

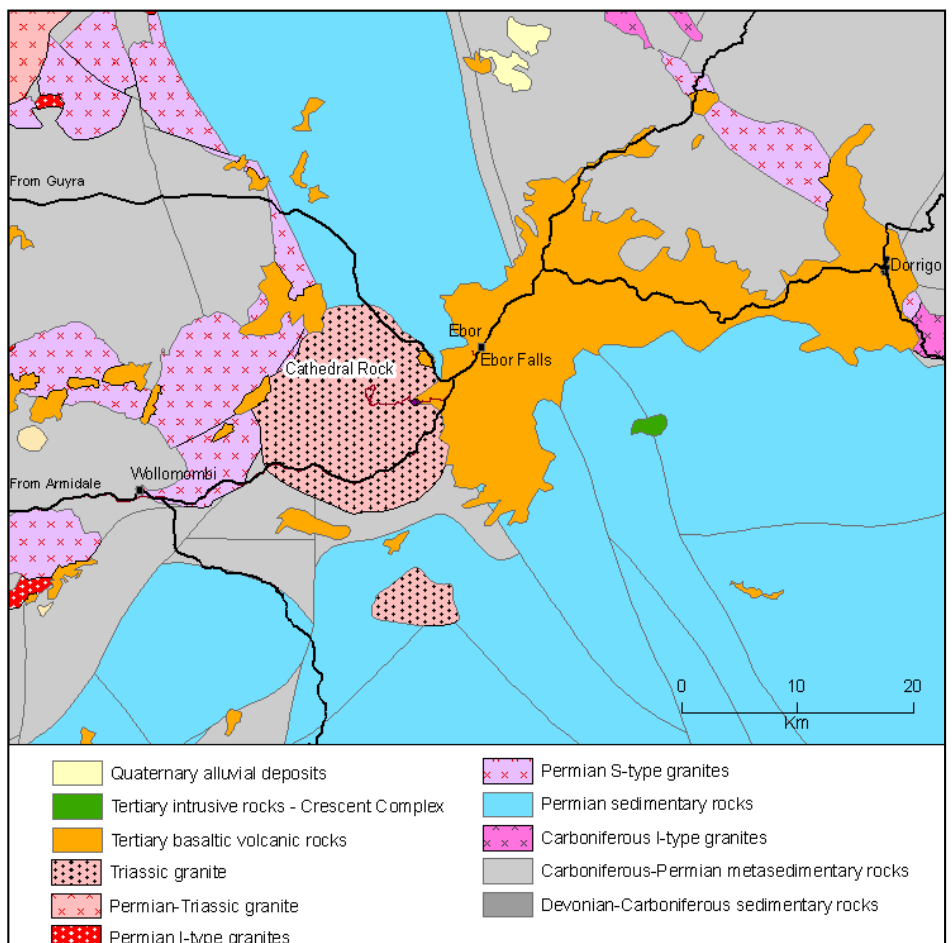


The Cathedral Rock National Park is situated on the northern tablelands in the New England region of New South Wales. The park lies between Armidale, Guyra and Dorrigo at a relatively high altitude of over 1000 metres. The park is well known for the spectacular granite landforms and beautiful native bushland. The park mainly occurs on a large granite mass (Map 1), but also includes some interesting basaltic rocks derived from different volcanic vents of various ages, including the extinct Ebor Volcano.

