BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Record 1979/87

THE GEOLOGY OF THE CANBERRA-QUEANBEYAN 1:50 000 MAP AREA

by

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INTRODUCTION

This Record documents current knowledge of the geology of the area covered by the revised 1:50 000-scale map of Canberra, Queanbeyan, and environs, that is due to be published in 1981. It contains a full bibliography, of both published and unpublished sources. A shorter account of the geology (Henderson, in prep.), including suggested in view of outcrops typical of the various formations, will be published in 1981 as a Miscellaneous Monograph.

The Canberra-Queanbeyan 1:50 000 geological map includes all the urban areas of Canberra and Queanbeyan and areas where planning for urban development is in progress or is expected in the near future. The map and explanatory text supersede the 1971 edition of the Canberra 1:50 000 geological map (Strusz and Henderson, 1971). The total area of the map is about 930 km^2. Grazing land, pine forest and bushland reserves surround the present urban area. The major transport routes out of the area are the Barton Highway northwest to Yass, the Federal Highway northeast to Goulburn, the main coast road (Kings Highway) from Queanbeyan to the east via Braidwood, and the Monaro Highway south to Cooma. A branch line joins Canberra to the New South Wales standard gauge railway system at Queanbeyan.

Mean annual precipitation at Fairbairn RAAF Base is 638 mm; this increases westwards across Canberra. In July, the coldest month, the average daily maximum temperature is 11.1°C, the average daily minimum -0.3°C, the lowest recorded is -10.0°C. The hottest month is January, for which the average range is 20.1°-27.4°C, and the highest recorded temperature is 42.2°C.

An outline of previous geological investigations and a full bibliography for the Canberra 1:250 000 Sheet area to 1970 can be found in Strusz (1971). The bibliography accompanying these notes is restricted to material relevant to the area covered by the Canberra-Queanbeyan 1:50 000 map sheet. The map has been compiled from previous sources (Opik, 1958; Phillips, 1956; Moore, 1957 etc), and from recent detailed geological maps accompanying reports of the Engineering Geology Group, Bureau of Mineral Resources (BMR), most of which have been included in unpublished records. A 2 km wide strip on the western edge of the map is in part derived from the Brindabella and Tantangara 1:100 000 Sheets (Owen and Wyborn, 1979), and the Tharwa area is based on Mackenzie (1966) and Richardson and Barron (1977), (Michelago 1:100 000 Sheet). Major changes to the stratigraphic interpretation from the previous map are confined principally to the volcanic rocks for which chemical analyses (to be listed fully in Abell, in prep.) carried out recently, and used in conjunction with petrographic studies have provided a useful correlative and stratigraphic tool. Much of the information on which the map is based has been gained from temporary excavations and drill holes in the urban area. Two deep stratigraphic drill holes, one near Parkes Way and the other at the southern foot of Black Mountain have been completed since 1971; their locations are shown on the map.

Extensive collections of fossils have been made over the years. However, with notable exceptions, they tend to be long-ranging facies-sensitive forms of limited use for precise correlation. A useful collection of shelly fossils was made from pipeline excavations in 1975 in the limestone west of Coppins Crossing. A selection of the more important fossil localities is shown on the map. Strusz (1975) gives details of fossil collections from Silurian formations in the Canberra area.

PHYSIOGRAPHY

Canberra is situated on undulating and rolling terrain interspersed with hills and ridges lying in the catchment of the Murrumbidgee River system. The Molonglo River, a major tributary of the Murrumbidgee River, flows west through the central part of the city. The river has been dammed to the west of the city by Scrivener Dam to form Lake Burley Griffin. Elevation in the map area ranges from 440 m in the gorge of the Murrumbidgee River west of Belconnen to more than 900 m in the ranges to the east and west of Tharwa. Most of the undulating and rolling country lies between 550 m and 650 m forming a peneplain with residual hills and ridges into which the Murrumbidgee River below Pine Island and the western reaches of the Molonglo River are entrenched. Many of the hills and ridges such as Black Mountain and the Ainslie-Majura ridge rise steeply from the peneplain to form prominent topographic features. A detailed classification of landforms in the Canberra region is given in Gunn and others (1969).

The origin of Canberra landforms is discussed from different approaches in a number of papers beginning with Taylor (1910), and including Craft (1933), Opik (1958) and Van Dijk (1959), and more recently Jennings (1972). Prominent amongst the processes involved are the formation of the regional horst and graben system (see Strusz, 1971), periodic uplift, dissection and peneplanation, and differential erosion related to variable resistance of underlying rock. The relation between topography and geology is evident in many of the resistant hills and ridges which coincide closely with particular rock formations, for example Black Mountain, Mount Ainslie and Red Hill.

STRATIGRAPHY

A summary of the main stratigraphic units shown on the map is given in Table 1; it includes thicknesses of units and other data not specifically mentioned below.

