COMMONWEALTH OF AUSTRALIA.

DEPARTMENT OF NATIONAL DEVELOPMENT.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS.

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BULLETIN No. 32

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# THE GEOLOGY OF THE CANBERRA CITY DISTRICT

BY

A. A. ÖPIK.



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*Issued under the Authority of Senator the Hon. W. H. Spooner, Minister for National Development.*

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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS.

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CONTENTS



ILLUSTRATIONS: The full page photographs were taken by Mr. Gordon Reid, Photographer to the Bureau; the remaining photographs are prints made by Mr. Reid from Kodachrome slides taken by the author.

The geomorphology and the general structure of the Canberra area are amply illustrated in CANBERRA, A NATION'S CAPITAL (A.N.Z.A.A.S. Handbook, 1954). Plates XVIa, XXIV-XXVI, and XXXI-XXXIII are particularly illuminating.

# INTRODUCTION

## Purpose and Methods

This Bulletin is a summary of the geological history of the Canberra City District and serves as an explanation to the accompanying geological and tectonic maps.

The original text was accidentally destroyed, together with all records except the maps here presented and one showing the locations of all studied outcrops (totalling 340); the collection of fossils, except for some graptolites, is still intact. The summary for the A.N.Z.A.A.S. Handbook (Öpik, 1954) was compiled from the original text and served as a basis in rewriting the present Bulletin. Because of subsequent building operations, many of the destroyed records cannot be restored.

The geological map requires some comment. The map is correct insofar as the visible sequence is concerned; where the sequence is obscured by faults it reflects the author's interpretation to satisfy all the circumstantial evidence — structural, lithological, and palaeontological — so far available.

The accuracy of the boundaries is not absolute: small outcrops of weathered, or even fresh, rocks (for example, calcareous mudstones) do not provide all criteria for their formational classification and, in marginal cases, have had to be classified according to the boundary already inferred, and not vice versa; some portions of the boundary between the Turner Mudstone and the Riverside Formation are so treated.

Large amounts of material moved during the growth of the city now conceal wide spaces of former bedrock outcrops which can no longer be tested for their stratigraphical position; masses of shifted Silurian and even Ordovician* rocks are already, and will be still more in the future, a possible source of confusion if the area is re-examined. In the present map, however, this source of error is eliminated, although the boundaries of Silurian outcrops against soil-cover and alluvium may be disputable. For instance, in some trenches Silurian was met at depths of 8 ft. or more below the alluvial cover, and the area was mapped as Silurian; but in places with intact soil-cover of far lesser thickness, but without visible bedrock, the map shows the soil. Several areas, shown as Silurian on Pittman's map, but now built on and thus no longer available for examination, are also mapped, together with the shifted earth, as soil-cover.

The area south-west of the Deakin Fault, comprising upper Silurian rocks, could be mapped in greater detail, especially the Yarralumula Formation. The sequence there is not directly connected with the sequence of the Canberra Plain east of the fault, and the rocks of the area, especially the Deakin Volcanics and various other igneous rocks, are a marginal fragment of a greater body and ought to be treated on a wider scale.

The mapping and study extended over the period 1948-1952 as a regular weekend occupation. This long period was essential, because only a few artificial exposures existed at any one time, and one had to wait for additional, and essential, information in the course of building activity in Canberra. Altogether 120 days

* Most widespread is the Acton Shale with its graptolites, used as a road-metal in the streets of Canberra.

were spent in the field in covering the 50 square miles, mostly on foot. Silurian and Ordovician fossils have been collected from more than 100 localities.

Canberra is a small segment of the region, and an even smaller one of the Palaeozoic terrain of southern New South Wales. It was chosen for study not by geological reconnaissance, but by the mere chance of the author's being a resident of Canberra, the site of which, in turn, was established by Commonwealth legislation. This selection, however, was geologically very appropriate, because Canberra covers the structurally most complicated, and stratigraphically most informative, segment within the region (see Fig. 3), and is a key to the understanding of the geology of the northern part of the Australian Capital Territory and adjacent parts of New South Wales.

## Previous Research

The last summary of the geology of Canberra was published by Woolnough (1938) in the A.N.Z.A.A.S. Handbook for Canberra. The main sources for the geology of Canberra are the report and lithological map of Pittman (1911) and the report by Mahony & Taylor (1913); the physiography and geomorphology of Canberra and the Australian Capital Territory are discussed by Taylor (1910). The above-mentioned papers contain general information on the geology and lithology and on some economic aspects. The limestones of the Parishes of Canberra and Narrabundah are discussed by Carne & Jones (1919), who, for the most part, quote the work of Pittman and Mahony & Taylor. Cotton's (1923) summary for the Pan-Pacific Guide-Book is also a compilation from the work of earlier authors. A brief summary of the present paper was published in the A.N.Z.A.A.S. Handbook for Canberra (Öpik, 1954).

## General Aspects of the Geology of Canberra

The structural features of the Canberra City District are the result of lower Palaeozoic marine sedimentation, igneous activity, and tectonism, distributed over a long range of time. The known geological record starts with marine sedimentation in the Ordovician Period, followed by folding, uplift and erosion at the beginning of the Silurian Period (Benambran Orogeny). During Silurian time marine sedimentation and volcanic activity prevailed again, followed in the upper Silurian by the Bowning Orogeny, uplift, and erosion. After this the record is rather incomplete; the Lower Devonian is represented by volcanic activity, and the Permian Period by glacial deposits. Particular stages of this development are explained in Figures 3, 10 and 46 and the maps.

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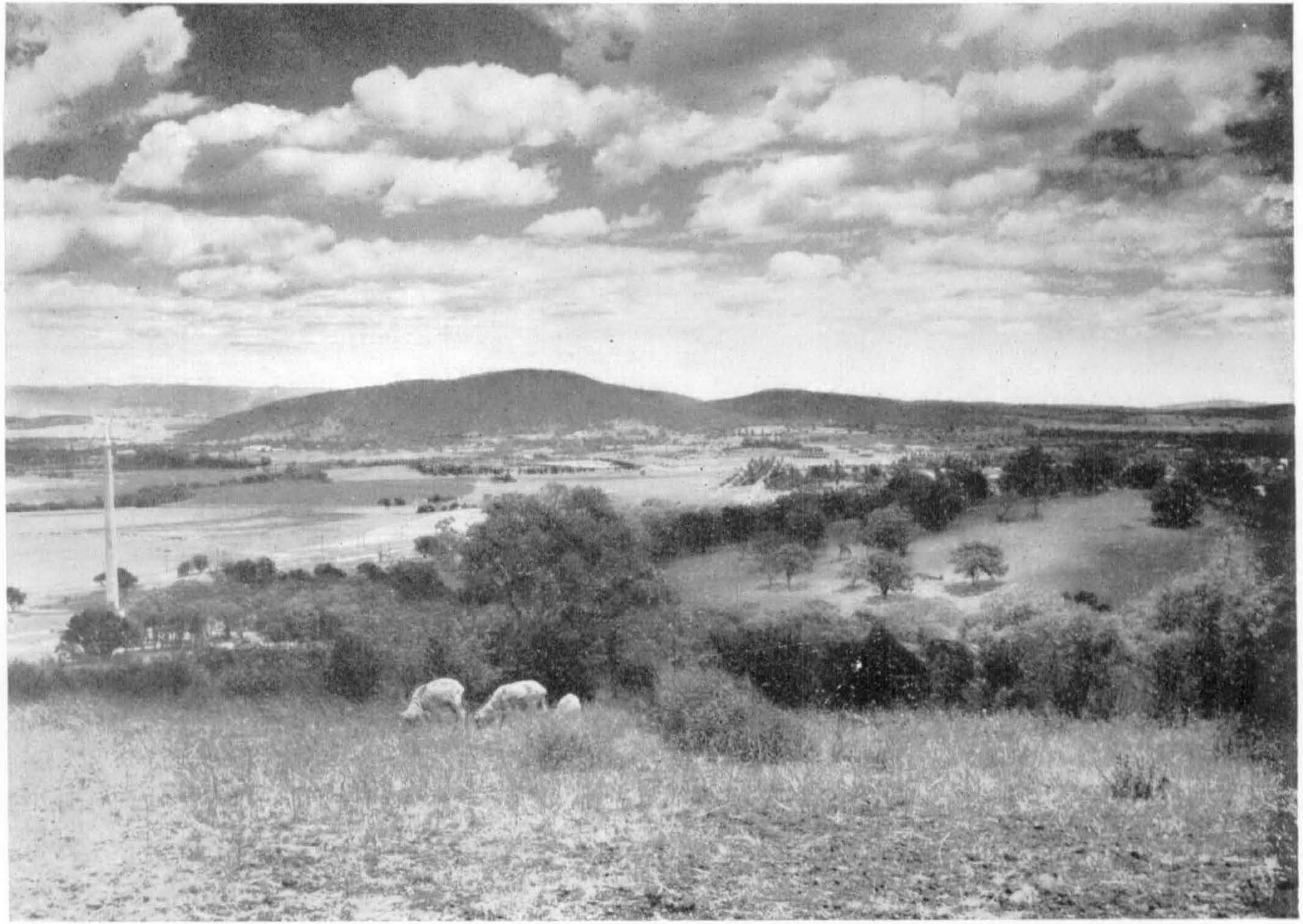
**Fig. 1.** Canberra. View from Mt. Russell to north_west. On the skyline on the left are the ranges of the Cotter Horst. On the skyline on right is One Tree Hill. Background, middle is Black Mountain (two summits). Low timbered ridge on right, in front of One Tree, is Southwells Ridge. Canberra Plain is in centre. Foreground: Mt. Russell (dacite), and a rhyolite hill (on right). U.S. War Memorial is on the left, on line with southern section of Commonwealth Bridge. For orientation, see maps, and Fig. 3.