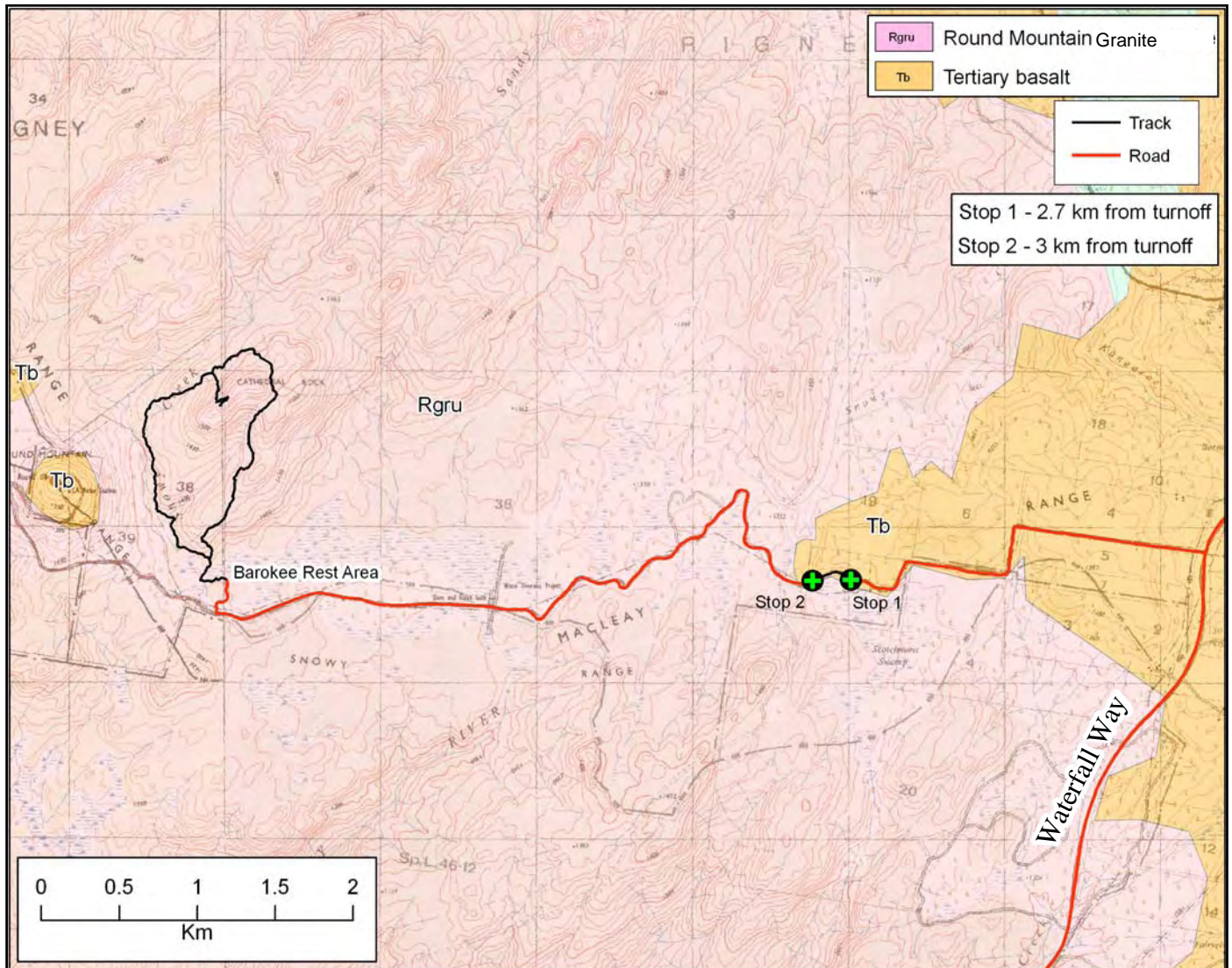
This guide provides a description of some of the rocks and landforms within and adjacent to the Cathedral Rock National Park, including Ebor Falls. The guide commences at the intersection of the Waterfall Way and the access road into the National Park (Map 2). Distances to the first stops are measured from that intersection. The descriptions focus on sites along the access road, the Barokee loop track and Cathedral Rock side track, and Ebor Falls.

LOCAL AND REGIONAL GEOLOGY

The Cathedral Rock region mainly comprises Carboniferous and Permian sedimentary rocks which have been intruded and metamorphosed by a number of Permian to Triassic granites (Table 1). These have been subsequently intruded by Eocene and Miocene basaltic magmas which locally reached the surface to extrude as lavas and ash. Accelerated erosion accompanying uplift of the Great Dividing Range has incised deeply into these rocks, forming the Great Escarpment and associated gorge-dominated terrain.



Map 1. Simplified geology of the Dorrigo-Ebor-Wollomombi region showing the Ebor Falls and Cathedral Rock areas.



Map 2. Geological map and access road into Cathedral Rock National Park. The Barokee Rest Area, loop track and side track to Cathedral Rock are shown. For more detail of this area see Map 2.

The oldest rocks present in the local region are Carboniferous to early Permian mudstones, siltstones, sandstones and cherts. These were formed in a very deep ocean many kilometres from land. They were transported to the edge of the continent by movement of the underlying crust toward a subduction zone which existed along the margin of the Australian landmass. The sediments were scraped off against the edge of the continent as their crust sank downwards into the subduction zone, forming a mass of compressed and deformed rocks known as an *accretionary wedge*. During this time Australia was moving about the surface of the earth by continental drift, becoming part of the supercontinent *Pangaea* in the early Permian. When *Pangaea* broke apart during the end of the Permian, Australia was part of *Gondwana*, which itself began to break apart in the Jurassic.

Melting of subducted crustal material during the Permian and into the earliest Triassic formed magmas which travelled upward through the crust. The oldest of these magmas were primarily melted from sedimentary rocks. These rose high into the crust where they cooled to form *S-type granites* (*S* = sedimentary origin). *S-type granites* are characterised by distinctive minerals and chemical compositions. The youngest, and most common granites were formed from the melting of igneous rocks or sedimentary or metamorphic rocks which were rich in igneous material. These are referred to as *I-type granites*. The large granite outcropping at Cathedral Rock is an *I-type granite*, the Round Mountain Granite, which was emplaced about 250 million years ago.