TABLE 1 - STRATIGRAPHIC UNITS IN THE CANBERRA-QUEANBEYAN AREA

UNIT (SYMBOL)	OCCURRENCE	ROCK TYPES	FOSSILS	DEPOSITIONAL STRUCTURES	DEPOSITIONAL ENVIRONMENT	TECTONIC STRUCTURES	THICKNESS	STRATIGRAPHIC RELATIONSHIPS	AGE AND CORRELATIONS
Unnamed ($uc)	East of Tharwa; along Murrumbidgee River in several places between Lanyon and Kambah Pool; and north of Mt Stromlo	Calcareous shale, sandstone, ashstone and tuff	Linguloid brachiopods and Acanthodian spines (east of Tharwa)		Estuarine or lagoonal	Gently to strongly folded		Unconformably overlie Deakin Volcanics east of Tharwa and interfingering with Laidlaw Volcanics	Late Silurian
Laidlaw Volcanics (Sul)	West Belconnen north to Yass; Weston Creek and Tuggeranong	Rhyodacitic and dacitic crystal tuff	-	Microscopic eutaxitic texture near lower contacts (at Weston Creek)	Terrestrial and shallow marine extrusives with minor intrusives (e.g. Sp_5)	Gently folded in most places	270–400 m+	Overlies Deakin Volcanics.	Late Silurian
Deakin Volcanics including Mugga Mugga Porphyry Member (Sud_{1-10}, Sud_{a-f})	Woden, Weston Creek, Tuggeranong, Belconnen, west of Goorooman Ponds	Rhyodacite, rhyolite; dacitic & rhyodacitic crystal tuff; tuff; minor agglomerate, ashstone, tuffaceous sandstone & shale	-	Occasional flow banding, spherulitic texture in Sud_6 in Weston Creek area	Partly shallow marine, partly terrestrial?	Folded moderate to gentle dips, occasional slight foliation (e.g. in Unit Sud_1)	700 m+	Conformably overlie Yarralumla Formation; overlain by Laidlaw Volcanics and, east of Tharwa, by unnamed unit Suc	Late Silurian
Yass Sub-Group (Sus)	Belconnen	As Suy	As Suy	-	As Suy	Folded, generally gentle dips	240 m	Conformably overlies Hawkins Volcanics; conformably overlain by Deakin Volcanics (Sud_{a-f})	Late Silurian; probable correlate of Yarralumla Formation
Yarralumla Formation (Suy)	Yarralumla, Hughes, Deakin, Red Hill and Lyons	Calcareous and tuffaceous shale and sandstone, tuff, limestone, hornfels	Brachiopods, trilobites, corals, bivalves, bryozoans, crinoids	Small scale current and graded bedding	Shallow marine	Folded, moderate dips	Variable from 100–300 m	Conformably? overlies Mount Painter Volcanics; overlain conformably by Deakin Volcanics	Late Silurian, probable correlate of Yass Sub-Group
Colinton Volcanics (Sav)	South of Queanbeyan extending southwards towards Cooma	Dacite, tuff, minor lenses of shale, and siltstone	Not found in Sheet area. Brachiopods, trilobites, coral to south	-	Shallow marine, possibly in part terrestrial	Mostly strongly foliated	Not reliably known but probably large 3000 m?	Overlies and interfingers with Cappanana Beds; probably unconformable on Pittman Formation	Middle or Late Silurian
Cappanana Beds (Sal)	South of Queanbeyan along Queanbeyan River	Limestone dolomite, marble, slaty shale	Not preserved in Sheet area. Brachiopods, corals, trilobites to south	-	As for Canberra Formation	Strongly folded, well developed cleavage	Variable 60–700 m	Interfingers with basal part of Colinton Volcanics in sheet area; inferred as such for structural reasons.	Middle Silurian?
Mount Painter Volcanics (Smb, $Smb_{1,2}$)	Coppins Crossing to to Narrabundah; west Belconnen?	Dacitic crystal tuff; minor agglomerate, tuff, ashstone, shale, sandstone and rhyolite	-	Xenoliths of igneous and sedimentary origin, local banding	Submarine and terrestrial extrusives with possible minor high level intrusives	Probably folded	Unknown	Overlain by Yarralumla Formation; base not exposed in type area; probably interfinger with higher parts of Walker Volcanics	Middle Silurian
Walker Volcanics (Smw_{1-4})	South Belconnen to west of Murrumbidgee River	Dacite, rhyodacite, rhyolite, shale, limestone, sandstone	Trilobites, conodonts, brachiopods and corals	Bioclastic limestone nodules, and slumping in sediments	Shallow marine, and in part terrestrial	Gently folded	1500 m+	Probably interfinger with Mount Painter Volcanics; contacts with other formations in Sheet area all faulted. Topmost volcanic unit (Smw_4) slightly unconformable on rest of sequence	Middle Silurian
Hawkins Volcanics (Smh_{1-5})	Belt extending north from Belconnen	Dacite, dacite crystal tuff, agglomerate, quartz andesite, minor shale, tuff	Brachiopods	Flow banding	As for Canberra Formation	Gentle to moderate folding; weak foliation locally	600 m+	Conformably overlie Canberra Formation, overlain conformably by Yass Sub-Group	Middle Silurian; correlate of Ainslie Volcanics and Walker Volcanics
Ainslie Volcanics (Sma_{1-4})	Ainslie–Majura–Goorooo ridge, south of Fyshwick, east of Canberra Airport and Majura Road	Dacite in part foliated, agglomerate, quartz andesite, andesite; minor rhyolite, tuff and shale	None found	Mudstone inclusions in volcanics, flow banding	As for Canberra Formation	Gently to strongly folded, in part strongly foliated	700 m+	Conformably overlies Canberra Formation with some interfingering; topmost part not preserved	Middle Silurian; correlate of Hawkins Volcanics; (includes former "Gladefield Volcanics")
Paddy's River Volcanics (Sap)	Near Tidbinbilla tracking station in Sheet area.	Grey to green dacite and tuff, lenses of limestone, calcareous shale and phyllite		-	As for Canberra Formation		Not known but probably large 1500 m ?	All contacts faulted or with intrusives in Sheet area; overlie Adaminaby Beds about 2 km northwest of Tidbinbilla tracking station	Middle Silurian correlate of Ainslie Volcanics and Canberra Formation?

TABLE 1 (continued)

UNIT (SYMBOL)	OCCURRENCE	ROCK TYPES	FOSSILS	DEPOSITIONAL STRUCTURES	DEPOSITIONAL ENVIRONMENT	TECTONIC STRUCTURES	THICKNESS	STRATIGRAPHIC RELATIONSHIPS	AGE AND CORRELATIONS
Canberra Formation (Smc, Smc_{1-3}, Smc_{a-e})	Belt from north Canberra through City Hill and Reid to Kingston, Fyshwick, Majura Road, Gungahlin	Calcareous and argillaceous siltstone and mudstone, limestone; minor argillaceous and tuffaceous sandstone, ashstone, tuff, dacite, calcareous sandstone and hornfels, slaty shale (Smc_b)	Brachiopods, trilobites, corals; some bivalves, crinoids, ostracodes and conodonts rare graptolites (north Gungahlin)	Ripple, current and graded bedding, minor slumping; liesegang rings common in siltstone	Shallow marine	Folded generally with moderate dips; cleavage well developed in mudstones	Smc 1000 m+ ("Camp Hill Sandstone" at base 0-60 m)	Camp Hill Sandstone Member at base unconformable on State Circle Shale, Black Mountain Sandstone and Pittman Formation; overlain conformably by Ainslie Volcanics and Hawkins Volcanics	Middle Silurian; correlate of Westmead Park Formation and Cappanana Beds
Black Mountain Sandstone (Slt, Slt_a)	Black Mountain, northeast Belconnen, Jerrabomberra Hill, Capital Hill	Massive to thickly bedded fine-medium grained quartz sandstone with a few thin shale and shale breccia interbeds; minor micaceous and feldspathic sandstone (Slg)	Worm casts	Current and ripple cross-bedding; slumping clay pellet bands	Probably shallow marine	As Sls	450 m+	Conformable on State Circle Shale; topmost beds not preserved	Early Silurian
State Circle Shale (Sls, Slp)	Capital Hill, flanks of Black Mountain, Jerrabomberra Hill, northeast Belconnen	Clay-shale and siltstone, minor sandstone; mudstone (Slp)	Graptolites; in particular Monograptus exiguus	Slumping; laminations almost ubiquitous	Marine, depth uncertain but probably not shallow	Gently to strongly folded, locally overturned bedding; cleavage in places	100-200 m overall (Slp 40 m thick at Giralang)	Overlies Pittman Formation; overlain unconformably by Camp Hill Sandstone Member (Smc_1) and by Smc_a (at Giralang)	Early Silurian (late Llandovery in upper part)
Adaminaby Beds (Oau)	Bullen Range area west of Tuggeranong	Sandstone, siltstone, shale	Graptolites	Graded bedding laminations, cross bedding	Marine; flysch sedimentation	As Omp	Not known	All contacts faulted or with intrusives in Sheet area; overlain by Paddys River Volcanics 2 km northwest of Tidbinbilla tracking station	Late Ordovician, correlate of Pittman Formation
Acton Shale Member (Oua)	As Omp	Grey to black, siliceous graptolitic, laminated shale	Graptolites very common	Laminations	Marine, depth uncertain; possible tuffaceous origin	As Omp	Variable to 60 m	Conformable within Omp; boundaries gradational over about 1 m	Late Ordovician (Eastonian)
Pittman Formation (Omp)	East Belconnen and meridional belt from Queanbeyan to Sutton	Silty quartz sandstone, feldspathic sandstone, greywacke, micaceous siltstone and shale, radiolarian chert, phyllite	Graptolites, radiolarians, rare brachiopods and conodonts	Rhythmic sedimentation, current bedding; laminations in some pelitic beds, graded bedding	Marine, depth uncertain chert possibly related to remote volcanism. No chert above Oua	Commonly strongly folded; folds may be isoclinal and overturned in places. Moderate to strong cleavage	Est. 800 m+ at Belconnen	Base not known; overlain disconformably? by early Silurian formations; overlain unconformably by Camp Hill Sandstone Member (Acton)	Middle to late Ordovician

ORDOVICIAN

Ordovician rocks form the oldest part of the sequence in the Canberra region. In the Sheet area Ordovician rocks occupy a fairly extensive meridional belt north from Queanbeyan, and smaller areas around Black Mountain and west of the Murrumbidgee River.