Along the foot of the Black Mountain the Acton fault crops out in several places and the slope itself is the receding fault scarp.



In the Black Mountain Horst, the Cullarin Horst, and the Cotter Horst* are exposed the pre-Silurian rocks that have been the basement of the Silurian deposition. This basement was folded (Canberra Phase of the Benambran Orogeny) and eroded during the lower and middle ages of the lower Silurian Llandovery Epoch. Marine deposition was resumed with the Camp Hill Sandstone and the State Circle Shale (with *Monograptus turriculatus* and *M. exiguus*) in the upper Llandovery. The resulting unconformity is exposed on Capital Hill (Figures 4-7).

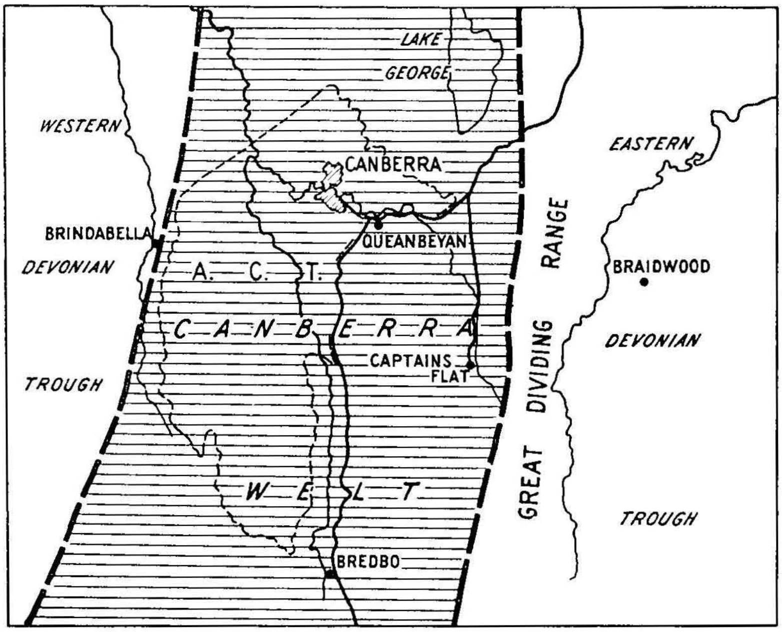



**Fig.** 2. Approximate boundaries of Canberra Welt, according to Noakes (1954).

Two phases of the Bowning Orogeny in upper Silurian time determined the main structural features of Canberra: the sediments and volcanic rocks were plicated in the Yarralumla Phase of the Orogeny, and fractured and faulted during the subsequent Painter Phase of movement. Two main faults of the Painter Phase, the Murrumbidgee Fault and Sullivan's Line (Fig. 3), delineate the near-oval Canberra Rift (about 16 miles wide and 34 miles long); and two smaller fractures, the Deakin Fault and the Acton Fault, form the Black Mountain Horst within the Canberra District proper. The Black Mountain Horst is eight miles long and about three miles wide at its widest part. The curved courses of the fault-lines, converging at several points, create the pattern of an irregular asymmetrical collapse-

* "Cullarin Horst" is a designation already used by Taylor (1923, p.5, explanation to Figure 1). In the same place the name "Bimberi Horst" was apparently applied to what is here called the "Cotter Horst". But Mt. Bimberi is west of the Cotter Fault (see Canberra 4-mile Sheet), and marks a separate structural unit, which seems to be part of the Cotter Horst (this paper) in a wider sense.

cauldron, with an eccentric intra-rift block (Black Mountain Horst). The deepest throw within the Canberra Rift is west of Black Mountain (estimated over 4,000 feet), whereas Canberra itself is situated on a step of the rift of a lesser throw (about 3,000 feet), extending between the Acton Fault and Sullivan's Line.

The mountain mass of the Bowning Orogeny was eroded at the end of Silurian and the beginning of Devonian time. In Lower Devonian time the Ainslie-Majura-Gooroo volcanoes were superimposed on the erosional surface, establishing the main features of the present topography of Canberra. The volcanic ridge fits well into the general cauldron picture of the region and may have been an ultimate consequence of the rift-subsidence.

The present relations of the structural elements are:

(1) the structures of the lower Silurian Canberra Phase, exposed in the Black Mountain Horst;
(2) the folds of the upper Silurian Yarralumla Phase, in the Canberra Plain;
(3) the faults (and the whole of the rift-and-horst structure) of the upper Silurian Painter Phase;
(4) the superimposed Lower Devonian volcanics.

Structures (1) - (3) now constitute the features of the Canberra Welt (Noakes, 1954).

Within the Lower Devonian Ainslie Volcanics signs of tectonic unrest (the Ainslie Phase) are preserved as an echo of a distant Middle Devonian orogeny, which occurred outside the Canberra region.

The nomenclature of the orogenies has been elaborated by W. R. Browne (1949) and the aspect of the Palaeozoic tectonic development in Canberra reflects his interpretation for south-eastern Australia in general.

The next event was the upper Palaeozoic glaciation, recorded in the Fyshwick Gravel, which is considered to be a fluvioglacial epicontinental deposit of Permian time. From here on, for the rest of Palaeozoic time and the whole of the Mesozoic and Tertiary periods, no depositional or any other geological records are preserved which could be exploited to elucidate the geological history of Canberra, as can be done for pre-Permian time.

