Black Mountain Symposium 2018 Background Paper No. 1

Geological evolution and features of Black Mountain Nature Reserve, Canberra

Douglas Finlayson

doug.finlayson@netspeed.com.au

Abstract. During the Paleozoic era from about 485 million years ago onwards, the Canberra region evolved as part of a much larger geological province called the Lachlan Orogen (or Lachlan Fold Belt) that now extends east from the Victorian/South Australian border to the south-east coast of Australia. The Lachlan Orogen evolved during three tectonic cycles, the Benambran, Tabberabberan and Kanimblan tectonic cycles. The Benambran Tectonic Cycle began about 485 million years ago with huge amounts of turbiditic sediment being deposited in an ocean basin about 5000 m deep off the Gondwana supercontinent. The sediments were then consolidated and brought to near the surface during crustal-scale crustal shortening (compression), uplift and folding associated with the Benambran Orogeny Phase 1 about 444–440 million years ago. The Early-Middle Ordovician Pittman Formation (mid-to-late Darriwilian, 464–458 Ma) of the Adaminaby Group and its associated Acton Shale Member (Late Ordovician, Gisbornian 458–453 Ma) then formed the foundation of most of the Lachlan Orogen/Fold Belt. Locally, these rock units now form the basement rocks of the Black Mountain Nature Reserve. The Pittman Formation can be seen prominently in the road cutting along Caswell Drive on the western side of the Black Mountain Nature Reserve. It is the oldest rock unit in the Canberra region. There was then a hiatus of about 10 million years during which there was deposition of a prograding fan complex comprising the Early Silurian Black Mountain Sandstone (Late Llandovery, 435–433 Ma) seen along the road to the summit of Black Mountain, and the underlying State Circle Shale (Llandovery, about 435 Ma) evident along Parkes Way at the base of Black Mount. The Black Mountain Sandstone is estimated as being between 450 and >800 metres thick. This depositional event was followed by another major tectonic episode, the Benambran Orogeny Phase 2 about 431–428 million year ago, that defined the end of the Benambran Tectonic Cycle.

By this time, all the rock units now seen within the Black Mountain Nature Reserve had been formed. Black Mountain is the oldest feature of the present-day Canberra area topography. It is a block of older rocks surrounded by outcrops of the younger Hawkins Volcanic Suite (433–430 Ma), e.g. Mt. Painter Volcanics, Mt. Ainslie Volcanics and the Laidlaw Volcanic Suite (427–425 Ma), e.g. Deakin Volcanics, formed during the Tabberabberan Tectonic Cycle. At the end of this cycle a whole series of north–south fault structures and associated splay faults evolved. These faults are still evident today around Canberra, e.g. the Murrumbidgee Fault extends 100 km from Cooma to near the Cotter Recreation Reserve, the Queanbeyan Fault crosses the coast road just to the east of the city of Queanbeyan. The cross-cutting Deakin Fault splays off Sullivans Fault from south of Queanbeyan, across the tip of Black Mountain Peninsula and is mapped trending north-west for about 50 km all the way to the Burrunjuck Dam. Several small north–south trending faults have been mapped splaying off the Deakin Fault near Black Mountain including the Acton Fault to the east, the Black Mountain Fault through the summit, and an unnamed fault on the west side separating the Pittman Formation from the Black Mountain Sandstone. The surface topography that we now see around Canberra and elsewhere across the Lachlan Orogen is a deeply eroded landscape that evolved since the early Paleozoic era. We now look at geological features that were formed quite deep within the Earth's crust. Most of the Canberra region river systems that we now see are essentially controlled by the fault systems established during the Tabberabberan Orogeny about 380–370 million years ago.

1. Preamble

The City of Canberra has often been referred to as the 'City in the Landscape' and Black Mountain has played a prominent part in the genesis of that catchphrase. The architects of Canberra's city

design, Walter Burley Griffin and his wife Marion Mahony Griffin, used Black Mountain as one of the high topographic features around the site chosen for the nation's capital when setting out their winning layout for the city. Although never having visited the region, they would have received the region's topographic maps prepared by Charles Scrivener (1909) and the geological map and report prepared by Edward Pittman (1911) as part of the design competition.

Black Mountain had been an attractive location for human habitation since long before the arrival of European settlers. Aboriginal artefacts found near the Molonglo River that flows at the foot of Black Mountain attest to a history of human habitation for hundreds, possibly thousands, of years, with early colonial records estimating 300–400 aboriginal inhabitants of the Limestone Plains region in the early 1800's (Gale 1927; Jackson-Nakano 2001; Brown 2014; Meyers 2010). In late 1820, Charles Throsby Smith, James Vaughan and Joseph Wild crossed from Lake George with two aboriginal guides and camped on the Molonglo River near Pialligo on 7 December of that year (Brown 2014). The following day they climbed Black Mountain in their quest to find new grazing lands for a rapidly increasing colonial population. They saw the landscape "…formed part of a stretch of magnificent country thickly peopled by an aboriginal tribe, because of its abundance of natural food supply" (Gale 1927).

Development of European settlements on the Limestone Plains from 1823 onwards used Black Mountain Sandstone as a building stone, for example when constructing St Johns Church in the period 1841–1845. Limestone was quarried from outcrops near the foot of Black Mountain for the production of lime mortar.

Site 1. Pittman Formation, a rock unit within the Adaminaby Group, outcrops on Caswell Drive at the foot of Black Mountain and is the oldest rock unit in the Canberra region**.** (GDA Easting 0689 780 Northing 6095 640)

How did the topographic feature that we now call Black Mountain evolve? To answer that question, we must look into the geological processes that have been shaping landscapes for hundreds of millions of years. We must embrace the geological concepts that demonstrate planet Earth has continually changed since its origin. Dynamic processes now referred to as 'plate tectonics' play a very important role in landscape evolution (*tectonicus*, Latin for building). A large heat engine in the Earth's deep interior drives turbulent convection currents in the mantle that move parts ('plates') of the Earth's outer layer, the lithosphere, in ways that resemble ice flows interacting on a frozen river.