Pittman Formation and Acton Shale Member (Omp, Oua)

Opik (1954, p. 136; 1958, p. 12) defined the Pittman Formation as "a rhythmic sequence of sandstone, micaceous sandy shales, mudstone, black argillaceous shale, and chert (radiolarite)". The type localities are in creek beds west of Black Mountain, near Caswell Drive. At Aranda, northwest of the type localities, the sequence passes up conformably into grey to black siliceous shale to which Opik gave the name Acton Shale. The type locality of the Acton Shale is at the mouth of Sullivans Creek at Acton. Opik interpreted all exposures of the Acton Shale as occupying the cores of synclines in the Pittman Formation. Subsequently, excavations at Aranda and several other places have shown that the shale is within the Pittman Formation, and it is now regarded as a Member of that Formation; the Acton Shale is a useful marker horizon.

The Ordovician rocks in the Queanbeyan area, which extend north beyond the Federal Highway, were first mapped as "Muriarra Formation"* overlain by Acton Shale (Phillips, 1956; Moore, 1957); the "Muriarra Formation" is now regarded as Pittman Formation. To the east of Jerrabomberra Hill the Acton Shale is conformably overlain by sandstone similar to that which forms the top of the Pittman Formation at Aranda.

Graptolites are common in the Acton Shale, and less so in the underlying parts of the Pittman Formation; no fossils have been found in the sandstone above the Acton Shale. The graptolites range in age from Middle to Late Ordovician; the Acton Shale is entirely Upper Ordovician (essentially Eastonian). The graptolite fauna are listed in Opik (1958) and also in Strusz and Henderson (1971).

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*Stratigraphic names that appear in this report within quotation marks are previously published names which do not appear on the 1:50 000 scale map. The units concerned have either been mapped as other units, or are considered too small to show at the scale of the map. It is proposed that the units not be retained.

Adaminaby Beds (Oub)

The Ordovician rocks west of the Murrumbidgee River have been mapped as Adaminaby Beds (Owen and Wyborn, 1979). The rocks are similar to the Pittman Formation with which they may be correlated.

LOWER SILURIAN

The Ordovician sequence is succeeded by rock units regarded as Lower Silurian. One of these units, the State Circle Shale, contains Early Silurian graptolites but the others are unfossiliferous. An unconformity between the Ordovician and Lower Silurian rocks is possible, but nowhere has one been recognised; where the boundary has been crossed in excavations at Belconnen the Ordovician strata appear to pass up conformably into Silurian rocks. The question is confused by uncertainty regarding the exact position of the boundary, and by the similar lithologies of sandstone units in the Ordovician and Lower Silurian rocks. Rocks regarded as of early Silurian age occur between Capital Hill and Belconnen, and on Jerrabomberra Hill.

State Circle Shale (Sls)

Opik (1954, p. 138; 1958, p. 24) described the State Circle Shale as "non-calcareous sandy shale and black shale, with beds of fine-grained sandstone". The type locality is the northwestern road cutting on State Circle near the South African Embassy. The shale is generally laminated and slumping is a notable feature. Graptolites including Monograptus exiguus have been found at a number of places including Capital Hill, the southern foot of Black Mountain and Belconnen; their age is late Llandovery (Early Silurian). Contrary to Opik's interpretation the State Circle Shale is now regarded as older, not younger, than the Capital Hill unconformity.

Black Mountain Sandstone (Slb)

First named by Pittman (1911) the Black Mountain Sandstone was described by Opik (1954, p. 134; 1958, p. 7) as "quartzose fine-grained sandstone, with rare and thin shaly beds". The type locality is the main cutting on the road to the summit of Black Mountain. Opik interpreted the unfossiliferous sandstone as being Ordovician, and older than the Pittman Formation, from

structural considerations. However it is now known to conformably overlie the State Circle Shale at the southern foot of Black Mountain, thus implying a late Llandovery, or perhaps slightly younger, age. The contact has recently been exposed during construction of the Molonglo Parkway.

Opik also mapped Black Mountain Sandstone at Capital Hill and to the west of State Circle. Recent mapping in the area indicates a complex stratigraphic and structural relation to the State Circle Shale, and the possibility exists that some of the sandstone mapped as Black Mountain Sandstone is older, not younger, than the shale.

Unnamed Units (Slp, Slb_a)

Several areas of siltstone (Slp) and sandstone (Slb_a) may be direct correlates of the State Circle Shale and Black Mountain Sandstone. Some of the siltstone and sandstone has previously been regarded as Ordovician.

Unit Slp is a non-laminated siltstone which is found between the Pittman Formation and the State Circle Shale at Belconnen; outcrops which are possibly the same unit, also occur between Black Mountain and Capital Hill. The shale in the abandoned brick-shale pit on Jerrabomberra Hill occupies the same stratigraphic position as Slp at Belconnen.

Sandstone mapped as Slb_a overlies the State Circle Shale at Giralang and along the Barton Highway at Belconnen. The dominant lithology is soft micaceous sandstone unlike the quartz-rich Black Mountain Sandstone, and for this reason it was previously regarded as Pittman Formation; however it also contains beds of shale breccia similar to those in the Black Mountain Sandstone. The relation of the sandstone to the State Circle Shale was previously unclear, but has now been well established as overlying the shale from exposures in excavations at Giralang. This observation is in agreement with the interpretation of Crook and others, 1973.

Phillips (1956) correlated the sandstone on the summit of Jerrabomberra Hill (Slb) with the Black Mountain Sandstone, on lithological grounds. The sandstone conformably overlies siltstone and mudstone now mapped as Sls, which places it in a stratigraphic position at least as high as that of the State Circle Shale.

MIDDLE SILURIAN

Middle to Upper Silurian sedimentary and volcanic rocks unconformably overlie the Ordovician and lower Silurian Formations. In the north-central part of the Sheet area the sedimentary rocks are extensive, and largely predate the volcanics. However, to the south of Queanbeyan and to the west of the Murrumbidgee River sedimentary rocks above the unconformity are minor and volcanics apparently directly overlie the Ordovician basement. The middle to upper Silurian sedimentary rocks differ from the Ordovician and lower Silurian formations by the dominance of shaly rocks and the presence of calcareous beds. Fossils are mainly corals and shelly forms, graptolites being rare. The stratigraphic position of the middle/upper Silurian boundary is indefinite throughout the Sheet area; consequently, this section includes all those formations which are middle or upper Silurian.

Canberra Formation (Smc, Smc_{1-3} - north to central Canberra)

The Canberra Formation is equivalent to what was formerly the Canberra Group (Opik, 1954, p. 139; 1958, p. 31), later redefined (Strusz and Henderson, 1971). The former Canberra Group comprises five formations which, in ascending order, were the Camp Hill Sandstone, "Turner Mudstone"*, "Riverside Formation", "City Hill Shale" and "St Johns Church Beds". The Camp Hill Sandstone rests with marked angular unconformity on the lower Silurian formations at Capital Hill and State Circle. Apart from the Camp Hill Sandstone at the base, the other formations in the former Canberra Group are poorly exposed and have proved difficult to identify; it has therefore been found appropriate to dispense with most of these formations and to rename the Canberra Group the Canberra Formation. The Camp Hill Sandstone has been retained as the Camp Hill Sandstone Member (Smc_1). The City Hill Shale will also be retained as a member for large scale detailed maps.