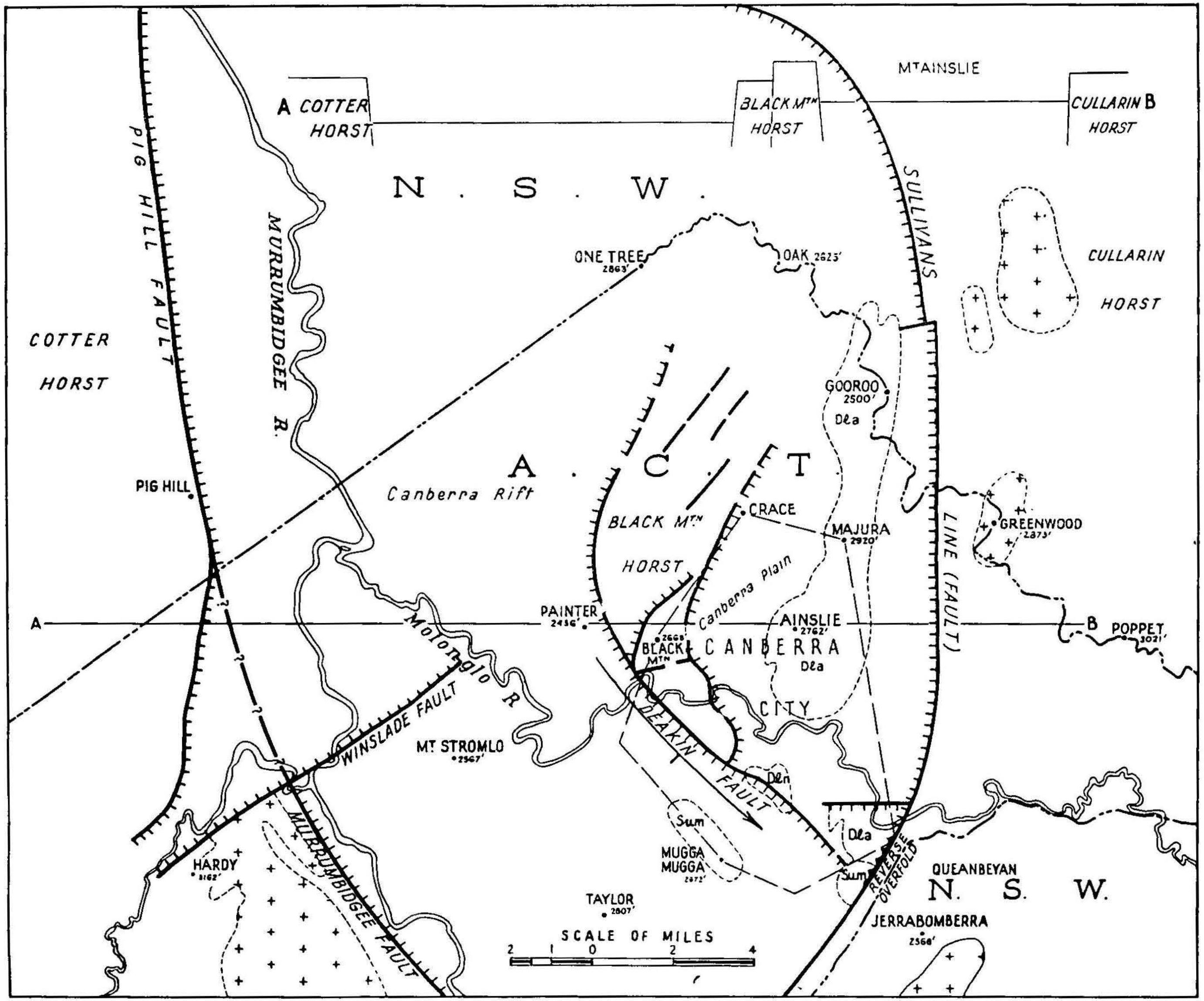
## THE GEOLOGICAL SEQUENCE

The oldest rocks exposed in Canberra are older than Middle Ordovician and are represented by the Black Mountain Sandstone. Most probably many thousands of feet of marine sediments occur below the Black Mountain Sandstone but are not exposed in Canberra. (See Table 5.)

### Before Middle Ordovician

#### *Black Mountain Sandstone*

The author of the name is Pittman (1911). The rock is a fine-grained quartzose sandstone with rare and thin shaly beds; the Sandstone contains very fine interstitial quartz-grains and some chlorite or mica and fragments of siliceous shale in some of


A COTTER HORST
BLACK Mᵀᴺ HORST
MᵀAINSLIE
CULLARIN B HORST
N. S. W.
PIG HILL FAULT
MURRUMBIDGEE R.
SULLIVANS LINE (FAULT)
ONE TREE 2863'
OAK 2625'
CULLARIN HORST
COTTER HORST
GOOROO 2500'
Dla
A. C. T
Canberra Rift
PIG HILL
BLACK Mᵀᴺ HORST
CRACE
MAJURA 2920'
GREENWOOD 2373'
Canberra Plain
PAINTER 2436'
AINSLIE 2762'
A
B
POPPET 3021'
BLACK Mᵀᴺ 2668
CANBERRA CITY
Molonglo R
WINSLADE FAULT
Mᵀ STROMLO 2567'
DEAKIN FAULT
Sum
MUGGA MUGGA 2672'
REVERSE OVERFOLD
QUEANBEYAN
N. S. W.
HARDY 3162'
MURRUMBIDGEE FAULT
TAYLOR 2807'
SCALE OF MILES
2 1 0 2 4
JERRABOMBERRA 2568'

the beds. The thickness of the Sandstone is not less than 1,500 feet. It is unfossiliferous except for worm-tracks in its lower portion. The type-locality is Black Mountain itself. The lowermost visible part of the unit, about 200 feet in thickness, has several interbedded shale beds.

The sandstone is silicified on the surface, but only medium-hard below. The quartz grains are rounded and up to 2mm. in diameter, with fine angular quartz fragments in between. Quartz veins are common along joints. Current bedding, ripple marks, bands with clay-pellets and local thin conglomerates with rounded pebbles, are observed. Disseminated pyrite is common in some localities. Slumping (Fig. 9) is common.

Igneous rocks are not present in the Black Mountain Sandstone, but the shales at its base may be tuffaceous.

Another occurrence is at Mount Jerrabomberra near Queanbeyan.

The lower contact of the Black Mountain Sandstone is eliminated by faults; an upper contact is seen in the unconformity on Capital Hill (Figure 4), and therefore the Sandstone is older than the basal Silurian Camp Hill Sandstone. Moreover, the Camp Hill Sandstone unconformably overlies the Upper Ordovician Acton Shale in Acton, and the next higher Silurian unit (the State Circle Shale) lies unconformably on the Middle Ordovician Pittman Formation in the Pittman Valley.

The Black Mountain Sandstone in Black Mountain is surrounded by rocks of the Pittman Formation, of the Acton Shale, and of various Silurian deposits, which all are faulted down against the Black Mountain Sandstone. Thus, the Black Mountain Sandstone cannot be placed into the sequence starting with the Pittman Formation. In the north-western corner of the map a block of vertical Black Mountain Sandstone is enveloped by rocks of the Pittman Formation above, and a discordant relation of the attitude of both the units is visible in the field. Therefore the Black Mountain Sandstone is here below and older than the Pittman Formation, but the character of the contact is not clear: it might be the suspected unconformity, or, more probably, the result of the decollement of the incompetent rocks of the Pittman Formation over the competent sandstone below. Thus the age of the Black Mountain Sandstone is Lower Ordovician, or older.

Previously the age of the Black Mountain Sandstone was considered to be Silurian.

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**Fig. 3.** Semi-diagrammatic map of Canberra Rift, to show the converging faults of the irregular cauldron-structure. The diagrammatic section A-B illustrates the relative downthrow of the various blocks along the faults of the Upper Silurian Painter Phase of the Bowning Orogeny, without reference to the ancient, pre-erosional topography. The northern extent of the Murrumbidgee Fault (the Pig Hill Fault) has been mapped by B. P. Walpole. The Winslade fault has been mapped by K. Malcolm and L. C. Noakes. The connexion of the Pig Hill Fault with the Murrumbidgee fault is postulated by the present author. The Sullivan's Line Fault has been mapped by C. J. Sullivan (unpublished), A. A. Day (unpublished), and the present writer. The distribution area of the Lower Devonian volcanics (Ainslie-Majura-Gooroo Ridge), two occurrences of the Mugga Mugga Porphyry (Sum), and the granites in the horsts nearest to the faults are indicated. The arrow along the Deakin Fault indicates the plunge of the Painter Porphyry. Modified after Öpik (1954).