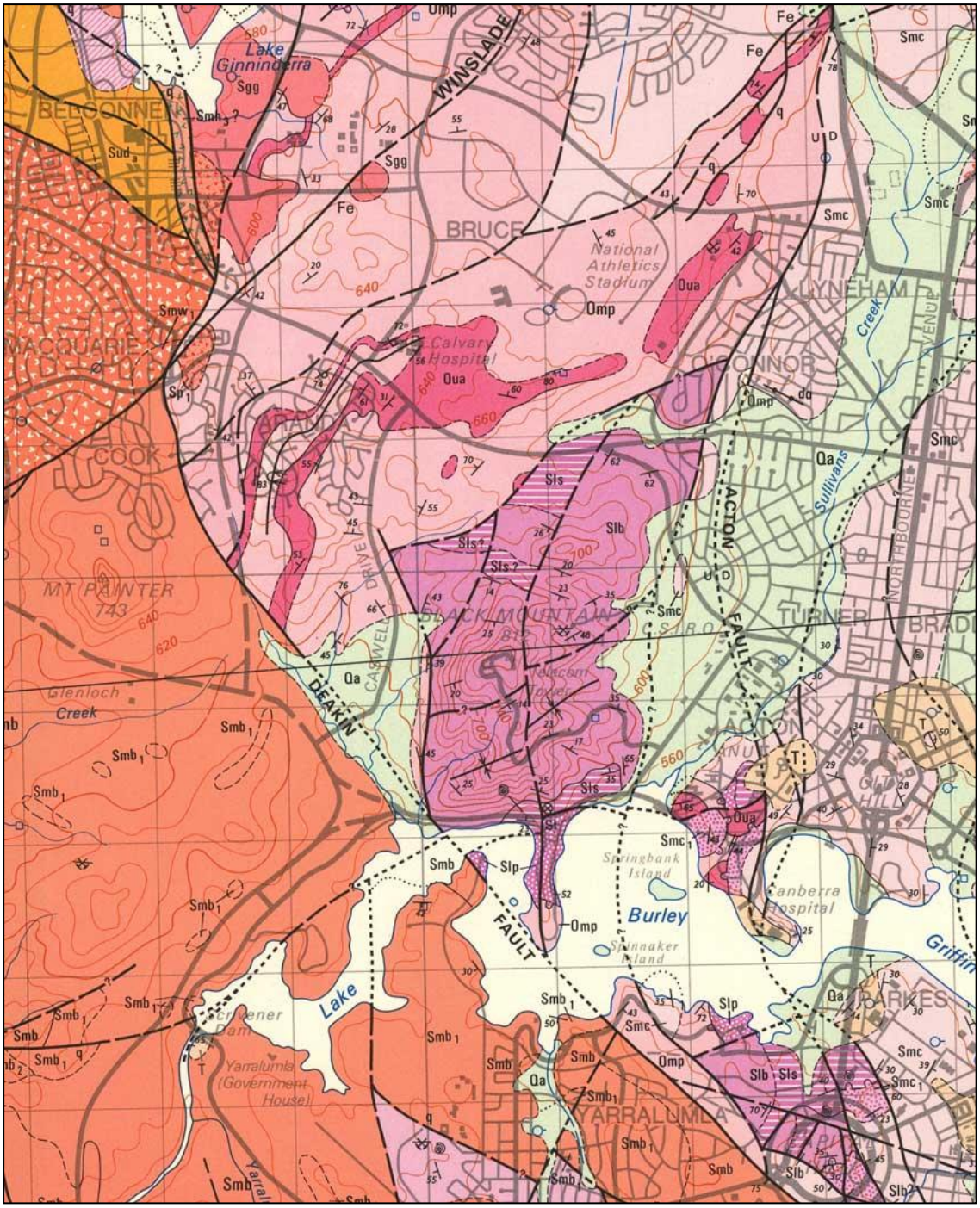


Fig 1a. Geology of the Black Mountain area (extract from the 1:50,000 scale Geological map of Canberra, Queanbeyan, and environs; Henderson 1980a).