A dacite flow at Crace Hill (Smc_2) is shown on the map as an unnamed unit within the Canberra Formation. The Narrabundah Ashstone (Smc_3) has now been found to be within the Canberra Formation, and not to be part of the younger Ainslie Volcanics; the ashstone has been given member status, as the Narrabundah Ashstone Member. The evidence for the revised stratigraphic position of ashstone was obtained from excavations at Fyshwick.

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*See footnote p. 3.

The range of lithologies in the Canberra Formation is evident from the descriptions of the units which Opik described. The Camp Hill Sandstone Member is a "flaggy, originally calcareous, quartzose sandstone", type locality Camp Hill. The formation is now much better exposed in State Circle than when described by Opik. A basal grit is overlain by beds of sandstone with siltstone interbeds, grading up into siltstone with minor sandstone. Opik's "Turner Mudstone" consists of "calcareous mudstone with thin layers of siltstone, fine-grained sandstone, and occasional tuffaceous bands", type locality Sullivans Creek in Turner. The "Riverside Formation" is composed of "calcareous shale and mudstone, current-bedded fine-grained sandstone, prominent limestone lenses, tuffaceous sediments, tuff and acid flows" (Crace Hill flow); the type locality is close to Bowen Drive, Barton. The City Hill Shale Member is dark "calcareous shale with limestone bands and lenses", type locality the eastern side of City Hill. The "St John's Church Beds" consists of "volcanic rocks (tuffs, porphyries) interbedded with tuffaceous mudstone, sandstone, limestone, shale and tuff, with limestone nodules". Apart from the Camp Hill Sandstone exposure mentioned above, rock is not exposed at the type localities of Opik's other formations.

On the western outskirts of Queanbeyan, Phillips (1956) mapped a Silurian sequence which is now identified with the Canberra Formation. The base of this sequence is sandstone which she correlated with the Camp Hill Sandstone Member. The sandstone appears to be faulted against the Ordovician rocks to the east; its greatest exposed thickness is found in quarries north of the Molonglo River.

Much of the Canberra Formation is moderately fossiliferous (see Strusz, 1975). The most significant fossils for correlation are the pentamerid brachiopod Rhipidium in the Camp Hill Sandstone Member, which is now regarded as indicating a middle Silurian age, and conodonts of late Silurian age in limestone at Braddon mapped as "Riverside Formation" by Opik (Link, 1970; Link and Druce, 1972).

The Canberra Formation has now been extended further to include the rocks mapped by Opik as "Fairbairn Group" (Opik, 1954, p. 140; 1958, p. 33). His "Fairbairn Group" consists of four formations, three of which, in ascending order, are the "Molonglo Ford Hornfels", "Molonglo Sandstone", and "Molonglo River Formation"; the fourth unit, the "Mahon Formation", was separated from the first three by faults. Opik's descriptions are as follows: the "Molonglo Ford Hornfels" is a "calcareous hornfels with bands of impure marble"; the hornfels is restricted to the northern edge of Fyshwick; the metamorphism is

attributable to andesitic dykes. The "Molonglo Sandstone" is a "flaggy, quartzose, calcareous" formation, whose type locality was near the former Molonglo Village internment camp, northeast Fyshwick. The "Molonglo River Formation" consists of "calcareous shale and limestone beds", type locality not specified. The "Mahon Formation" consists of "calcareous shale with limestone lenses ...., calcareous shales and limestones in a near-rhythmic lamination, and impure limestone beds and tuffs"; the type locality was Mahon Hill and its slopes. Rocks of the "Mahon Formation" were first described by Mahony and Taylor (1913).

The "Fairbairn Group" is confined mainly to the Fyshwick area, but rocks regarded as "Molonglo River Formation" were also mapped by Opik on the western slopes of Mount Majura and by Moore (1957) along Majura Road and to the north beyond the Federal Highway.

Opik regarded the "Fairbairn Group" as conformably overlying the "St John's Church Beds" (top of Canberra Formation). However it is now known that the Ainslie Volcanics are conformable on the Canberra Formation at Russell and Duntroon. Further, the Ainslie Volcanics are now regarded as conformable also on the "Mahon Formation" south of Fyshwick. Therefore it seems likely that the "Fairbairn Group" is equivalent to the upper part of the Canberra Formation. Fossils from localities formerly mapped as "Fairbairn Group" are similar to fossils from localities formerly regarded as "Canberra Group" (D.L. Strusz, pers. comm.).

Canberra Formation (Smc_{a-e} - north Canberra)

The "Westmead Park Formation" was first named by Smith (1964), with its type locality about 6 km beyond the northern margin of the Sheet area. Subsequent mapping by Hohnen (1974) and Henderson (1978c) has established that the "Westmead Park Formation" extends south as far as Belconnen where the basal part of the formation has been observed unconformably overlying the State Circle Shale. This relationship, plus fossils (see Strusz, 1975), and the range of lithologies, indicate that the "Westmead Park Formation" is a correlate of the Canberra Formation. All occurrences on the map are shown as Canberra Formation. Graptolites of middle Silurian age are known from rocks regarded as "Westmead Park Formation" (see Sherrard, 1952).

Cappanana Beds (Sml)

In accordance with Strusz (1975) the lenses of limestone and shale south of Queanbeyan first mapped by Phillips (1956) (her "Morley Formation") are shown as Cappanana Beds (Best et al., 1964), the type locality of which is east of Bredbo. Phillips noted metamorphism of the limestone and attributed it to contact effects of the adjacent foliated dacite (Colinton Volcanics), which she regarded as intrusive. The Cappanana Beds are fossiliferous but fossils have not been found in the Sheet area (see Strusz, 1975); a middle or early late Silurian age is indicated.

Colinton Volcanics (Smo)

The Colinton Volcanics (Best et al., 1964) extend from Queanbeyan to south of Bredbo. In the Sheet area they consist essentially of well-foliated dacite and tuff with minor sedimentary lenses. A major sedimentary unit has been mapped as Cappanana Beds (see above) which is thought to intertongue with the volcanics in the Sheet area. Stauffer and Rickard (1966) have put forward an explanation involving overthrusting to account for the two lenses of Ordovician Acton Shale in the volcanics. However, if Phillips is correct in regarding the adjacent foliated dacite as intrusive, Stauffer and Rickard's explanation would not be required. Another possible explanation is that the foliated dacite is unconformable on the Acton Shale. Contact relations between the Acton Shale, with some associated sandstone, and the foliated dacite are exposed in road cuttings; the contacts appear to be parallel to the foliation in the dacite, which coincides with the bedding in the shale. The age of the Colinton Volcanics is middle or late Silurian.

Paddys River Volcanics (Smp)

The type area of the Paddys River Volcanics (Malcolm, 1954) is along Paddys River south of the Cotter Reserve; the unit extends onto the western margin of the Sheet area near the Tidbinbilla Tracking Station. It consists of dacitic lava and tuff with lenses of shale and limestone, and is regarded as middle Silurian in age (see also Owen and Wyborn, 1979).