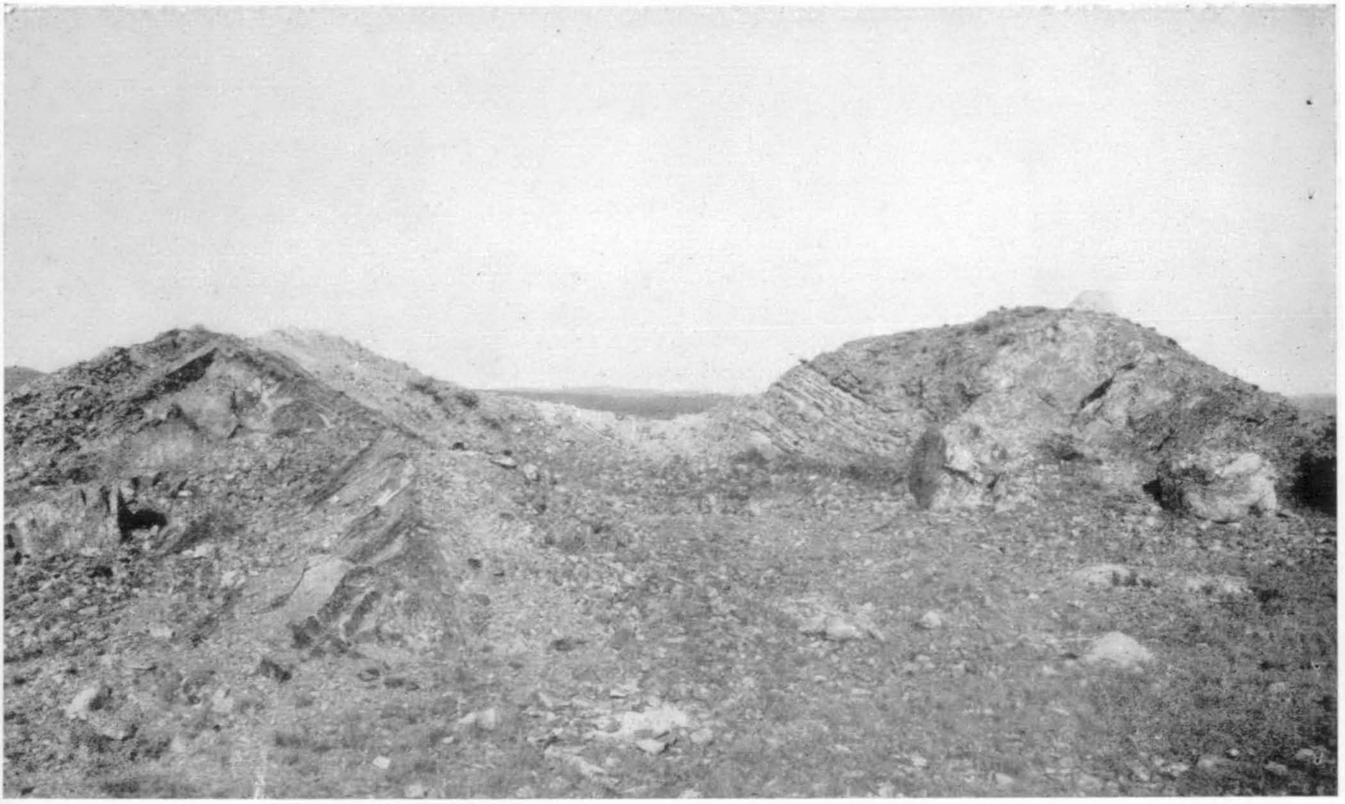

**Fig. 4.** Capital Hill: Unconformity between Camp Hill Sandstone and Black Mountain Sandstone. View looking east. See Fig. 5 for explanation; details in Figs. 6 and 7.


**Fig. 5.** Semi-diagrammatic section through unconformity on Capital Hill, Canberra.

The Black Mountain Sandstone of the basement is silicified, and the bedding is obscured by jointing; but the bedding-planes are recognized by ripple-marks and conglomerate bands. The sub-Silurian surface is in parts slightly uneven and otherwise nearly smooth. The date of the silicification is earlier than Camp Hill, for the latter is not silicified. No basal conglomerate is present, and the Silurian sequence starts with a fossiliferous grit bed, up to 4 inches thick. The angular unconformity is 68 degrees. As a result of a subsequent tilt to the south (Bowning Orogeny) the Black Mountain Sandstone is now half-way back towards its depositional position. No signs of subsequent movements along the unconformity are present; it is a healed contact. Vertical and horizontal scales are approximately the same; the length of the section is about 30 feet.

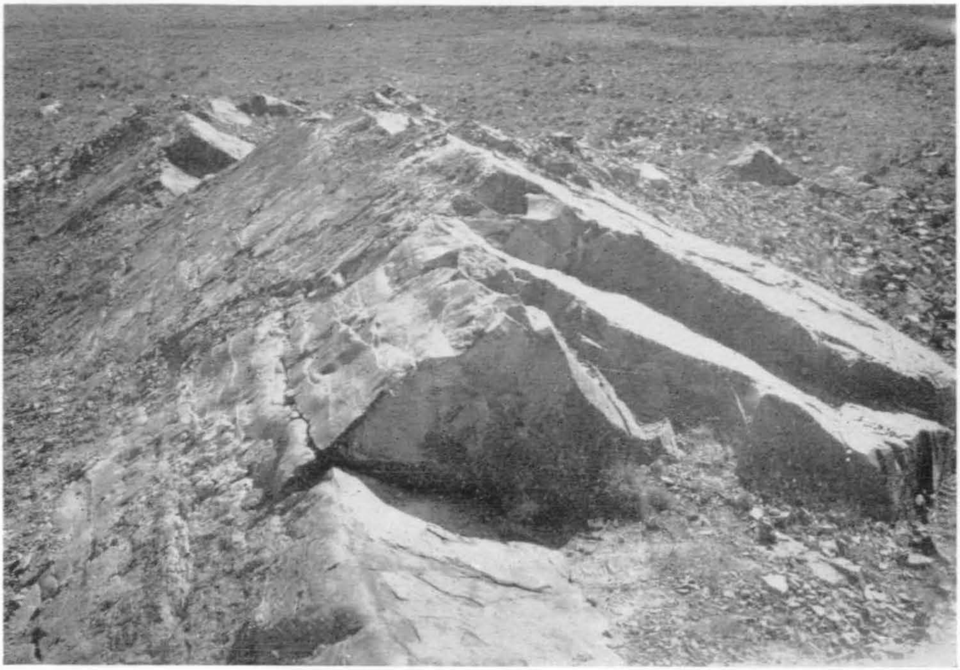

Fig. 6. Detail of unconformity on Capital Hill, view looking west. Veneer of Silurian Camp Hill Sandstone dips to left. Massive silicified Black Mountain Sandstone dips to right (north).

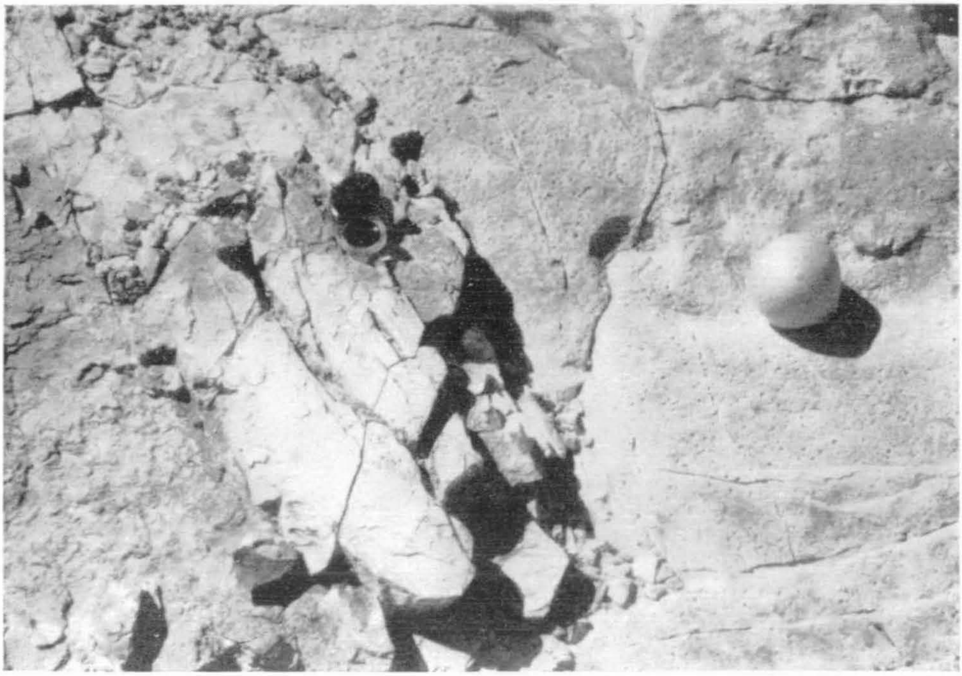

Fig. 7. Detail of unconformity on Capital Hill. Lens marks friable Silurian basal grit (Camp Hill Sandstone); orange marks Black Mountain Sandstone. The silicified pre-Silurian surface is smooth and minutely pitted.