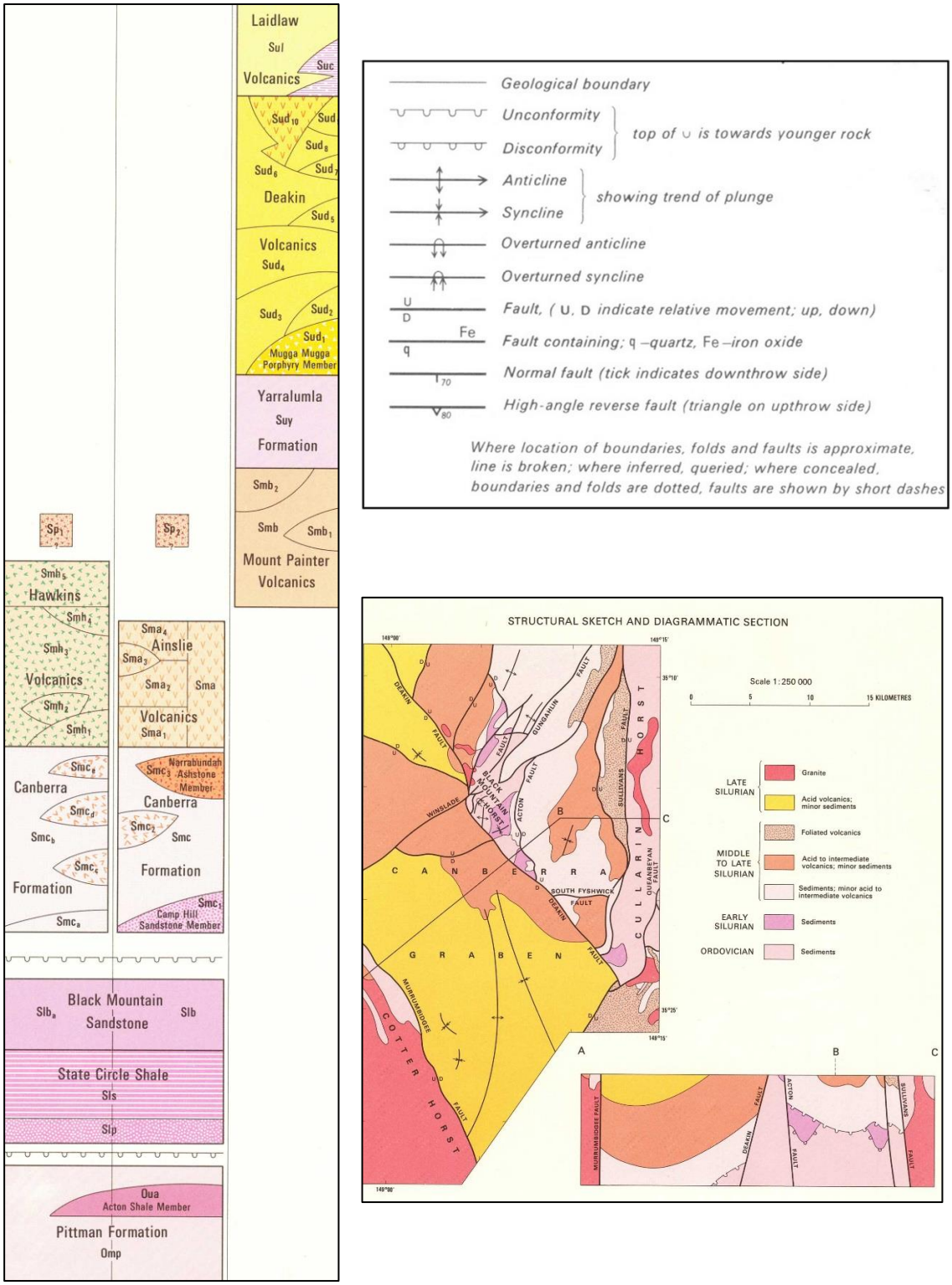


Fig. 1b. Geology of the Black Mountain area: legend and structural sketch (from Henderson 1980a).

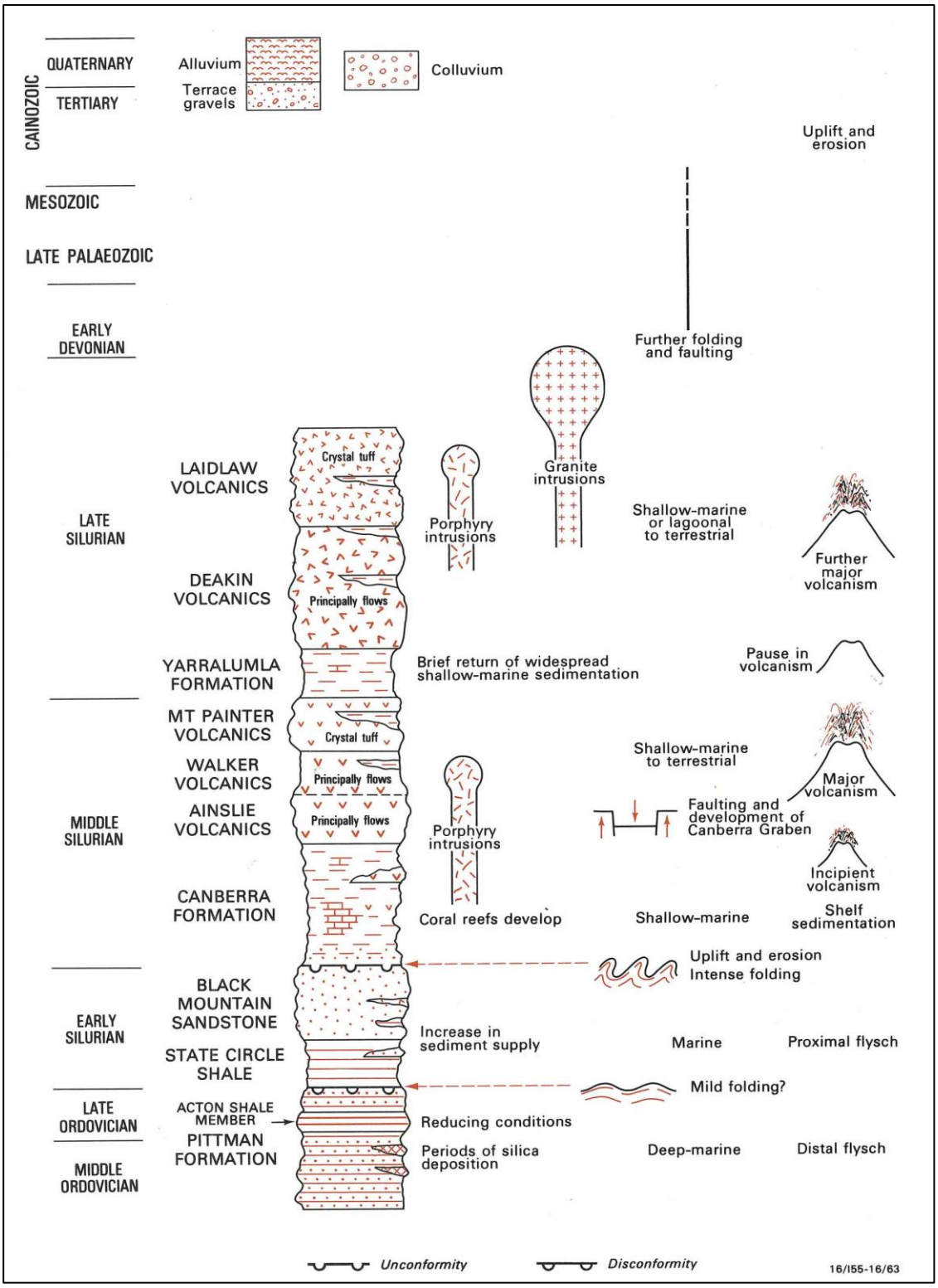


Fig. 2. Geological history of the Canberra–Queanbeyan region (from Henderson 1981).