Hawkins Volcanics (Smh_{1-5})

The Hawkins Volcanics, for which the type area is east of Yass (Cramsie et al., 1975), are now known to extend as far south as Belconnen from mapping by Sherrard (1952), Henderson (1975b and 1975c), Hohnen (1973 and 1977) and Henderson (in prep.). The volcanics in the Sheet area are of acid to acid-intermediate composition, and appear to conformably overlie limestone of the "Westmead Park Formation" northwest of One Tree Hill on the A.C.T.-N.S.W. border. The volcanics have so far been mapped in sufficient detail to distinguish four volcanic units; in addition, various shale lenses (Smh_2) are present as indicated on the map. Some of the volcanics, particularly the quartz andesites which contain small and sparse phenocrysts, are chemically and lithologically similar to part of the Ainslie Volcanics (see below). The Hawkins Volcanics are regarded as of middle Silurian age in the type area.

Ainslie Volcanics (Sma)

Opik (1954, p. 145; 1958, p. 54) described the Ainslie Volcanics as "acid to dacitic pyroclastic rocks and volcanic flows", and interpreted them as unconformable on the "St John's Church Beds" (Canberra Formation) and the "Mahon Formation" ("Fairbairn Group"), and, as such, probably of early Devonian age. However, recent mapping of excavations indicate that the contacts with the underlying strata are conformable, and the volanics are now regarded as a less-deformed correlate of the Silurian "Gladefield Volcanics" (Moore, 1957). This conclusion is supported by chemical and petrographic studies. The "Gladefield Volcanics", which Moore described as comprising "acid lavas, tuffs and ashstones with some interbedded shales" conformably overlying the Fairbairn Group to the east of Majura Road, have now been included in the Ainslie Volcanics. Chemical and lithological similarity between the Ainslie Volcanics and the Hawkins Volcanics is also evident.

Subdivision of the Ainslie Volcanics around the type area, Mt Ainslie, has been carried out from recent mapping, and the subdivisions extended north to Gooroo Hill. An area west of Gooroo Hill, although previously mapped as Ainslie Volcanics, contains strongly foliated dacite similar to what was previously mapped as "Gladefield Volcanics" in areas to the east. Opik's Silurian "Mount Pleasant Porphyry" (1958, p. 32) which he regarded as an inlier in the Ainslie Volcanics, has been found in other places and is now considered as belonging to the volcanics; it is shown as Sms on the map. Insufficient mapping has been done of the volcanics south of Fyshwick and east of Fairbairn Aerodrome.

Walker Volcanics (Smw_{1-4})

The Walker Volcanics (Owen and Wyborn, 1979), formerly the Walker Member of the Uriarra Volcanics (Malcolm, 1954), are now regarded as extending east as far as the Belconnen suburb of Macquarie, to include areas previously mapped as Deakin Volcanics and unnamed porphyry. The type locality of the volcanics is Walker trig, south of Uriarra Crossing (west of the Sheet area).

The Walker Volcanics in the Sheet area have been subdivided, on the basis of mapping by Lang and Purcell (1976) and Henderson (1970a), into three volcanic units and an interbedded sedimentary unit. The sedimentary unit includes lenses of limestone and shale about 2 km northwest of Coppins Crossing which have yielded a rich fossil fauna (see Strusz, 1975). The fossils were regarded at first by Strusz as similar to those in the Canberra Group but he now recognizes affinities with those in the Yass Sub-Group (pers. comm.); he regards the brachiopod fauna as consistent with a late Wenlock (middle Silurian) age. Stratigraphic considerations indicate that the Walker Volcanics are younger than the Canberra Formation and therefore of late Silurian age if the conodont fauna in the Canberra Formation (Link, 1970; Link and Druce, 1977) is taken into account. Chemically the volcanics show similarities to the Ainslie Volcanics and Hawkins Volcanics but also some differences. Field characteristics are more akin to those of the Deakin Volcanics (see below); these include the purple colour of some flows and a lack of andesitic flows with sparse phenocrysts. However, except in the rhyolite (Smw_2), the Walker Volcanics do not contain the pink feldspar which is common in some of the Deakin Volcanics and in other volcanics near the top of the Silurian sequence. The topmost rhyodacite (Smw_4) is slightly unconformable on the underlying sedimentary and volcanic rocks.

Mount Painter Volcanics (Smb)

Opik (1954, p. 143) described a formation which he named the "Mount Painter Porphyry" as a "dark, massive porphyry with numerous xenoliths of igneous and sedimentary origin", containing garnet in places. Mount Painter was designated as the type locality. Opik interpreted the formation as an intrusive sill, and in his subsequent publication (1958, pp. 44-48) discussed this conclusion at some length. More recent petrographic studies have revealed a consistently volcanic crystal tuff texture, and, although locally intrusive

relations with sedimentary rocks have been confirmed, an entirely, or even dominantly, intrusive origin is not now accepted. It has been deemed appropriate, therefore, to rename the formation the Mount Painter Volcanics.

The Mount Painter Volcanics are dacitic in composition and extend from Mount Painter to Narrabundah. Although generally massive the volcanics in places contain lenses of agglomerate and banded tuff. A relatively high iron content, as indicated by chemical analysis, is responsible for the distinctive dark red-brown colour of the highly weathered rock and overlying soil. The fresh rock is generally dark grey or blue-grey. Rocks of similar composition and texture to the Mount Painter Volcanics have also been mapped to the west of Belconnen (Lang and Purcell, 1976); they are tentatively identified as Mount Painter Volcanics on the map.

Unnamed Sedimentary and Volcanic Rocks (Smb_1, Smb_2)

Lenses of sedimentary rocks, and of volcanic rocks such as ashstone and rhyolite which are distinguishable, from the adjacent Mount Painter Volcanics, have been mapped as units Suf and Suo. Rocks of unit Suf probably occur at several horizons in the Mount Painter Volcanics, and consist of sandstone, massive and banded ashstone, and hornfels derived from shaly sediments. Unit Suo consists of white rhyolite, ashstone and overlying tuffs all at the top of the Mount Painter Volcanics.

Units Smb_1 and Smb_2 are equivalent to the rocks mapped by Opik as the Deakin Volcanics, but which are not now mapped as such for reasons discussed below in the section headed Deakin Volcanics. Possibly these units are rafts, or in part rafts, which may account for the intrusive relations with the Mount Painter Volcanics observed in places.

UPPER SILURIAN

The formations described hereunder are thought to be conformable on the Middle Silurian formations already described, although almost all contacts are faulted in the Sheet area. The formations occur in much of the central-southern part of the Sheet area and also at Belconnen.

Yarralumla Formation (Suy)

The Yarralumla Formation was described by Opik (1954, p. 142; 1958, p. 43) as consisting of "more or less tuffaceous calcareous shale and sandstone with thin interbedded limestone", type locality the old brick-shale pit at Yarralumla. Henderson (1975a) discusses the lithological sequence within the Formation and the cause of the metamorphism on Red Hill. Fossils are common in the formation (see Strusz, 1975); they are regarded as of late Silurian age.

Yass Sub-Group (Sua)

The sedimentary rocks of the Yass Sub-Group (Cramsie et al., 1975) have been traced to within 4 km of Hall (Henderson, 1975b) where they are conformably overlain by volcanic rocks, which in turn can be traced to Belconnen (Henderson, 1975c). The volcanic rocks at Belconnen conformably overlie a sedimentary unit previously mapped as Yarralumla Formation (Strusz and Henderson, 1971) but now regarded as Yass Sub-Group by association with the overlying volcanics. However, the sediments at Belconnen contain a fossil fauna "not inconsistent" with a correlation with the Yarralumla Formation (see Strusz, 1975).