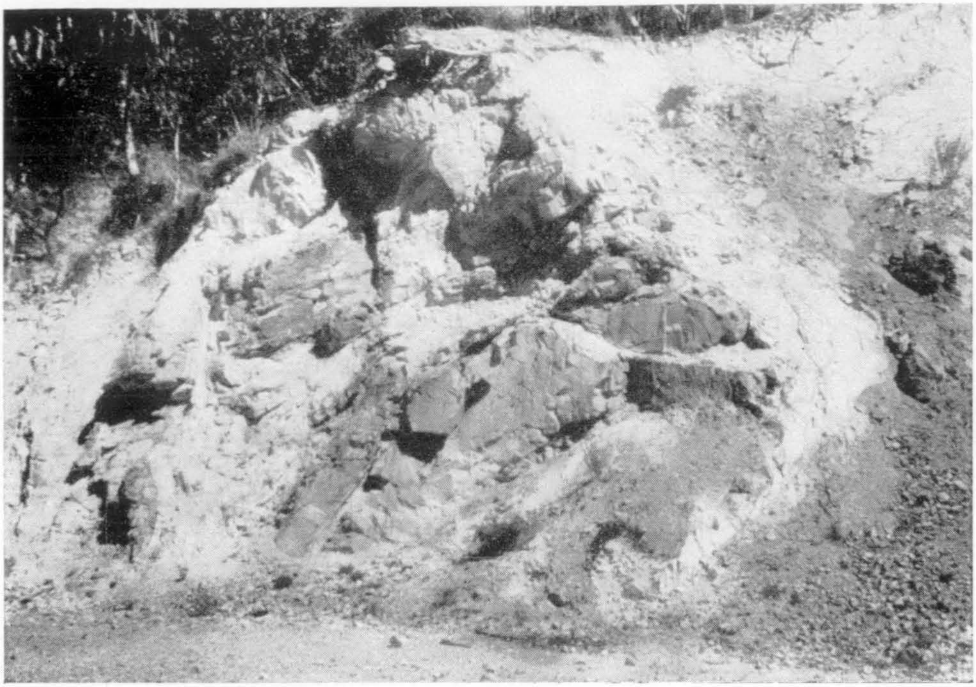

**Fig. 8.** Black Mountain Sandstone, western face of quarry on Black Mountain. The rock is crushed and distorted.

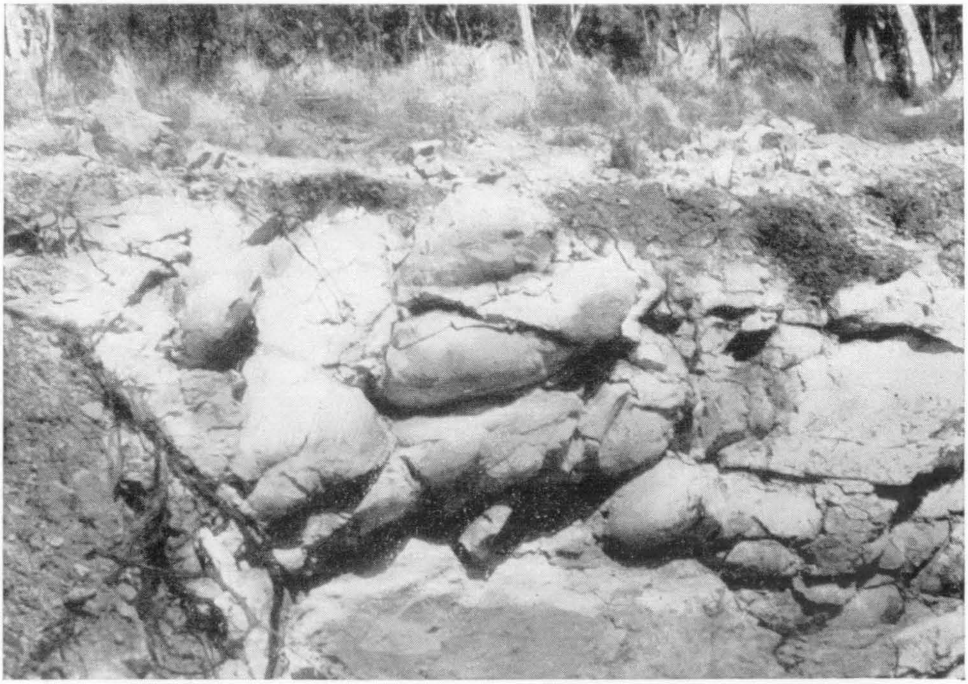

**Fig. 9.** Black Mountain Sandstone, southern face of quarry on Black Mountain, Bedding vertical, with a cluster of slump rolls. It represents the bottom of a bed.

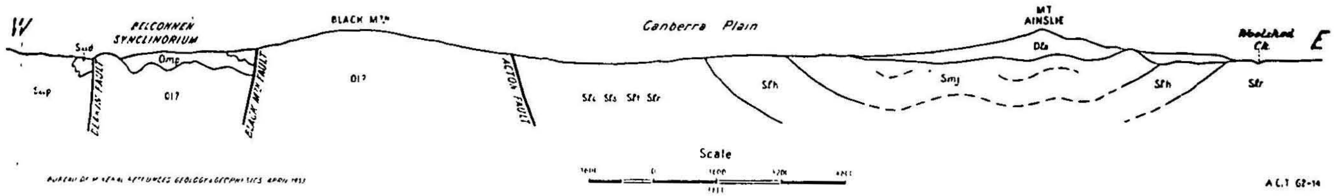


**Fig. 10.** Semi-diagrammatic and partly projected section across northern portion of Canberra. (Letter-symbols correspond to similar symbols on maps).

The structural elements are: (A) The basement, folded in the Lower Silurian Canberra Phase, and consisting of the Black Mountain Sandstone (Ol?), Pittman Formation (Omp), and Acton Shale (Oua: not shown in section); (B) The upper storey of Silurian rocks folded by the Bowning Orogeny, the units shown being: State Circle Shale (Sls), Canberra Group (Slt, Slr, Slh), St. John's Church Beds (Smj), Deakin Volcanics (Sud), as a roof-pendant of Sup, Painter Porphyry (Sup); (C) Lower Devonian Ainslie Volcanics (Dla) superimposed on the erosional post-Bowning land-surface.



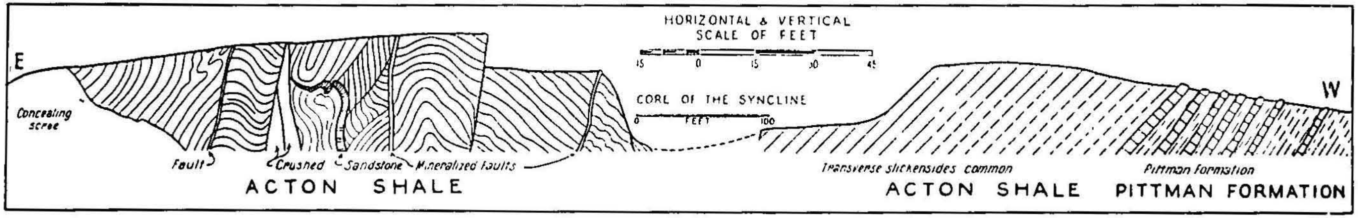


**Fig. 11.** Section across Ordovician rocks of north end of Southwells Ridge (road-metal quarry). Most of the section is by now quarried away. Generally, it is a syncline with a strongly contorted and sliced minor anticline near the eastern limb of the syncline. Farther in the east the structure is cut off by a SSW-trending fault (possibly a steep-angle thrust). The Acton shale in the quarry is silicified and leached, with only a little of the carbonaceous matter preserved. See also Fig. 14.