Following emplacement of the granites in the Jurassic, *Gondwana* began to break apart. Australia was still attached to Antarctica and New Zealand. During the Cretaceous large parts of eastern and central Australia sagged below sea level, and large sedimentary basins resulted. Then from the Paleocene the present eastern

PERIOD	YEARS AGO	LIFE FORMS	GEOLOGICAL EVENTS
Holocene	0 - 10,000	Human Beings	Continued erosion of Great Divide, and westerly retreat of Great Escarpment.
Pleistocene	10,000 - 1,800,000		Last Ice Age reached greatest intensity 20,000 years ago, and had ceased in Australia by about 11,700.
Pliocene	1,800,000 - 5,300,000		Continued uplift of Great Divide and erosion along east to form Great Escarpment.
Miocene	5,300,000 - 23,000,000	Grazing and carnivorous Mammals	Eruption of Ebor Volcano above mantle hotspot 19.6-19.2 million years ago.
Oligocene	23,000,000 - 33,900,000		Continued uplift of Great Divide and erosion along east to form Great Escarpment.
Eocene	33,900,000 - 55,800,000	Modern mammals	Round Mountain volcano erupted about 48 million years ago. Australia separated from Antarctica 55 million years ago and began moving rapidly northward.
Paleocene	55,800,000 - 66,500,000	Placental animals	Beginning of uplift of the Great Dividing Range - continues to Pliocene
Cretaceous	66,500,000 - 145,500,000	Last dinosaurs. First flowering plants	
Jurassic	145,500,000-200,000,000	First birds. Reptiles and ammonites abundant.	Gondwana begins to break apart.
Triassic	200,000,000-250,000,000	First dinosaurs, ammonites and primitive mammals	Formation of Gondwana. I-type granites intrude.
Permian	250,000,000-299,000,000	Mammal-like reptiles. Last trilobites.	I-type granites intrude.
Carboniferous	299,000,000-359,000,000	First reptiles, fern forests	Formation of new supercontinent, Pangaea. S-type granites intrude. Deep water marine sedimentary rocks form part of accretionary wedge.
Devonian	359,000,000-416,000,000	First amphibians and insects	Deep water marine sedimentary rocks form part of accretionary wedge
Silurian	416,000,000-443,000,000	Vascular land plants	No rocks from this time in local area.
Ordovician	444,000,000-488,000,000	First corals, fish with vertebrae	
Cambrian	488,000,000-542,000,000	Shellfish, trilobites	

Table 1. Simplified geological history of northeastern New South Wales.

coastline began to uplift and Antarctica and subsequently New Zealand were split from Australia. Eastern Australian uplift formed the great dividing range, with its associated deep gorges and retreating escarpment.

During the Eocene, tensional stresses within the eastern Australian continent resulted in a period of *intraplate* volcanic activity (which accompanied uplift of the Great Divide) and locally formed the *Doughboy province* lava field. *Lava fields* spanning the two age ranges from 70-14 million years and 5-0.001 million years are common in eastern Australia (Figure 1). Most lava fields were formed between 60 and 20 million years ago. They are distinguished from *Central Volcanoes* based upon the types of lavas and the form of the volcanic edifices. Lava fields typically erupted from small vents and fissures, and produce basaltic lavas of *alkaline* basaltic composition. *Alkaline basaltic* lavas (see Glossary) are iron-poor and silica-undersaturated; consequently they may contain feldspathoids (e.g. nepheline, leucite, analcite). Common basaltic alkaline lavas include *olivine basalt* (olivine + plagioclase + augite) and *basanite* (plagioclase + augite + olivine + feldspathoids). The lava fields may cover extensive areas and form very thick deposits of lava and ash.

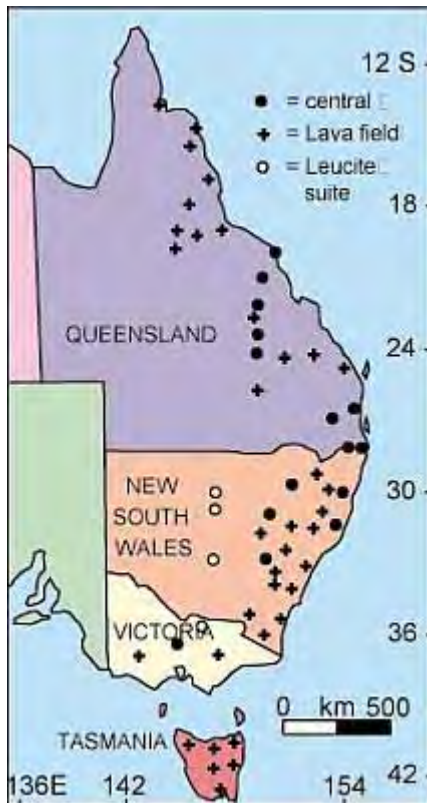


Figure 1. The distribution of Paleocene to Holocene lava fields and central volcanoes in eastern Australia.