Deakin Volcanics (Sud_{1-10} - Woden, Tuggeranong)

The Deakin Volcanics were described by Opik (1954, p. 142; 1958, p. 34) as "a formation of acid volcanic rocks (tuffs, rhyolites) interbedded with tuffaceous sandstone and in places with tuffaceous shales with limestone bands, and jasper". The type locality was given as Red Hill Quarry. Opik mapped the Deakin Volcanics as a formation conformably underlying the Yarralumla Formation. Although volcanics and interbedded tuffaceous sediments fitting Opik's description have since been mapped below the Yarralumla Formation (units Smb_1 and Smb_2 on map), it is now evident that the type locality is in a younger volcanic formation which conformably overlies the Yarralumla Formation. These younger volcanics, which crop out extensively to the south and west of the type locality to the southern limits of the Sheet area, have now been mapped as the Deakin Volcanics. They now also include at the base the Mugga Mugga Porphyry Member (Sud_1) which Opik regarded as intrusive but which now appears to be an unusually coarse volcanic rock, with volcanic features such as flow banding.

The Mugga Mugga Porphyry Member and many of the other flows in the Deakin Volcanics are rhyodacites in composition. Two rhyolitic units have also been mapped. The lower unit (Sud_5) is composite and consists of several rhyolite flows of various compositions and texture, together with tuffaceous sedimentary interbeds. The upper unit (Sud_{10}) coincides with what is shown as the "Tuggeranong Granite" on the 2nd edition of the Canberra 1:250 000 geological map (Best and others, 1964), and as the "Tuggeranong Tuff Member" on the Michelago 1:100 000 geological map (Richardson and Barron, 1977); the unit is undoubtedly volcanic.

Units high in the Deakin Volcanics (Sud_{7-9}) occur to the east of Tharwa, where they are overlain, apparently unconformably, by a sedimentary formation (Suc) at the base of the Laidlaw Volcanics (see below). The subdivisions of the Deakin Volcanics, as shown on the map, have been made principally on the basis of reports by Wilson and Newstead (1967), Gardner (1968), Jackson (1970), Rossiter (1971), Mackenzie (1966), Vanden Broek (1974), Ceplecha (1975), and Goldsmith (1975b), and on reports in preparation, supplemented by further field work and petrographic studies. More recently Kellett (in prep.) has mapped an area on Lanyon Station to the northeast of Tharwa in great detail, and this work has been incorporated in the map as far as practicable. One unit (Sud_5) as shown on the map contains several well-defined sedimentary and volcanic units as mapped by Kellett.

The Deakin Volcanics are commonly purple but may also be grey or green-grey. The Mugga Mugga Porphyry Member (Sud_1) and unit Sud_5 generally contain pink feldspar grains; unit Sud_{10} is mostly leached white.

Deakin Volcanics (Sud_{a-f} - Belconnen)

The acid volcanic rocks which conformably overlie the Yass Subgroup in the Belconnen and Gooromon Ponds areas have been subdivided into several rhyodacite and rhyolite flows; a bedded tuff unit (Sud_d) has also been mapped (see Henderson, 1975c). The volcanics are commonly purple; flow banding is evident in unit Sud_3, some parts of which contain pink feldspar; pink feldspar is common in the rhyolites (Sud_e and Sud_f), but is rare in the lowermost unit (Sud_a). The volcanics are chemically and mineralogically similar to but not identical with some of the Deakin Volcanics with which they are tentatively correlated; however one chemical analysis of unit Sus shows similarity to some of the Walker Volcanics.

The contact of the Walker Volcanics with the units Sud_d-Sud_f is the inferred continuation east of a high angle reverse fault mapped in the Ginninderra sewer tunnel west of Macgregor. The fault has thrown the Laidlaw Volcanics (see below) to the north of it down against the sedimentary and volcanic units (Smw_2 and Smb?) mapped as part of the Walker Volcanics to the south. This indicates that the volcanic units farther to the east immediately north of the fault, Sud_a, Sud_b, Sud_c and Sud_f, are younger than the units of the Walker Volcanics (Smw_1 and Smw_4) immediately south of the fault.

Unnamed Sedimentary Rocks (Suc)

Sedimentary rocks, containing interbedded tuffs in places, have been mapped at the base of and within the Laidlaw Volcanics (see below). They crop out to the north of Mount Stromlo and along the Murrumbidgee valley between Tharwa and Kambah Pool. The outcrops to the north of Mount Stromlo are possibly conformable with and belonging to the Deakin Volcanics. Some of the sandstone and shale near Point Hut Crossing is shown as Yarralumla Formation on the 2nd edition of the Canberra 1:250 000 geological map, but this does not accord with the stratigraphic position of these outcrops which are within the Laidlaw Volcanics.

The shale and coarse sandstone to the east of Tharwa mapped as Suc are appreciably unconformable on the Deakin Volcanics, and are in turn overlain, possibly unconformably, by the Laidlaw Volcanics. An early Devonian age was previously interpreted for the sedimentary rocks which were mapped in detail by Mackenzie (1966) because of the presence of Acanthodian spines in the shale (pers. comm. D.L. Strusz), but this age is now seen to be inconsistent with the late Silurian age of the overlying Laidlaw Volcanics. According to G. Young (pers. comm.) Acanthodians, while more common in the Devonian, are not now unknown in Middle and Upper Silurian formations. A Late Silurian age for these sedimentary rocks as indicated by the volcanic succession is therefore regarded as tenable.

Laidlaw Volcanics (Sul)

An extensive volcanic formation of crystal tuff that crops out from Mount Stromlo to Tharwa, and also at Belconnen, is now regarded from chemical and petrographic studies (Owen and Wyborn, in prep.; Henderson, 1975b) as being

a southern extension of the Upper Silurian Laidlaw Volcanics at Yass (equivalent to "Willow Bridge Tuff" of Cramsie et al., 1975) (Owen and Wyborn, in prep.). The composition ranges from rhyodacite to dacite. The rock is generally pale or dark grey and in many places contains a few small pink feldspar grains; where pale grey the rock generally contains unaltered biotite. In some places particularly at Tuggeranong, the outcrops are not easy to distinguish in the field from those of adjacent volcanics.

The Laidlaw Volcanics are slightly unconformable on the Deakin Volcanics particularly overlapping units Sud_5, Sud_e and Sud_f at Belconnen; in places (e.g. at Pine Island) they appear to intrude associated sedimentary lenses (unit Suc), but, as with the Mount Painter Volcanics, this feature is not now regarded as indicating an intrusive origin for the whole formation. Possible roof pendants of intrusive porphyry (Sp_5) and inclusions of similar porphyry within the volcanics indicate that magma may have been initially intruded at a high level before erupting. Thus parts of units Sp_5 and Suc which appear to be within the volcanics could be rafts. A gentle southerly-dipping contact between the Laidlaw and Deakin Volcanics was exposed in the Tuggeranong/Weston Creek sewer tunnel beneath the suburb of Fisher.

HIGH-LEVEL INTRUSIVE PORPHYRIES OF MIDDLE AND LATE SILURIAN AGE

A number of unnamed acid porphyritic rock units, which are associated with volcanic rocks show relationships with sedimentary rocks, or microscopic textures, which indicate that some at least may be high-level intrusives.

Unnamed Porphyries (Sp_1, Sp_2, Sp_3, Sp_4, Sp_5, Sp_6, Sp_7)

A green-grey dacite (Sp_1) was mapped as Mount Painter Porphyry by Wilson (1961). However, from differences in texture and relationships with other stratigraphic units, the porphyry is now considered a separate unit. Intrusive contacts with Acton Shale (Ordovician) have been mapped near the eastern abutment of Lake Ginninderra dam.