2. Early geological evolution

About 485 million years ago (Ma) during the Paleozoic geological era (541–252 Ma), the Australian continent's coastline was near Broken Hill and its landmass to the west was part of a supercontinent called Gondwana that also included Africa, India, Antarctica and South America. The Broken Hill region was near the equator and a paleo-Pacific oceanic plate was colliding with that coastline. The region of what is now Canberra was a small part of a deep ocean basin, perhaps about 5000 metres deep, off the super-continent's margin. Huge river systems across Gondwana were pouring enormous volumes of fine turbiditic sediment into the deep ocean basin where they built up significant thickness (perhaps up to 5 km; Thomas and Pogson 2012). At that time, there was no terrestrial vegetation to slow down erosion. These turbiditic sediments would eventually become part of a rock unit called the Pittman Formation that we can now see prominently in the road cutting along Caswell Drive on the western side of the Black Mountain Nature Reserve, the oldest rock unit in the Canberra region. Microfossil conodont fauna (Middle Ordovician Llanvirnian age [mid-to-late Darriwilian], 464–458 Ma) have been recovered from the Pittman Formation outcrop on Etheridge Creek in the northern part of Black Mountain Nature Reserve near Belconnen Way (Nicoll 1980). The tectonic history of the region described below indicates that "Black Mountain is the oldest hill of the present [Canberra area] topography" (Öpik 1958).

During the Paleozoic era, the Canberra region evolved as part of a much larger geological province called the Lachlan Orogen[1] (or Lachlan Fold Belt) that now extends east from the Victorian – South Australian border to the present south-east coast of Australia (ancient Greek: ὄρος *oros*, 'mountain' + γένεσις *genesis* for 'creation, origin'). The Lachlan Orogen evolved during three tectonic cycles, the Benambran, Tabberabberan and Kanimblan, during the Paleozoic geological era (Glen 2005; Finlayson 2008).

Tectonic cycles are dynamic processes in which rock materials can change over extended time intervals as older rocks are eroded and deposited in the ocean basins, then in some cases subducted into the Earth's interior at convergent plate boundaries where they are melted/mixed and erupted along volcanic arcs to form new igneous rocks. A final stage of the cycle often involves crustal compression or shortening and mountain building, like that happening today in the western Pacific and along the Himalayan Mountain Chain.

Site 2. Acton Shale Member of the Pittman Formation exposed on Caswell Drive near the exit and overpass to Aranda. (GDA Easting 0689 876 Northing 6095 951)

[1] In this paper, the most recent age dating across the eastern Lachlan Orogen has been used, as defined by the biostratigraphy of Percival and Zhen (2017) and the International Commission on Stratigraphy (ICS 2017) and supersedes any previous age dates.

2.1 Benambran Tectonic Cycle (about 485–428 Ma)

The Benambran Tectonic Cycle began about 485 million years ago with deposition of huge volumes of turbiditic sediments in a deep ocean basin off the Gondwana supercontinent. The sediments were then consolidated and brought to near the surface during crustal shortening, folding and uplift associated with the Benambran Orogeny Phase 1 about 444–440 million years ago. The Early-Middle Ordovician Pittman Formation (mid-to-late Darriwilian, 464–458 Ma) of the Adaminaby Group and its associated Acton Shale Member (Late Ordovician, Gisbornian 458–453 Ma) then formed the foundation to much of the Lachlan Orogen/Fold Belt. Other rock units of the Adaminaby Group are found extensively across south-eastern Australia (Glen 2005).

There followed a hiatus of about 10 million years during which there was deposition of a prograding fan complex comprising the Early Silurian Black Mountain Sandstone (Late Llandovery, 435–433 Ma) and the underlying State Circle Shale (Llandovery, about 435 Ma) evident along Parkes Way at the base of Black Mountain. The Black Mountain Sandstone is estimated as being between 450 and >800 metres thick. This depositional event was followed by the Benambran Orogeny Phase 2 about 431–428 million year ago that involved further crustal shortening, uplift and folding, thus adding again to the foundations of a continental crust along eastern Australia. By the end of the Benambran Tectonic Cycle all the sedimentary rock units now seen within the Black Mountain Nature Reserve had been laid down. However, the landscape subsequently continued to evolve above sea level, with uplift inevitably being followed by surface weathering and erosion.

Site 3. Massive outcrop of Black Mountain Sandstone on the Summit Trail to the west of Black Mountain Tower. (GDA Easting 0690 664 Northing 6094 690)

2.2 Tabberabberan Tectonic Cycle (about 428–385 Ma)

The transition to the Tabberabberan Tectonic Cycle is dramatically seen in the State Circle road cutting around the Australian Parliament House building. Here a geological unconformity marks the boundary between the lower Early Silurian State Circle Shale (Llandovery, about 435 Ma) and the overlying stratified layers of the Camp Hill Sandstone (maximum thickness about 100 metres), a rock unit (member) within the Early Silurian Canberra Formation (Wenlock, 433–427 Ma). The unconformity formed when older rocks were tectonically uplifted and the environment was changed from deep to shallow marine conditions. In the basement of the Parliament House building, outcrop of the Camp Hill Sandstone unconformably overlies the Black Mountain Sandstone that, in turn, overlies the State Circle Shale at the base of Black Mountain on Parkes Way.