A correlation of the Black Mountain Sandstone within New South Wales is uncertain. Öpik (1952a, unpublished, and Table 5, below) correlates it with the upper part of the Bolton Greywacke (Fairbridge, 1953, (Bolton Formation); Öpik, loc. cit.), of the Snowy Mountains, which is also older than Middle Ordovician. Because the Bolton Greywacke, itself of a great thickness, is underlain by older sediments, a similar sequence might be expected in Canberra below the Black Mountain Sandstone: even Cambrian rocks might be expected.

The Black Mountain Sandstone is interpreted as a shallow-water (most probably marine) deposit in conditions of rapid sedimentation and gradual subsidence.

## ORDOVICIAN

The Ordovician of Canberra is represented by two conformable units, the Pittman Formation — essentially Middle Ordovician — and the Acton Shale — Upper Ordovician. Both names were first used by the author (Öpik, 1954). No igneous rocks of Ordovician age are present in Canberra. Rocks of Ordovician age have not been mentioned by previous authors, except for the occurrence in Queanbeyan (Keble & Harris, 1929), which is outside the Australian Capital Territory.

### *Pittman Formation* (Omp.)

The Pittman Formation is a rhythmic sequence of sandstone, micaceous sandy shales, mudstones, black argillaceous shale, and chert (radiolarite), of a total visible thickness of 700 feet. Graded bedding, clay-pellets, and current bedding are common in several horizons of the sandstone. The type localities are in the Pittman Valley, in the beds of Etheridge, Andrews, and Carne Creeks. The formation is fossiliferous and contains graptolites in various horizons, radiolarians, conodonts (in two different horizons), and rare brachiopods and sponges. Carbonate rocks are not preserved, except for a small outcrop of calcareous schist north of the Weetangerra Road, which seems to belong to the basal part of the formation. The schist is of local significance only.

Owing to the rhythmic arrangement of harder sandstone and softer shale the formation is incompetently folded (Fig. 12) and is easily eroded. Therefore it does not form conspicuous hills and outcrops and is mostly found in creek-beds and gullies.

The lithological composition of the Pittman Formation may be illustrated by the following section (Table 1), measured at the heads of Etheridge Creek in its bed in the Pittman Valley. Despite the number of small beds shown, it is still a generalized section. The beds dip mostly at 75 degrees to the west-north-west (305°). The section represents a middle portion of the formation, corresponding to the upper half of the Middle Ordovician.

From the attitude of the rocks, and allowing for the covered portions of the section, the total visible thickness is nearly 240 feet. Higher in the sequence and upstream, similar rocks with the same attitude occur over a distance of 120 yards, but are too much under cover to be measured satisfactorily.

TABLE 1

*Section of Pittman Formation*

| | "Sandstone" | "Shale" | Chert |
|---|---|---|---|
| 30. Contorted sequence of sandstone and chert beds. Creek bed covered by debris over a distance of about 25 ft. | 25 ft. | — | — |
| 29. Sandstone | 15 ft. | — | — |
| 28. Radiolarian chert with a lamina of carbonaceous sandstone with *graptolites* | — | — | 4 ft. |
| 27. Sandstone | 12 ft. | — | — |
| 26. Sandy shale (sandstone) | — | 5 ft. | — |
| 25. Interlaminated shale and sandstone, partly covered by debris | — | 15 ft. | — |
| 24. Sandstone | 1 ft. | — | — |
| 23. Argillaceous shale, similar to bed 22; no graptolites | — | 12 ft. | — |
| 22. Carbonaceous shale with sandstone laminae, with ripple-marks below; *main graptolite horizon* | — | 5 ft. | — |
| 21. Sandstone | 5 ft. | — | — |
| 20. Carbonaceous mudstone with *graptolites* near top | — | 10 ft. | — |
| 19. *Radiolarian* chert | — | — | 3 ft. |
| 18. Shale | — | 2 ft. | — |
| Sequence interrupted by a fault; for a distance of 12 yards the beds (chert, sandstone, and shale) are crushed and not measurable | | | |
| 17. Sandy shale | — | 3 ft. | — |
| 16. Sandstone | 3 ft. | — | — |
| 15. Chert with *radiolarians* | — | — | 2 ft. |
| 14. Shale with *conodonts and radiolarians* | — | 5 in. | — |
| 13. Sandstone, siliceous | — | — | 2 ft. |
| 12. Micaceous shale | — | 1½ ft. | — |
| 11. Shaly micaceous sandstone with sandstone lenses | 6 ft. | — | — |
| 10. Sandstone | 12 ft. | — | — |
| 9. Shaly sandstone | — | 1½ ft. | — |
| 8. Sandy micaceous shale | — | 1 ft. | — |
| 7. Sandstone | 1 ft. | — | — |
| 6. Shaly sandstone and shale | — | 1½ ft. | — |
| 5. Sandstone | 3 ft. | — | — |
| 4. Micaceous shaly sandstone, represented as "shale" | — | 7-8 ft. | — |
| 3. Sandstone, thick bedded | 3 ft. | — | — |
| 2. Sandy micaceous shale | — | 2 ft. | — |
| 1. Bedded sandstone | 4 ft. | — | — |
| Total approximately | 90 ft. | 70 ft. | 11 ft. |



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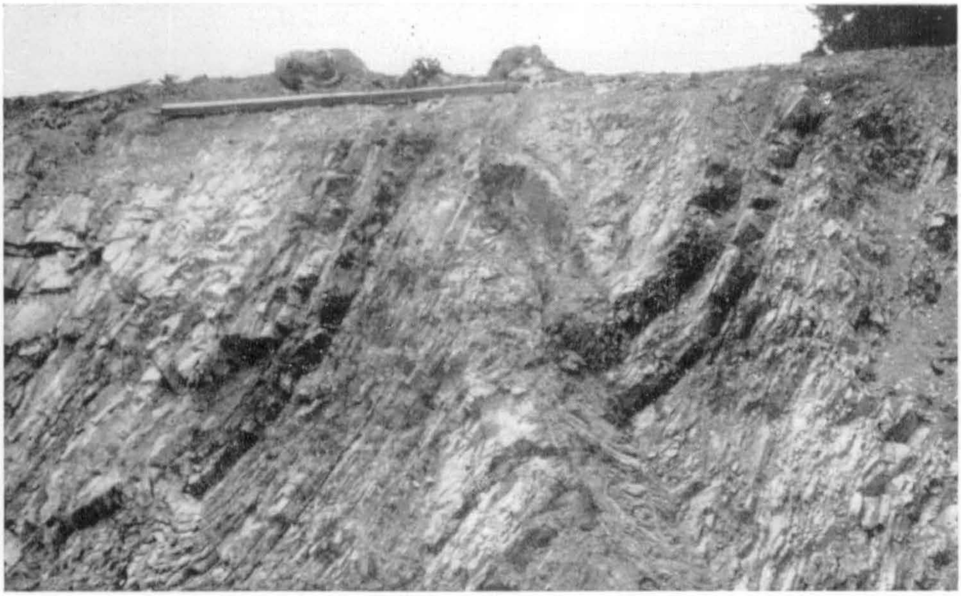

**Fig. 12.** Foundation of Medical School, Acton. Contorted interbedded shale and sandstone of the Pittman Formation. The structure consists of disrupted close folds steeply plunging towards the reader. See also Fig. 13.

**Fig. 13.** Pittman Formation, detail of Fig. 12; lower left end of fold, on left side of Fig. 12.

Fossils are very rare. In weathered rocks on the surface they are completely obliterated and the sequence seems to be unfossiliferous. Purposeful search, however, initially produced several localities with graptolites in a state of preservation sufficient for determination of genera and of some species, and for a stratigraphical interpretation of assemblages. Most of the fossils have been collected by digging in creek-beds. Graptolites occur without exception in beds of argillaceous black shale. Radiolarians occur in shales adjacent to the cherts and are amassed in the cherts themselves. They are not very well preserved; the best specimens occur in the chert near the contacts with shale. Conodonts are found in all three rock-types (sandstone, shale, and chert) but are confined to a few thin bands. Small inarticulate brachiopods (*Lingulella*) occur in association with graptolites, but are very rare indeed. Only the graptolites have been studied in any detail, but not all of them are adequately determined as yet.