A dacite between Hackett and the Federal Highway (Sp_2) appears to intrude calcareous sedimentary rocks of the Canberra Group with some resultant contact metamorphism.

Coarse green-grey rhyodacite west of Belconnen (Sp_3) has been mapped as intrusive from contacts mapped along the Murrumbidgee River west of the Sheet area (Henderson, 1975b) and in the Ginninderra sewer tunnel.

Dykes of pink and green rhyolite (Sp_4) intrude volcanic rocks south of Oakey Hill between Woden and Weston Creek. One of the dykes is exposed in a cutting of the Tuggeranong Freeway.

Coarse pink-brown rhyodacite (Sp_5), whose texture indicates an intrusive origin, crops out in the Kambah area (see Rossiter, 1971). In places inclusions of the porphyry are found in the Willow Bridge Tuff, for example on the southern slopes of Mount Taylor. A coarse rhyodacite northwest of the Belconnen suburb of Charnwood (Sp_7) resembles the rhyodacite Sp_5 in texture.

A coarse, dark grey rhyodacite with large pink feldspars (Sp_6) possibly intrudes sedimentary rocks beside the Murrumbidgee River at Lambrigg, near Point Hut Crossing. Alternatively the rhyodacite could be an extrusive rock unconformable on the Laidlaw Volcanics and parts of Suc. The rhyodacite extends from Lambrigg to about 1 km north of Tharwa.

INTRUSIVES OF LATE SILURIAN AND OTHER AGES

Rock Units of the Murrumbidgee Batholith (Sgs, Sgc, Sgr, Sgm)

The Murrumbidgee Batholith is a composite intrusive body west of the Murrumbidgee River which consists of a number of named lithostratigraphic units (see Snelling, 1960). Four of them, the Tharwa Adamellite (Sgr), the Shannons Flat Adamellite (Sgs), the Clear Range Granodiorite (Sgc), and the Booroomba Leucogranite (Sgm), occur in the Sheet area. The age of the batholith has now been determined as 424 $\pm$ 2 my (Roddick and Compston, 1976), which indicate that it was emplaced during the late Silurian. This age is consistent with the observed intrusive relationship with the Ordovician Adaminaby Beds and middle Silurian Paddys River Volcanics.

Greenwood Granite (Sgw)

Moore (1957) described the Greenwood Granite as a "eucrystalline, fine-grained biotite granite". The granite and associated microgranite dyke swarms intrude the Pittman Formation between Queanbeyan and the Federal Highway.

Barrack Creek Adamellite (Sgb)

The Barrack Creek Adamellite (Phillips, 1956) is a medium-grained leuco-adamellite which intrudes Ordovician and Silurian rocks south of Queanbeyan. The origin of a marked strike swing of the Silurian rocks around

the eastern and southern side of the intrusion is discussed by Stauffer (1967a). Recent mapping (Henderson, 1978d) indicates that the strike swing is also present in the Ordovician rocks immediately northwest of the adamellite.

Googong Adamellite (Sgo)

The Googong Adamellite is a coarse-grained adamellite with porphyritic margins (see Stauffer, 1967a); it intrudes the Silurian Colinton Volcanics west of Googong Dam.

Glebe Farm Adamellite (Sgg)

The Glebe Farm Adamellite (Strusz and Henderson, 1971) comprises several coarse-grained porphyritic adamellite bodies which intrude Ordovician and Silurian rocks at Belconnen.

Unnamed Intrusives (Sgh & Sga)

Small bodies of coarse-grained leucocratic granite (Sgh) have been mapped near the entrance to HMAS Harman, and about 2 km to the west, near Jerrabomberra Creek; they intrude the Ainslie Volcanics and the Canberra Formation.

Outcrops of hornblende granodiorite and diorite (Sga) occur on the western edge of the Federal Golfcourse west of Red Hill. This rock is now regarded as having been mainly responsible for the metamorphism of the Yarralumla Formation on Red Hill.

CAINOZOIC

Tertiary Gravel (T)

High-level gravels cover terraces and low hills bordering the Molonglo and Murrumbidgee Rivers. The gravels at Fyshwick were considered by Opik to be Permian fluvioglacial deposits, but this was challenged by Jennings (1972). Temporary exposures in the Googong Pipeline trench in 1976 showed blocks of weathered bedrock within the gravel; the gravel lay on a sloping bedrock surface and the relationship indicated slumping as the mechanism for incorporation of the bedrock block rather than fluvioglacial rafting. The age of the gravels has not been established, but a Tertiary or possibly Quaternary age now seems likely.

Quaternary Alluvium and Colluvium (Qa)

Deposits of alluvium and colluvium are extensive in some areas, the thickest deposits being in the Pialligo area (see Gardner, 1967). The cycles of Quaternary soil formation have been studied by Van Dijk (1959). Lake sedimentation in the Lyneham area is discussed by Opik (1958), and the age and significance of the colluvial fanglomerate on the lower slopes of Black Mountain is discussed by Costin and Polach (1973).

According to Van Dijk periodic climate changes during the Quaternary have been responsible for the layered variations in composition of the alluvial and some of the colluvial deposits. Thus the fanglomerate on Black Mountain would have accumulated during an arid period when no vegetation was present to retain the soil or scree. Wet periods would have led to the accumulation of organic silts and clays. The fine-grained aeolian sand along the Molonglo Valley would have been derived from a dry Molonglo River bed.

The composition and thickness of alluvium and colluvium is also governed by geomorphology and the geology of the source areas. Poorly sorted fanglomerate and scree, commonly of considerable thickness has accumulated at the change of slope around the base of prominent hills such as Black Mountain and Mount Ainslie. Some of the colluvium has then been re-deposited along the tributaries of the main watercourses where it has become increasingly well sorted and layered with distance from sources, and consists of clayey gravel, silty and sandy clay and sand. Well-sorted sand, silt and gravel is only developed extensively along the Molonglo River between Queanbeyan and Central Canberra. Along the Murrumbidgee River and the other stretches of the Molonglo River entrenchment of the rivers has confined alluvial deposits mainly to the bed and adjacent banks of the rivers.

STRUCTURE

Most of the Sheet area lies within the Canberra Graben (Strusz, 1971) which is bounded on the west by the Murrumbidgee Fault, and on the east by Sullivans Fault and the Queanbeyan Fault (see structural sketch in margin of map). The adjacent horsts, the Cotter Horst to the west and the Cullarin Horst to the east, consists mostly of Ordovician sedimentary rocks and Silurian granite; Silurian sedimentary and volcanic rocks are the main rocks exposed in the graben. A major fault within the graben, the Deakin Fault, strikes north-

west. The fault forms the southwestern boundary of the Black Mountain Horst, a fault-bounded inlier of Ordovician and lower Silurian rocks which extends from southeast of Capital Hill to eastern Belconnen.

All the sedimentary and volcanic rocks in the area are folded to a greater or lesser extent. Folding is most complex in the Ordovician rocks, especially to the east of Queanbeyan where some folds are downward-facing (see Stauffer and Rickard, 1966). Middle Silurian and younger rocks are generally less strongly folded than Ordovician and lower Silurian rocks. However, rocks of all ages are more deformed to the east of a line approximately coinciding with Sullivans Fault. Considerable variations in the strike of fold axes are related to the fault pattern. For instance, folds between the Murrumbidgee and Deakin Faults tend to strike parallel to those faults, whereas north and northeast of the Black Mountain Horst, fold axes are aligned sub-parallel to the numerous northeast-trending faults. Axial plane cleavage is common in most of the sedimentary rocks, particularly in the shales and mudstones. Some of the older Silurian volcanic rocks in the east of the Sheet area, for example the Colinton Volcanics and part of the Ainslie Volcanics exhibit a metamorphic foliation; the Colinton Volcanics are also tightly folded. The presence of foliation in only some of the volcanic rocks may indicate that these rocks were more deeply buried at the time of shearing movements and therefore susceptible to homogeneous deformation whereas the younger volcanics would have failed only along strike-slip faults.