During the Tabberabberan Tectonic Cycle there was still a convergent plate margin to the east of Gondwana. At that time the eastern Lachlan Orogen, as part of the Gondwana supercontinent, was at tropical latitudes. There was significant volcanic activity along a volcanic arc, nearby shallow marine depositional environments, and the emplacement/solidification of Siluro–Devonian granite batholiths at a few kilometres depth within the Earth's crust. The shallow water marine environment

during the Silurian geological period is indicated by the 426–423 Ma brachiopod fossils preserved in mudstones of the Canberra Formation at Woolshed Creek near Canberra Airport (Strusz 2011).

Black Mountain is an isolated block of older rocks surrounded by outcrops of the younger Hawkins Volcanic Suite (433–430 Ma) and the Laidlaw Volcanic Suite (427–425 Ma) (Percival and Zhen 2017) that include Mount Painter to the west and Mount Ainslie to the east. Weston Park and Yarralumla to the south and historic Gungahlin Homestead and the suburb of Mitchell to the north are also underlain by rocks of these volcanic suites.

Site 4. State Circle Shale that underlies Black Mountain Sandstone at the base of Black Mountain near Parkes way (under power lines going to the summit) and at Black Mountain Peninsula. (GDA Easting 0691 201 Northing 6093 509)

Across south-east NSW there are extensive outcrops of the granite igneous rocks that were emplaced at about five kilometres depth during the Silurian and Devonian geological periods; plutons within Namadgi National Park of the Murrumbidgee Batholith to the west and the Bega Batholith to the east of Black Mountain are impressive landscape features. However, it was the Tabberabberan Orogeny about 380–370 million years ago that really changed the structure of the eastern Australia margin. Deformation and folding took place at different times across the whole Lachlan Orogen. Up until then the width of this margin of the Precambrian Australian continent from near Broken Hill was about 1400 km. During the Tabberabberan Orogeny tectonic convergence squeezed this margin to about 700 km with consequent huge crustal uplift, faulting and folding.

Fig. 3. Geological unconformity (arrow) between the lower State Circle Shale and the overlying thinly bedded Camp Hill Sandstone exposed within the State Circle road cutting around Parliament House.

2.3 Faults

Across large parts of the eastern Lachlan Orogen a whole series of north–south fault structures and associated splay faults formed during the Tabberabberan Orogeny. These faults, or breaks in the rocks, are still evident today around Canberra. The Murrumbidgee Fault extends 100 km from Cooma to near the Cotter Recreation Reserve. The Queanbeyan Fault crosses the coast road just to the east of the city of Queanbeyan. The north–south trending Cotter Fault hosts the Cotter River and water supply dams. Sullivans Fault trends north from near Molonglo Gorge, just outside Queanbeyan, for at least 50 km towards Lake George.

The cross-cutting Deakin Fault splays off Sullivans Fault from south of Queanbeyan, across the tip of Black Mountain Peninsula and is mapped trending north-west for about 50 km all the way to the Burrinjuck Dam. The crosscutting Winslade Fault is almost at right-angles and trends north-east from near Cotter Recreational Reserve to cross Belconnen Way near Bruce and meets up with the Gungahlin Fault to the north of Black Mountain on the same trend, a distance of about 30 km. Several small north–south trending faults have been mapped splaying off the Deakin Fault near Black Mountain including the Acton Fault to the east, the Black Mountain Fault through the summit, and an unnamed fault on the west side separating the Pittman Formation from the Black Mountain Sandstone.

2.4 Kanimblan Tectonic Cycle (about 385–318 Ma)

None of the effects of the Kanimblan Tectonic Cycle are evident on Black Mountain. This tectonic cycle affected both the western and eastern parts of the Lachlan Orogen at various different times. Some of these effects in the Canberra region are readily evident around Wee Jasper and Burrunjuck Dam 30 km north of Canberra, such as the folding of limestone outcrops seen across rolling farming landscapes (Finlayson 2008; Percival and Zhen 2017).

3. Denudation and erosion

The Tabberabberan Orogeny effectively ended marine conditions and a non-marine continental crust had been consolidated across south-eastern Australia. There then followed hundreds of millions of years of denudation and erosion. In general terms, the denudation rate across the whole Australian continent is about 5–10 metres per million years. The outcrops of granite plutons at the surface around south-east Australia attest to the fact that perhaps about 5 km of rock overburden has been eroded by water, snow, ice and wind. Much of this eroded sediment eventually ended up in the Sydney Basin to the north of the Lachlan Orogen, on the NSW South Coast, and in central NSW.

The surface topography that we see around Canberra and elsewhere across the Lachlan Orogen is a deeply eroded landscape. We now look at geological features that were formed quite deep within the Earth's crust. Many of the regional river systems that we now see are constrained by the geological features and fault systems established during the Tabberabberan Orogeny.

Plate tectonics and drifting continents influence denudation. For instance, the eastern Australian part of Gondwana moved to polar latitudes during Carboniferous-Permian geological periods about 320 million years ago. Large land areas were covered by glaciers that would have caused huge amounts of erosion and controlled landscape evolution in some areas. Gouging and scarring of rock surfaces by glaciers and erratic boulders transported by glaciers are found in many places across south-eastern Australia.

4. More recent events

In more recent geological times dynamic tectonic processes are still evident. They have affected the drainage systems that once drained Lake George. These have been blocked in the last five million years by the tectonic elevation of the Cullarin Uplift, a block of Ordovician Adaminaby Group rock units. Farther south, the Molonglo River succeeded in cutting through the same uplift at Molonglo

Gorge near Queanbeyan and now flows near the southern boundary of the Black Mountain Nature Reserve.

The effect of the last ice age in the Black Mountain area about 21,000 years ago are evident in numerous gullies across the reserve. There was no glacier ice in the Canberra area but in the gullies, river erosion has exposed fanglomerate outcrops. Fanglomerates can result from heavy frosts and deep snows that result in frost shattered rocks and their erosional slumping down steep slopes to form alluvial fans.