From the Paleocene to present, the Australian plate has moved northward across a *mantle hotspot*. Mantle hotspots occur above fixed *convection cells*, where outward directed heat is focused in the top of the mantle and lower crust, resulting in melting of the rocks near the top of the cell (Figure 2). The hotspot has resulted in the formation of a long, broad track of extinct central volcanoes extending from the oldest in north Queensland, to the youngest in Victoria (Figure 1). The hotspot is presently believed to be

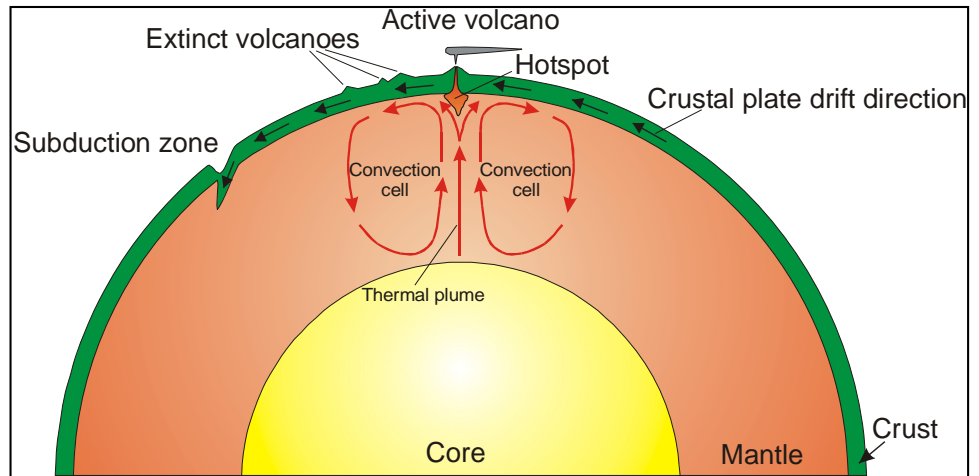


Figure 2. Diagrammatic representation of a mantle hotspot, showing convection cells. The slowly drifting crustal plate passes across the hotspot, where magma formed by melting at the hotspot intrudes outward, erupting at the surface to form a volcano. As the volcano passes away from the hotspot its magma cools and hardens and the volcano becomes extinct.

beneath Bass Strait, where seismic activity first detected in 2002 suggests that magma is beginning to rise again. The hotspot has formed magmas of *tholeiitic* basaltic composition, which in some places are accompanied by volumetrically less *dacite*, *trachyte* and *rhyolite* (e.g. The Nandewar and Ebor Volcanoes). Large volumes of very hot and fluid basalt erupting from the volcano commonly travel large distances from the vent, forming a volcano with a broad, gently curved profile resembling an ancient Roman or Greek shield. As a result, these volcanoes are termed *shield volcanoes*.

As the continental plate moved across the hotspot, the line of volcanoes progressed through Queensland toward New South Wales. The first of these volcanoes to form in northern New South Wales was the Tweed Volcano, which erupted between 23 and 20 million years ago. It is estimated that this volcano reached a height of 2000 m and a diameter of about 100 km (Ferrett, 2005). At almost the same time, between 21 and 17 million years ago, the Nandewar Volcano was erupting to the east of Narrabri. The continuous northward drift of the continent removed the Tweed Volcano from its source of magma, and a new vent erupted between 19.6 and 19.2 million years ago, forming the Ebor volcano.

The Ebor Volcano erupted onto an uplifted and incised terrain with a relief of over 100 m. The land surface comprised Permian to Triassic granites, Carboniferous to Permian metasedimentary rocks, and Eocene basaltic rocks of the Round Mountain lava field (Figure 3). The volcano erupted mainly tholeiitic basaltic lavas as flows to 60 m thick, with minor areas of fragmental rocks and local sedimentary rocks (Ashley, Duncan & Feebrey 1995). Late in the history of the volcano, several intrusions of trachyte, dacite and rhyolite were emplaced, probably erupting at the surface. The volcano was at least 45 km across and rose to a height of more than 800 m above the land surface. More than 90% of the volcano has been removed by erosion and retreat of the Great Escarpment. The eruptive throat of the Ebor Volcano is partially preserved as the *Crescent Complex* (Map 1), a mixture of intrusive *gabbro* and subsequent plugs and dykes of rocks ranging in composition from *monzodiorite* to *monzogranite*. The complex is now exposed at a level about 1500 m beneath the top of the original volcano (Ashley, Duncan & Feebrey 1995).