Faults in the area are numerous. Many faults have fracture fillings of quartz and ironstone, by which they can be traced; others are evident from structural discontinuities. Movement along most faults took place during Palaeozoic orogenies and topographic expression of displacement has been removed by erosion. However, some later movement along the Queanbeyan and Murrumbidgee Faults probably took place in late Tertiary to Pleistocene times and recognisable scarps still mark the margins of the uplifted blocks. Most faults appear to have a dominantly vertical component of movement. However, small strike slip movements have been recognised along some faults such as the north-trending fault on Black Mountain Peninsula and the fault which displaces the Deakin Fault at Kingston. Larger strike-slip movements may have taken place along the Deakin and other faults west and south of Jerrabomberra Hill, and along faults which diverge from the Winslade Fault near Belconnen Way; strike slip movements are also probable along some of the faults in the Tharwa area.

ECONOMIC RESOURCES

MINERAL DEPOSITS

Although numerous small mineral deposits are recorded in the region few have been of commercial value. The history of mining and prospecting in the Australian Capital Territory and environs is reviewed by Smith (1963). Relevant data are also given in Gilligan (1975). Most of the mineral deposits mentioned specifically by Smith are outside the Sheet area, but one is reported as about 800 m west of Hall, where a shaft was sunk on a copper prospect. Smith's sources include references to a number of large "gossan outcrops" in the Queanbeyan district, and another to ironstone in the Ginninderra area.

Some attempts appear to have been made to extract gold from alluvial deposits near Queanbeyan. Records show that work was done at a locality on the Molonglo River about 10 km from Queanbeyan. Another reference is to an auriferous drift on a low hill about 800 m from the centre of the town which was worked in 1893. Gold Creek near Hall owes its name to early gold prospecting in the area.

ROCK AGGREGATE AND ROAD METAL

Four major quarries for rock aggregate and road metal are in operation. They are the Mugga Quarry operated by the Department of Construction, a quarry east of Mugga Lane operated by Blue Metal and Gravel Pty Ltd and two quarries operated by Readymix Pty Ltd, one about 5 km south of Queanbeyan and the other south of the Federal Highway immediately to the east of the A.C.T.-N.S.W. border. Mugga Mugga Porphyry is quarried at the first two, Barrack Creek Adamellite at the Queanbeyan quarry and dacite of the Ainslie Volcanics (formerlypart of the "Gladefield Volcanics") at the Federal Highway quarry. Some difficulties with pyrite mineralization have been encountered in the past in the Federal Highway Quarry.

A new quarry was recently opened in Mount Painter Volcanics about 1.5 km northwest of Scrivener Dam to supply rockfill for reclamation of part of Lake Burley Griffin for the Molonglo Freeway. The quarry has now been backfilled and landscaped.

Various small quarries were operated before and during Canberra's early development and are now abandoned. They include two on Mount Ainslie and one on the eastern side of Black Mountain. Two others, one in Acton Shale west of

Lyneham, and the other on a spur of Red Hill at Deakin, have now been filled with refuse and covered with soil. Limestone was quarried to a limited extent from sites on Wells Station to the north of Canberra, and from beside the Queanbeyan River about 4 km to the south of Queanbeyan.

STONE

Rough stone for the facing of cuttings and embankments is obtained from Mugga Quarry and from a small quarry in Camp Hill Sandstone east of Pialligo. The sandstone in the latter quarry is well-bedded and steeply dipping, and provides a good working face for extraction of suitably sized blocks. St John's Church was built from locally quarried Black Mountain Sandstone and possibly Ainslie Volcanics.

BRICK SHALE

Much of the Silurian shale in the Canberra area is suitable for the production of bricks (see Gardner, 1960a). The major supplier of bricks in the A.C.T. is the Commonwealth Brickworks which formerly operated the quarry and brickworks at Yarralumla. A new brickworks was recently constructed at Crace and a quarry for brick shale has been opened about 2 km to the northwest of Crace. Calcareous bands and veins are undesirable in brick shale, and their presence at both Yarralumla and Crace has presented difficulties.

A brick shale quarry was also operated by Commonwealth Brickworks for some years on the eastern slopes of Jerrabomberra Hill at Queanbeyan. Quarrying operations were confined between sandstone beds both to the east and the west, and a minor porphyry dyke was centrally located in the quarry. The quarry is now being used for refuse disposal by the Queanbeyan City Council. Other sources of brick shale in the past have been the reclaimed quarries at Deakin Oval and on the southern shore of Lake Burley Griffin at Yarralumla. The shale removed when Cork Hill, in front of Parliament House, was levelled some years ago was used for brick shale.

SAND

Before Lake Burley Griffin was formed, most of Canberra's coarse sand was supplied from alluvial terraces along the Molonglo River in and near Canberra (see Gardner, 1958c). Sand is still dredged from the Molonglo River at

Pialligo, but many other deposits such as one about 5 km downstream from Coppins Crossing have been worked out. Sand is known to remain beneath East Basin and recent investigations (Goldsmith and Pettifer, 1977) have proved that sand is present in the alluvium of Dairy Flat. Coarse sand was also won from the Murrumbidgee near Tharwa for some years until scouring around the main supports of the Tharwa bridge was attributed to sand removal, and forced a cessation of operations. Sand in the bed of the Murrumbidgee River and the Molonglo River at Pialligo is periodically replenished by sand transported by downstream by floods. Other sand deposits along the Murrumbidgee River worked at various times are outside the Sheet area.

Fine wind-deposited sand occurs as dunes on terraces above the Molonglo flood plain (Gardner, 1966) and has been won from a number of localities; however, all the major deposits are now worked out. Fine sand is now mainly obtained from dunes near the southern edge of Lake George.

ROAD GRAVEL

Road surfacing material for gravel roads, generally weathered granite or volcanic rocks, has been obtained from a number of small pits, and several investigations from new sources have been carried out (see Hansen, 1973; Kellett and Vanden Broek, 1971).

HYDROGEOLOGY

Hydrogeological studies in the A.C.T. and surrounding areas of N.S.W. since about 1954 have involved the siting of many farm bores, and the regular recording of water level in the observation bores (see Burton, 1961, 1967, 1969). Groundwater is generally obtained from fractured rock aquifers with yields mostly between 12 and 200 cubic metres per day. According to Burton (1967) the salinity of the water is generally within acceptable limits, the chief disadvantage being its hardness. Only 5% of analyses show total dissolved solids of more than 1600 ppm and 53% are less than 800 ppm. However 91% of analyses show greater than 180 ppm of $CaCO_3$ the lower limit of the "very hard" category. Depth to groundwater depends on location and hydrogeological conditions; occasionally, flowing bores have been drilled, but this is attributable to locally confined aquifers of limited extent, and is not a general characteristic of the area.

The bore locations shown on the map have been derived from the records of BMR and the Water Resources Commission of N.S.W. Some of the observation bores are no longer monitored as the projects for which they were drilled have been completed.

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