The lowest known graptolite horizon of the Pittman Formation, in Carne Creek and south of it, has *Phyllograptus anna, Trigonograptus ensiformis, Pterograptus, Didymograptus, Isograptus, Hallograptus,* etc., and corresponds to Zone 5 of the British Ordovician sequence (lower Middle Ordovician). Still deeper beds have been encountered, but no fossils have been found in them as yet. The base of the formation has not been observed.

About 100 feet below the top of the Pittman Formation a different assemblage of graptolites, including *Dicellograptus sextans* and *D. divaricatus salopiensis,* has been collected. It indicates a lower Upper Ordovician (Gisbornian) age. Obviously the Pittman Formation covers not less than the whole of Middle Ordovician and a part of lower Upper Ordovician time in Canberra. Some aspects of the conditions of the deposition of the Pittman Formation are discussed below; the most significant is perhaps the appearance of the rhythmic sedimentation (see section, Table 1 above) and the presence of chert.

The cherts form beds ranging in thickness from a few inches up to 20 feet (e.g. in Andrews Creek). They are bedded and laminated, the lamination being apparent through colour banding.

Fresh pyrite is common. The rock is silica (chalcedony), in places dark with carbonaceous matter.

Flowage and fragmentation of the cherts are observable in slides. The fragments are clumps of the same rock, even fragments of the same laminae, in which they are embedded. Slumping in chert has not yet been observed. The cherts of the Pittman Formation cannot be explained merely as coagulated precipitates of silica. Of course, each bed, or even lamina, can be interpreted in that way, but a distinct sequence and a superpositional, normal layering is obvious. The radiolarians are better preserved in the cherts than in the shales, on the principle of "silica in silica", but are not confined biotopically to the cherts alone. They are here not an indication of deep water, because the intimate association of cherts and black shales with current-bedded sandstone layers points towards a generally shallow but, of course, marine environment.

The rhythmic sequence is not an expression of conditions within the sea itself: it rather reflects the mode of supply of detritus from the land. The parent rocks probably also consisted of sandstones and shales of a not very high degree of lithification, because no conglomerates of any kind (except clay-pellets and fragments) have been found. The rhythm itself may be explained as follows:

(1) The sandstone beds mark an increased supply of detritus and fast sedimentation, during which the suspended lutitic matter had little time to settle.

(2) The shale beds were each laid down over a longer time-interval and represent the "normal sediment". During the sedimentation of the sand-beds the sedimentation of lutites was continuous, but, being slow, it was also "diluted" by the invasion of sand.

(3) The described relations are reflected in the usual gradation of the tops of the sandstone beds into the shale beds above them; a reverse gradation (the top of a shale bed into the sandstone bed above) may occur but is not general.

(4) The sandstone beds are laterally discontinuous and peter out into bedding-planes, through major suites of sandstone beds preserve their position in the sequence. Shale beds may vary considerably in thickness, and may peter out also, but generally are persistent over larger distances.

(5) Chert beds mark local interruptions to the detrital supply and are usually replaced laterally by shale beds. Moreover, silica was occasionally precipitated together with the lutitic matter in the form of siliceous-argillaceous shale.

(6) Carbonaceous matter is most prominent in argillaceous shales and may occur in mudstones, but is also common in cherts and even in selected sandstone beds.

The environment can be reconstructed, but not completely. The condition of a marine basin of long duration (Middle and lower Upper Ordovician) and slow sedimentation (700 feet) prevailed; the basin was, perhaps, subdivided by islands and submarine ridges. The water was deep enough to allow the spreading of sediments and persistence of a bottom layer poor in oxygen, favourable to the survival of carbonaceous matter but unfavourable to benthos. Most probably the water was cool. The cherts may indicate remote volcanic activity (for example, the approximately contemporaneous andesites of the *Kiandra Beds* of the Snowy Mountains — see Table 5, below) or, according to modern concepts, times and places of invasion of fresh water from the land and mixing with the salt. The rhythm created by sand-beds might be an expression of climatic or, more likely, tectonic oscillations of the land. Slow sedimentation, persistent over a long range of time, is a sign of slow subsidence of the bottom of the sea.

After the foregoing interpretation was composed, the paper on turbidity currents by Hills & Thomas (1954) was published. The new outlook in interpretation of rhythmic Ordovician sediments has not been exploited here because it needs more time and study. It seems possible that turbidity currents had some part in the deposition of the Pittman Formation; but the thickness is too small (only about 700 feet) to be compared with the Victorian sequence (10,000 feet and 2,000 graded turbidity beds at any locality).

*Acton Shale* (Oua)

The Acton Shale consists of siliceous black shale over 200 feet thick, conformably overlying the Pittman Formation. The type-locality is in Acton, at the racecourse (Fig. 21).

The black shale is mostly leached, often silicified, and grey or nearly white in colour, but carbonaceous matter is still preserved in places. It is composed mostly of quartz dust as observable under the microscope. Minute puckering and subsequent silicification have given the rock a secondary granulate, rough structure with the external appearance of a fine-grained sandstone. It is, of course, a "pseudo-sandstone".

The Acton Shale is preserved only in synclinal cores, infolds into the Pittman Formation, within the structures of the Canberra Orogenic Phase (Figs. 11 and 14).

Brachiopods, conodonts, and sponges are noted, but are rare. Graptolites are common and ubiquitous, but their preservation is mostly unsatisfactory, and many of the finds cannot be identified specifically. Nevertheless, characteristic assemblages are recognizable and permit the dating of the formation. The best collections were obtained at the type locality, where the fossils have to be won by digging on a footpath, and on the southern end of Southwell's Ridge (fence-post holes at Prof. Oliphant's residence).

In the lower beds *Dicranograptus nicholsoni* may indicate the uppermost Gisbornian. Above it follows the usual Eastonian fauna with *Climacograptus bicornis, C. hastatus, C. tubuliferus, Dicellograptus elegans, Dicranograptus hians,* and in higher levels perhaps *Pleurograptus linearis* (compare Table 5), which may manifest the incoming of the uppermost Ordovician stage (Bolindian). However, it seems that most of the Bolindian rocks were eroded away to some extent before the Canberra Phase and even more so during the subsequent uplift. It is hardly reasonable to claim that the uppermost beds of the Acton Shale preserved in the infolds of the Canberra area represent the very last Ordovician deposits miraculously preserved after two orogenies and subsequent epochs of land conditions and erosion.

The first evidence for the presence of Eastonian in the Canberra area (west of Black Mountain) was contributed by H. S. Edgell (unpublished), although Keble & Harris (1929) had earlier described Eastonian graptolites from Queanbeyan, only a few miles east of Canberra, from the border of New South Wales and the Australian Capital Territory. The occurrence is also of Acton Shale.

The environment was "marine black shale", to which the current concepts of the origin of carbonaceous shale can be applied.

The leached and silicified Acton Shale in Southwell's Quarry (Figs. 11, 14) is used in Canberra as a road-metal. The most prominent occurrence is Clarke Ridge, north of the Pittman Valley.

The lithological character of the Acton Shale may be termed "euxinic". It is a carbonaceous fine-grained shale with planktonic fossils and pyrite. However, it could be a special case of an anaerobic environment different in some aspects from that of the present Black Sea.

A great number of localities of Ordovician black shales are recorded from New South Wales, as shown by Joplin (1945); most of them are of Eastonian age similar to the Acton Shale in Canberra. The southern half of the area of localities shown on Joplin's map (loc. cit., Fig. 1) covers more than 10,000 square miles; here the Eastonian black shales have an identical lithological composition and contain the same fauna; the thickness, too, is of the same magnitude. It may be concluded that all the occurrences mentioned by Joplin are remnants of an extended blanket of a single deposit, which in turn might be a fragment of an even larger body. Thus, even real euxinic dimensions cannot be denied.

There is, of course, another possible interpretation. According to Joplin (loc.cit.,p.170), the black shale consists of "large accumulations of volcanic ash which encased the plankton and prevented oxidation of the carbon content; the rocks are highly siliceous and their siliceous nature is probably original".

Browne (in David, 1950, Vol. 1, p.171) commenting on this statement rightly remarks that "the manifestations of contemporaneous volcanic activity were astonishingly few, if we leave out of account the possibility that the black graptolitic slates are composed largely of acid volcanic dust". This suggests a simplification of Joplin's hypothesis: the siliceous black shales are dust deposits. There was a continuous supply of dust, of course, from the surface of the barren Ordovician land, and in the sea it became visible as deposits in those places where other material had no access and where no masking of the dust by more voluminous sediments was possible. It is not necessary to assume the existence of an uninterrupted blanket of euxinic sediments: instead, patches of black mud were simultaneously deposited within "normal" sediment.