Site 5. Fanglomerates in a gully at the start of the climb up Black Mountain Summit Trail near the ANU quarry site. (GDA Easting 6091 405 Northing 6094 797)

Site 6. Fanglomerates in gully near Caswell Drive car park entrance to reserve. Photo: R. Purdie. (GDA Easting 0689 962 Northing 6094 244)

These and other processes will have been eroding Black Mountain for thousands, perhaps millions, of years. Ice cores from Antarctica tell us that ice ages have been occurring for at least 500,000 years as predicted by James Croll (1821–1890), a self-taught Scottish millwright and janitor at Andersonian University, Glasgow, who was eventually elected a Fellow of the Royal Society, London. The theory was refined later by the Serbian mathematician and astronomer Milutin Milankovitch in the 1920s. The episodic nature of the Earth's glacial and interglacial periods is caused primarily by cyclical changes in the Earth's circumnavigation of the Sun. Variations in the Earth's eccentricity, axial tilt and precession are used to predict the so-called Milankovitch Cycles that have a periodicity of about 100,000 years (see Fig. 4).

The Black Mountain landscape is high above the city centre of Canberra because it is capped by rocks that are harder to erode than the softer rocks of the surrounding areas. Over many thousands

of years this has led to an elevation of the summit above the Molonglo River by about 270 metres.

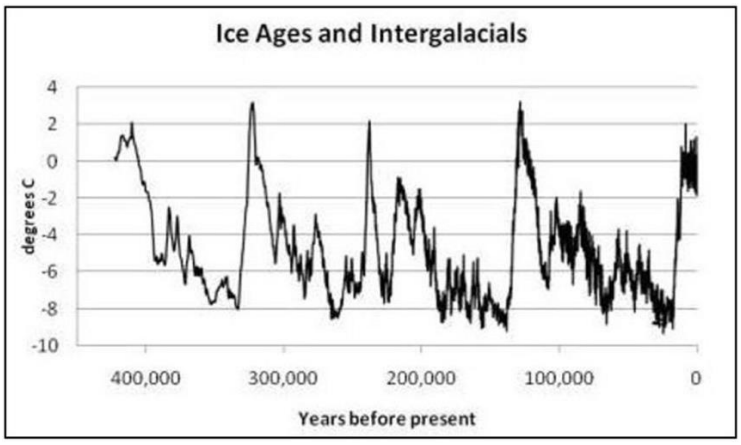


Fig. 4. Milankovitch Cycles over the last 400,000 years (taken from https://www.sott.net/article/207727-Ice-Age-theories-warming-up).

Long periods of colder climates, with freezing conditions, in the Canberra region have also formed screes deposits on some steep slopes in the Black Mountain Nature Reserve. Rock shattering by rainwater freezing in cliff crevasses can dislodge large quantities of small (and large) boulders to accumulate over thousands of years as scree on the lower slopes.

Site 7. Scree slope on the side of one of the creeks draining south from the summit towards Lake Burley Griffin. (GDA Easting 0690 399 Northing 6093 863)

5. Breakup of Gondwana, ongoing tectonic events and earthquakes

About 130 million years ago the Gondwana supercontinent began to break up with Africa and South America going their own way. India started separating about 100 million years ago and the Southern Ocean began to form between Australia and Antarctica (Li and Powell 2001). By 95 Ma the Otway Basin began to develop to the south of the Lachlan Orogen and the Tasman Sea had begun to open. A large part of the eastern Lachlan Orogen was rifted from the Australian continent and eventually ended up as part of the largely-submerged 4.9 million km^2 continent of Zealandia along with the Norfolk Ridge, New Zealand, the Lord Howe Rise and the Campbell Plateau. Australia began drifting northwards at about seven centimetres per year.

The stress regime set up within the continental crust by the northward drift of Australia has resulted in continuing tectonic activity including crustal deformation and intra-cratonic earthquakes (Fig. 5). At 7:51 am AEST on 29 November 1985 a shallow, magnitude 2.4 earthquake was felt strongly

in the Black Mountain – Turner area (Leiba 1996; see Fig. 6). Today there are numerous intra-cratonic earthquakes all across the Lachlan Orogen and elsewhere in Australia.

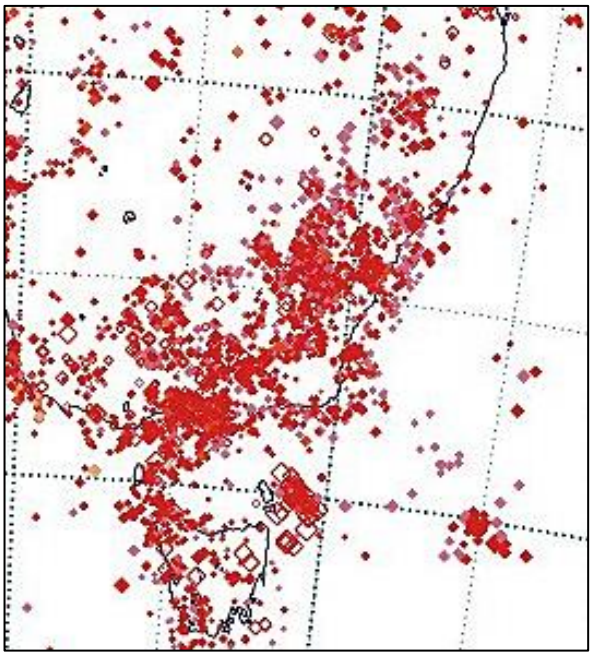


Fig. 5. Earthquake epicentres (magnitude Mw greater than 3) for south-eastern Australia, 1840–2016 (extract from Kennett and Wei 2017).