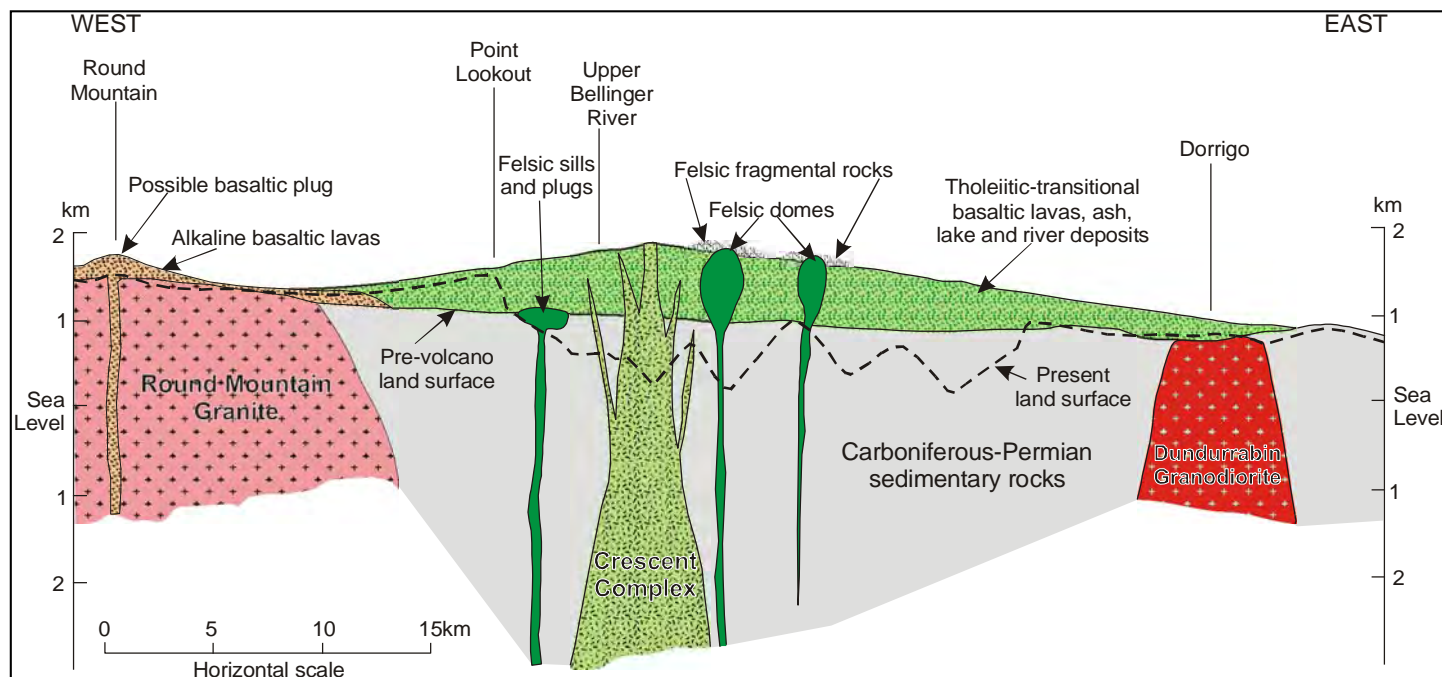


Figure 3. Cross section between Round Mountain and Dorrigo showing the Tertiary form of the Ebor Volcano, the pre-volcano land surface, and the present land surface. Modified from Ashley, Duncan & Feebrey 1995.

THE EXCURSION

Turn off the Waterfall Way onto the access road to the Cathedral Rock National Park (Map 2). The road commences in poorly exposed basalts of the Ebor Volcano, which locally form black to red soils. Travel 2.67 km to a small road cutting and park safely on the edge of the road.

Stop 1. Grid reference 432108 6631852.

Outcrop of black, fine-grained tholeiitic basalt with large, scattered feldspar phenocrysts. A poorly preserved columnar jointing is present. The rock is very hard, and fractures with a conchoidal pattern. Note the very large, lath-like crystals of colourless plagioclase. Many of the lavas from the Ebor Volcano cooled to form columnar joints, such as are well-developed at Ebor Falls. Lavas with an abundance of gas bubbles (*vesicles*) are present in some localities, with concentrations of the vesicles mainly toward the tops of each flow. The flows range in thickness from 10 to 60 m.



Photo 1. Fine-grained, porphyritic tholeiitic basalt erupted from the Ebor Volcano.

Continue along the road for a further 300 m and park safely off the road near the bend. Walk back along the road for about 40 m to the low hill on the western edge of the road.

Stop 2. Grid reference 431870 6631839.

