILITY DIAGRAM

[B] [B] [C] [F] [A] [E] [D]

Geology based on -
(see responsibility diagram)

A. Forsyth, S.M. 1:100,000 New mapping 2002.

B. Edwards, A.N., 1990. Regional geology of the Koonya area with emphasis on the Triassic Palaeogeography. B.Sc. (Hons.) thesis, University of Tasmania; Forsyth, S.M. 1:100,000 New mapping 2002

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Base information from Land Information Services Division, Department of Primary Industries, Water and Environment.

Map produced by the Data Management Branch, Mineral Resources Tasmania using G.I.S. software.

Figure 1 (legend)
(printed 1:25 000 scale maps are available from Mineral Resources Tasmania)