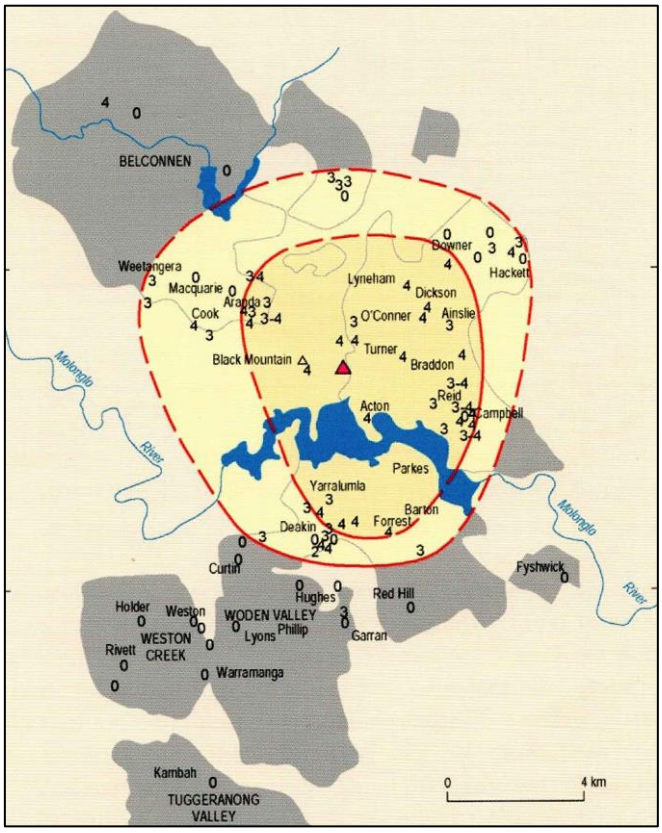


Fig. 6. Epicentre of the Black Mountain magnitude ML 2.4 earthquake, 29 November 1985 (Leiba 2007). The numbers on the map are reported felt intensities based on the Modified Mercalli intensity scale.

6. Some rock outcrops and features worth a visit

Black Mountain Nature Reserve is quite thickly wooded and finding good outcrops of some of the rock units is not always easy. However, some suggestions are given below; their locations are shown on the map at Appendix 1.

6.1 Pittman Formation

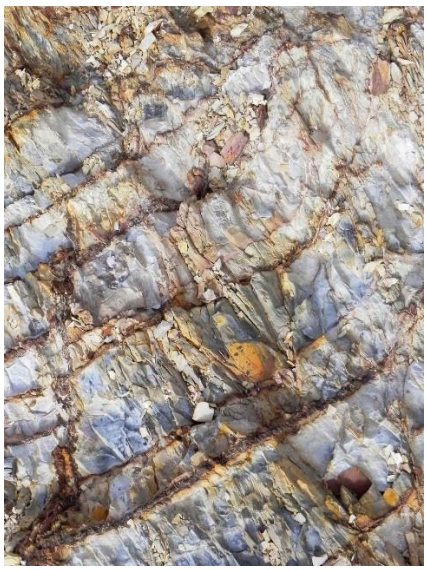
The outcrop of Pittman Formation exposed in the Caswell Drive road cutting shown earlier in this paper is difficult to access on foot because of busy traffic. However, more accessible smaller outcrops of Pittman Formation rocks are seen in the bed of Etheridge Creek within the nature reserve near the northern boundary along Belconnen Way. These outcrops were used to obtain Ordovician conodont microfossils by Öpik (1958) and Nicoll (1980).

Site 8. Pittman Formation outcrop on Etheridge Creek**.** (GDA Easting 0690 683 Northing 6095 933)

Site 1. Pittman Formation on Caswell Drive road cutting. (GDA Easting 0689 780 Northing 6095 640)

Site 9. Pittman Formation in creek bed near the Caswell Drive walking track underpass. (GDA Easting 0689 920 Northing 6095 171)

6.2 Acton Shale Member of the Pittman Formation



Site 2. This outcrop is exposed along the road cuttings associated with Caswell Drive, eastern side, on the road off-ramp and overpass into Aranda. (GDA Easting 0689 876 Northing 6095 951)

Öpik (1958) named Pittman Valley, as the area along the track through the Black Mountain Nature Reserve between Belconnen Way/Bruce Ridge south-west to Caswell Drive along the Old Weetangera Road. Beneath the vegetation cover it is mostly on Ordovician rocks of the Pittman Formation, a rock unit within the Adaminaby Group. The valley and old road traverse the water shed between north-east flowing Etheridge Creek in the north and south-west flowing Andrews Creek and Carne Creek in the south that flow through the Caswell Drive dual carriageway underpass on part of the Canberra Centenary Trail.

6.3 Black Mountain Sandstone

At the Black Mountain Drive turnoff to the summit from Clunies Ross Street, an Australian National Botanic Gardens nature trail starts on the far side of the open dirt area on the left. Walk along this trail for about 300 metres and you will come across boulders of Black Mountain Sandstone, some used to make steps in the trail that leads to a lookout.

Site 10. Quarry at the Australian National University laboratory site. There is no public access. (GDA Easting 0691 260 Northing 6094 631)

The old quarry on the eastern side of Black Mountain provided stone for 19th century Canberra buildings such as St John Church, Reid. The quarry is now fenced off and is a laboratory site for the Australian National University with no public access.

Site 11. About half way up the road to the summit you will find a car park on the left-hand side of a sharp bend in the road. The road cutting opposite the car park area is the geological type section for the Black Mountain Sandstone. (GDA Easting 0690 782 Northing 6093 750)

Site 12. Black Mountain Sandstone outcrop along the Forest Trail around the summit. (GDA Easting 0690 697 Northing 6094 747)

6.4 State Circle Shale

Underlying the Black Mountain Sandstone at the base of the mountain near Parkes Way (near power lines leading up the mountain) and at cycleway turnoff into the eastern side of Black Mountain Peninsula there are outcrops of the Stale Circle Shale at the lakeside.

Site 13. State Circle Shale at the lakeside on Black Mountain Peninsula. (GDA Easting 0691 193 Northing 6093 181)

7. Acknowledgements

The author wishes to thank Prof. Ken McQueen and Dr Des Strusz for reviewing this paper and helping to produce a better presentation for the 2018 Black Mountain Symposium.