The hill on the roadside is composed of abundant outcrops of hard, black basanite with locally abundant inclusions of pale to dark green *lherzolite*. Rapid chemical decomposition of the lherzolite results in abundant round voids throughout the rock. Lherzolite is a coarse grained rock derived from the mantle consisting of 40 to 90% olivine along with significant orthopyroxene and lesser clinopyroxene. The presence of lherzolite in the basanite demonstrates its origin from great depths below the base of the crust.

The rock at this locality is significantly different to that examined at Stop 1. These basanites are significantly

older, and were probably erupted from a vent on top of Round Mountain four kilometres to the west (Map 2). The lava examined at Stop 1 has flowed over this rock, but has since been eroded away to reveal the older lava.

Several hundred metres west of this site, along the access road, the first outcrops of the Round Mountain Granite are encountered. These are evident as large, low-set outcrops of massive, pale-coloured rock (Photo 3).

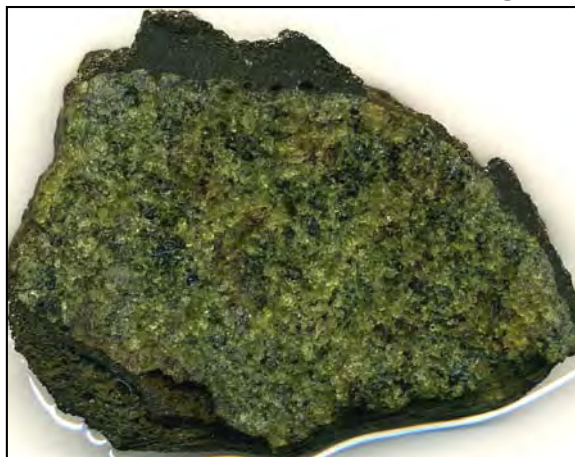


Photo 2. A green Iherzolite inclusion in basalt. Although this is not a local specimen, it is typical of many inclusions found in basalts in the New England region.



Photo 3. Lichen-covered boulders of Round Mountain Granite a short distance from Stop 2.

landforms dominate the loop walk scenery (Photo 4). Individual tors, stacked tors, and high, massive faces of granite are abundant, forming a dramatic skyline.

Tors are rounded, block-like outcrops of granite. They form in hard, massive granite which has cracked along vertical and horizontal fractures. The fractures are known as *joints*. Vertical joints form as a molten granite cools and contracts within the Earth's crust (Figure 4). Some granites have abundant, closely-spaced (metres apart) joints, whereas others have very widely-spaced (hundreds of metres apart) joints. Horizontal joints form as the rocks covering the granite are eroded away, reducing the mass of overlying rock. This is the process of *unloading*. Unloading results in expansion of the rocks nearing the Earth's surface, which results in horizontal cracking. As groundwater moves into the joints it begins to react with the fresh minerals in the

The Round Mountain Granite is composed of interlocking crystals of white quartz, orthoclase, plagioclase and minor black biotite mica. The relatively low proportion of biotite makes the rock very pale. The granite weathers to form sandy and clayey soils which are relatively poor in nutrients. The poor soils are not favoured for agriculture, and naturally support plant communities tolerant of low nutrients and poor drainage.

Continue along the access road, passing further into the granite. The tall, basalt-capped peak of Round Mountain is visible as the turnoff to Barokee Rest Area. The loop track about Cathedral Rock sets off from the rest area.

The loop walk is a relatively easy stroll through well forested granite country, with easy uphill grades. The ascent to the crest of Cathedral Rock is locally steep, and in places requires scrambling over exposed granite rock faces where a fall would potentially be fatal. The ascent may be dangerous in wet or snowy weather, and is not recommended for acute agrophobics.

An amazing range of tors and rugged granite



Photo 4. Stacked tors of granite viewed from the crest of Cathedral Rock.

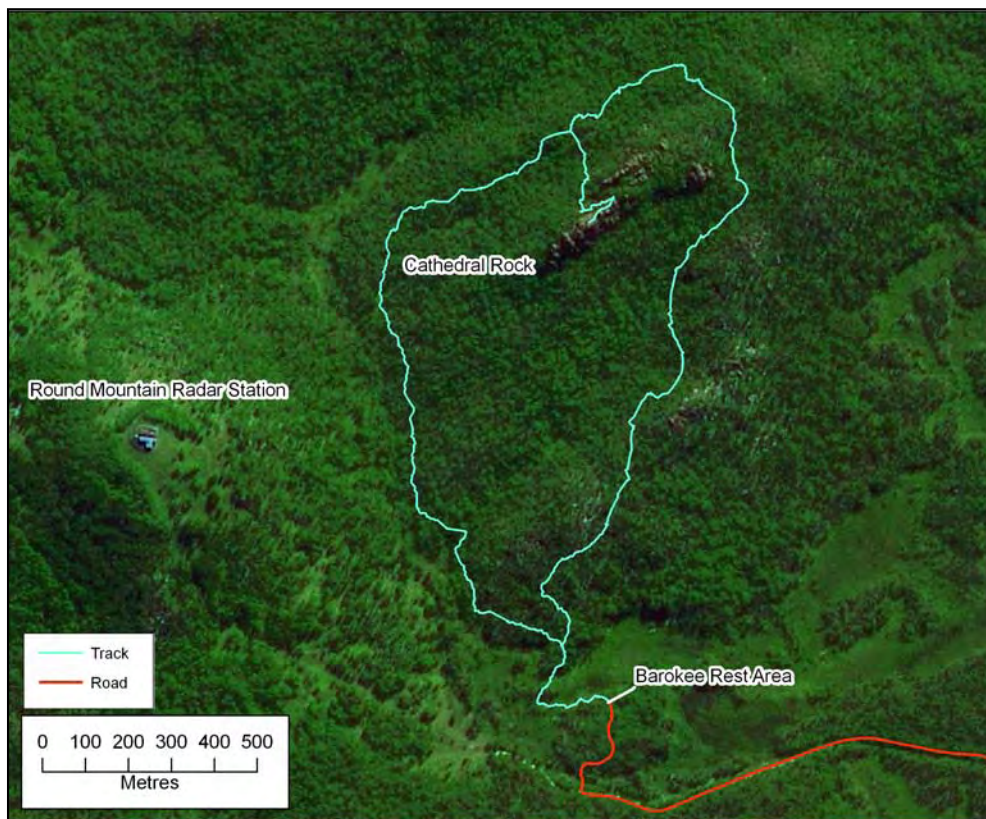


Figure 4. Satellite image of the Cathedral Rock area, showing the entrance road and loop walk. Note the northeast-trending jointing pattern in the granite, which is evident as aligned creeks, gullies and the ridge crest of Cathedral Rock.

granite, causing the minerals to break down into other species, whilst the granite weakens and begins to exfoliate from the underlying fresh rock. Rinds of weathered granite wrapping about fresh granite may resemble the structure of an onion, giving rise to the term *onion skin weathering* for this phenomenon.

In places, *dykes of aplite* cut the granite (Photo 5). Aplite is formed from the final, residual magma left over when the bulk of the granite has crystallised. That final magma is composed of low temperature minerals such as quartz and orthoclase which subsequently crystallise to form aplite. The dykes forced their way through the crystallising granite by forces generated by the contraction of the newly formed rock.

Joints in the granite can be observed in individual outcrops, and their effects upon the landscape are also evident in satellite images (Figure 4). Joints provide pathways for weathering and erosion of the granite, which leads in turn to the formation of gullies and then creeks and rivers. It is common for jointed granites to produce a landscape with parallel watercourses with many angular bends, such as is the case in the Cathedral Rock region.

As the granite cooled in the earth's crust, the outer regions began to crystallise first. Convection within the still molten granite caused some degree of movement in the viscous magma prior to crystallisation, with the result that in some places a form of layering was created. The layering is a subtle variation in composition, or possibly an orientation of elongate minerals. This layering is usually difficult or impossible to see until the rock begins to weather, at which stage the different layers become visible. Layering is apparent in at least one place on the eastern part of the loop track as almost horizontal lines on the edges of some rock faces (Photo 6).

After completing the loop track a visit to Ebor Falls is recommended. This is a journey of about 5 km from the Barokee Rest Area, achieved by returning to the Waterfall Way, turning left, and then proceeding towards Ebor village. The turnoff to the falls is about 100 m before entering Ebor.