The author also wishes to thank Geoscience Australia (GA) for permission to use extracts from the 1980 1:50,000 scale Geological Map of Canberra, Queanbeyan and Environs and the earthquake location diagram from Leiba (2007) Geoscience Australia publication (© Commonwealth of Australia; Geoscience Australia 2007).

All photos in this paper were taken by the author, Doug Finlayson, unless stated otherwise in the accompanying text.

8. References and other information sources

Abell, RS (1991) Geology of the Canberra 1:100,000 sheet area, New South Wales and Australian Capital Territory. *Bureau of Mineral Resources, Geology and Geophysics Bulletin* 233.

Abell, RS, Brown, C, Finlayson, DM, Lenz, S, Mayer, W, McCue, K, McQueen, K, Pillans, B, Rickard, M & Strusz, D (2008) *Geology of the Australian Capital Territory, 1:100,000 scale map.* Geological Society of Australia (ACT Division), Canberra.

Brown, N (2014) *A History of Canberra*. Cambridge University Press.

Finlayson, DM (author and editor) (2008) Co-authors: Abell, RS, Strusz, DL, Wellman, P, Rickard, MJ, Clark, D, McCue, K, Campbell, KSW, McQueen, KG & Pillans, B. A *Geological Guide to the Canberra Region and Namadgi National Park*. Geological Society of Australia, ACT Division.

Gale, J (1927) *Canberra: Its History and Legends*. AM Fallish & Sons, Queanbeyan.

Gillespie, LL (1992) *Ginninderra, Forerunner to Canberra: a History of the Ginninderra District.* Lyall L Gillespie, Canberra ACT, 1992.

Gillespie, LL (1991) *Canberra 1820–1913*. Australian Government Printing Service, Canberra.

Glen, RA (2005) The Tasmanides of eastern Australia. In: *Terrane Processes at the Margins of Gondwana* (eds APM Vaughan, PT Leat & RJ Parkhurst). Geological Society of London Special Publication 246, 23–96.

Henderson, GAM (1980a) *Geology of Canberra, Queanbeyan and Environs – 1:50,000 scale geological map*. Bureau of Mineral Resources, Geology and Geophysics, Canberra.

Henderson, GAM (1980b) *Commentary on the Coppins Crossing 1:10,000 engineering geological sheet, Canberra*. Bureau of Mineral Resources, Geology and Geophysics.

Henderson, GAM (1981) *Geology of Canberra, Queanbeyan and Environs – Notes to accompany the 1980 1:50,000 geological map*. Bureau of Mineral Resources, Geology and Geophysics, Canberra.

Henderson, GAM (1985) *Engineering geological map, ACT Central Canberra Sheet 208-600, 1:10,000 scale*. Bureau of Mineral Resources, Geology and Geophysics.

ICS (International Commission on Stratigraphy) (2017) *International Chronostratigraphic Chart v2017/02.* International Commission on Stratigraphy.

Jackson-Nakano, A (2001) *The Kamberri.; a history of aboriginal families in the ACT and surrounds, 1820–1927, and historical overview 1928–2001.* Australian National University Printing, Canberra.

Kennett, BLN & Wei, Z (2017) High-frequency ground motion from Australian earthquakes. *Australian Journal of Earth Sciences* 64, 769–777.

Leiba, M (2007) *Earthquakes in the Canberra region*. Geoscience Australia, Canberra.

Li, ZX & Powell, CMcA (2001) An outline of the palaeogeographic evolution of the Australasian region since the beginning of the Neoproterozoic. *Earth Science Reviews* 53, 237–277.

Meyers, D (2010) *Lairds, Lags and Larrikins; an early history of the Limestone Plains.* Sefton Publications, Pearce, ACT.

National Capital Development Authority (1988) Sites of significance in the ACT. Volume 2. Inner Canberra. *NCDC Technical Paper* 56. Australian Government Printing Service, Canberra.

Nicoll, RS (1980) Middle Ordovician conodonts from the Pittman Formation, Canberra, ACT. *BMR Journal of Geology and Geophysics* 5(2), 150–153.

Öpik, AA (1958) The geology of the Canberra City District. *Bureau of Mineral Resources, Geology and Geophysics Bulletin* 32.

Owen, M (1987) *Geological monuments in the Australian Capital Territory.* A report prepared by the Monuments Subcommittee of the Territories Division of the Geological Society of Australia for the Australian Heritage Commission.

Percival, IG & Zhen, YI (2017) Précis of Palaeozoic palaeontology in the Southern Tablelands region of New South Wales. *Proceedings of the Linnean Society of New South Wales* 139, 9–56.

Pittman, EF (1911) *Reports on the geology of the federal capital site.* Minister of Home Affairs, Commonwealth of Australia.

Scrivener, CR (1909) *Federal capital, proposed site at Yass-Canberra* [map portfolio]. Commonwealth Government Printer, Melbourne.

Strusz, DL (1971) Explanatory notes for the 1:250,000 scale Canberra sheet area, Australian Capital Territory and New South Wales. *Bureau of Mineral Resources, Geology and Geophysics Notes* SI/55-16.

Strusz, DL & Henderson, GAM (1971) *1:50,000 geological map and explanatory notes, Canberra City A.C.T.* Bureau of Mineral Resources, Geology and Geophysics.

Strusz, DL & Jenkins, CJ (1982) The stratigraphic implications of *Monograptus Exiguus* from Camp Hill, Canberra, ACT. *BMR Journal of Geology and Geophysics* 7, 78–79.

Strusz, DL (2011) Silurian brachiopods from the historic Woolshed Creek area, Canberra, Australia. *Proceedings of the Linnean Society of New South Wales* 133, 31–47.

Thomas, OD & Pogson, DJ (compilers) (2012) *Explanatory notes for the Goulburn 1:250,000 geology sheet SI/55-12, 2nd edition.* Geological Survey of New South Wales.

Appendix 1

Location of geological sites around Black Mountain Nature Reserve