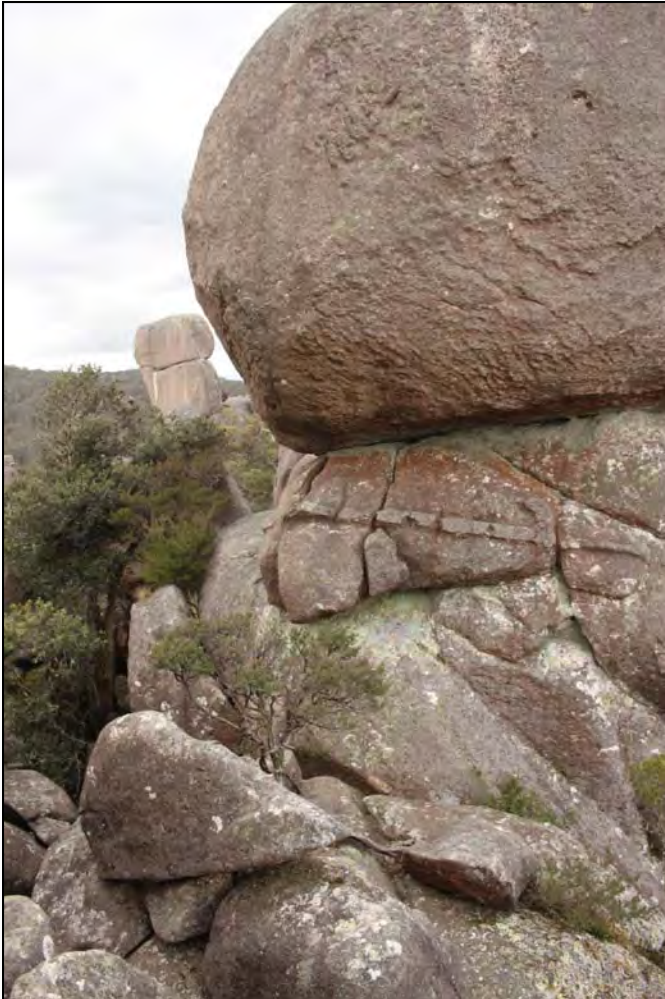


Photo 5. An aplite dyke dipping at a low angle beneath the large tor.

Ebor Falls comprise two main waterfalls. The upper falls drop 115 m in two stages over columnar jointed basalts of the Ebor Volcano (Photo 7). When thick bodies of lava or shallow intrusions (sills or dykes) cool slowly and evenly they crystallise and decrease in volume. Cracks develop perpendicularly to the tops and bottoms of the flow or the walls of the intrusion. The cracking forms 5 or 6 sided, straight to curved columns. These are referred to as *columnar joints* or *cooling columns*. Lavas which cool quickly or unevenly don't form columnar jointing. In places where the lava flow was crystallising on a slope or was subjected to outside pressures the columns may be curved, demonstrating



Photo 7. The upper Ebor Falls passing over 4 columnar jointed basalt flows.



Photo 6. Subtle horizontal layering in granite. Note the prominent horizontal lines, with numerous less well-defined lines above and below.

that the lava had cracked whilst still in a non-solid form. The basalt lavas at Ebor Falls evidently cooled slowly. Note the approximately equal thickness of the four flows.

About 600 m downstream lie the lower Ebor Falls. These plummet over the Permian sedimentary rocks which underlie the lavas of the Ebor Volcano.

We hope you have enjoyed exploring the Cathedral Rock area and have gained something from examining the geology of this location. We welcome any constructive criticism or comments.

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GLOSSARY

- Alkaline rock suites** are those in which the total of alkali oxides ($\text{Na}_2\text{O}+\text{K}_2\text{O}$) exceeds that of CaO at a silica content less than 51% (undersaturated), of which alkali basalts are the most important, but also including syenites, nepheline syenites, and phonolites (silica undersaturated, alkali feldspar and feldspathoid-rich analogues of granites and rhyolites).
- Aplite:** a very fine-grained, pale-coloured igneous rock composed of crystals of quartz and feldspar of the same grainsize.
- Dacite** is a grey lava intermediate in composition between rhyolite and andesite. It consists mostly of plagioclase feldspar with biotite, hornblende, and pyroxene (augite and/or enstatite). It has quartz as phenocrysts, or as an element of the groundmass with plagioclase.
- Dyke:** a sheet-like body of igneous rock which has intruded into another rock across the boundaries of that body or across its internal layering. Dykes are often very steeply dipping.
- Gabbro** is a coarse-grained, black rock comprising pyroxene, plagioclase, amphibole, and olivine. It is chemically equivalent to basalt.
- Granite** is a coarse-grained, light-colored igneous rock consisting chiefly of quartz, orthoclase or microcline, and biotite or muscovite mica.
- Monzogranite** is a rock of granitic composition characterized by the presence of quartz, plagioclase feldspar, and potassic feldspar accompanied by biotite and/or hornblende. The two feldspar types occur in approximately equal proportions.
- Monzodiorite** is a coarse-grained igneous rock consisting of essential plagioclase, orthoclase, hornblende, and biotite, with or without pyroxene. Plagioclase is the dominant feldspar making up 60–90% of the total feldspar.
- Rhyolite** is a pale-coloured lava of felsic (silica-rich) composition (typically $> 69\% \text{SiO}_2$) comprising quartz, alkali feldspar and plagioclase. Biotite and hornblende are common accessory minerals. Rhyolite is the extrusive equivalent of granite.
- Tholeiitic basalt** is a silica-oversaturated, iron-enriched, black basalt characterized by the presence of low-calcium pyroxenes (orthopyroxene and/or pigeonite) in addition to clinopyroxene and calcic plagioclase. Olivine is very uncommon, and feldspathoids are absent.
- Trachyte** is a lava with an aphanitic to porphyritic texture. The mineral assemblage consists of essential and dominant alkali feldspar with relatively minor plagioclase and quartz or a feldspathoid such as nepheline may also be present.