*Comparison of the pre-Silurian sequence in the horsts with the Ordovician of Canberra*

The Pittman Formation, or rocks of a similar character, is widespread in the Ordovician outside the faults of the Canberra Rift. East of Sullivan's Line, in the Queanbeyan area south of the Molonglo River, the similarity is so great that there is little hesitation in applying the name of the formation. Similar radiolarian cherts even are present, as well as infolds of the black Acton Shale; and, to complete the sequence, the Black Mountain Sandstone provides a similar base.

At Queanbeyan, north of the Molonglo River, a sequence of greywackes emerges from beneath the Pittman rocks, the Black Mountain Sandstone being here absent. These greywackes seem to represent an older sequence not seen in Canberra. The relationship suggests that the Pittman deposits lie unconformably on the greywackes, and that the Black Mountain Sandstone was eroded away during the interval and was preserved as a residual (Mt. Jerrabomberra) farther to the south. If this conjecture is correct, the base of the Black Mountain Sandstone should grade into the greywackes below.

The position of the interval mentioned above would correspond to the postulated break (unconformity) between the Pittman Formation and the Black Mountain Sandstone in Canberra (p.7), but, of course, in both cases further evidence has to be searched for.

**Fig. 14.** Acton Shale in Southwell's quarry. Picture corresponds to left (eastern) end of section, Fig. 11. The rest is quarried away.

**Fig. 15.** Etheridge Creek cutting Black Mountain Fault. Explanation in Fig. 16.

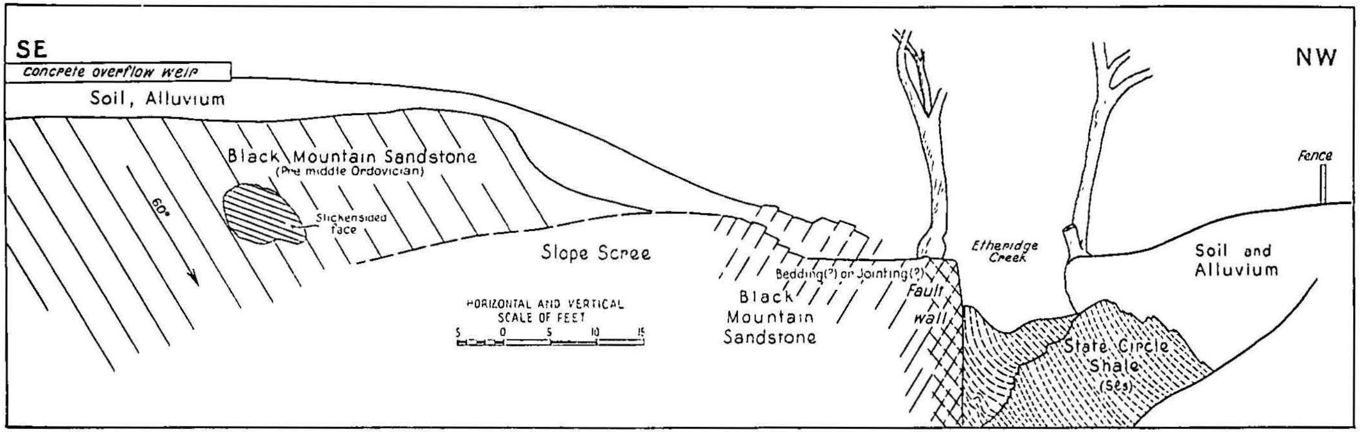


Fig. 16. Section across Black Mountain Fault. Compare Fig. 15.

North of Canberra, just north of the northern end of Sullivan's Line, along the Murrumbateman Road, 4 miles north of Spring Hill (See Canberra 4-mile Sheet), rocks of the Pittman Formation are well exposed. Well-preserved conodonts, together with graptolites perhaps of Gisbornian age, are present at one locality at least. The lithology, however, differs notably; no cherts have been seen as yet, and the shales and the sandstone beds contain in some layers large amounts of rock fragments similar to the matrix of the same beds (mostly shale). Similar fragmental rocks are common in the Cullarin Horst between Queanbeyan and the locality on the Murrumbateman Road. Infolds, and perhaps interbeds, of black shales are also present, but no fossils have been recorded from them as yet.

North of the Molonglo River at Queanbeyan and between Canberra and Lake George, on a surface of about 150 square miles, the lithology of the Pittman Formation prevails, and the thickness of the sequence seems to be many times that of the 700 feet observed in Canberra. The application of the formation name (Pittman) to this area must be reserved until the sequence is adequately studied. No rocks of the Black Mountain type have yet been seen in the area. The age is Ordovician, but older rocks might be present, as, for example, in the possible culminations around the Greenwood and Sutton Granites, and, perhaps, along Lake George itself. Most of our knowledge of this area has been contributed by Garretty (1936, 1937a, 1937b).

West of Canberra, in the Cotter Horst, the Ordovician is developed in a style similar to the Pittman Formation of Canberra. Black shale of the Acton type with Eastonian graptolites is seen at two localities, but may be merely lenses included in the general Ordovician sequence. The relationship is not yet clear, but is indicated by the occurrences of Eastonian graptolites *(Dicranograptus, Dicellograptus,* etc.) in a layer of shale ("knotted schists") in a Pittman-like sequence of shale and sandstone at Mt. Franklin in the Brindabella Range. In the same Range, stratigraphically above a black shale with Eastonian graptolites, shale and sandstone follow, suggesting the presence of possibly Bolindian (uppermost Ordovician) rocks. Radiolarian cherts have not yet been seen in the Cotter Horst.

Although the sequence of rocks of the Cotter Horst is not yet established in print, in unpublished reports the Ordovician sequence is usually referred to as the "Mt. Franklin Formation" (name by L. C. Noakes), as distinct from the Tidbinbilla Quartzite (Noakes, 1954). The name "Mt. Franklin Formation" is mentioned here for the information of the many users of the unpublished material. The application of the name "Pittman Formation" to the Ordovician rocks of the Cotter Horst is not advisable until a comparison in the field is completed.

If the Ordovician sequence of Canberra (Pittman Formation and Acton Shale) is compared with its development in the horsts, (1) the sequence in the horsts is evidently thicker; (2) in the horsts, rocks similar in lithology and position to the Black Mountain Sandstone are unknown; and, consequently, (3) in Canberra the Ordovician sequence may well be incomplete on account of a possible break at its base against the Black Mountain Sandstone.

## SILURIAN

### *The Canberra Orogenic Phase*

The name "Canberra Orogenic Phase" was applied for the first time in Öpik (1954) to designate an early Silurian folding of the Benambran Orogeny illustrated by the unconformity between the Upper Ordovician and Lower Silurian rocks in Canberra.

According to Browne (in David, 1950, Vol. 1, p.168), the Benambran Orogeny is a tectonic event in southern New South Wales and eastern Victoria that occurred at the end of Ordovician or the beginning of Silurian time. In Canberra the evidence of its presence is best seen in the unconformity on Capital Hill (Figs. 4-7). The dating of the whole of the Benambran Orogeny is not accurate, because at the type locality (Benambra, Victoria) it refers to an unconformity between metamorphosed and folded Ordovician (Upper Ordovician) and overlying Devonian rocks. The present author considers that metamorphosed Upper Ordovician rocks logically suggest a roof of younger (Silurian) rocks at the time of diastrophism in the type area, which, in turn, indicates an advanced Silurian age of the event. In Canberra, as is manifested in the unconformity, the latest possible date for the folding is middle Llandovery, which is very low in the Silurian sequence indeed. Thus, the possibility of several distinct phases of folding seems evident. The character of folding of the Acton Shale in Canberra, which is the youngest preserved pre-Benambran rock, also suggests an overburden of some thickness at the time of the plication.

The event in Canberra can be described as follows: After the deposition of the Acton Shale and, possibly, uppermost Ordovician rocks which are no longer preserved, marine conditions were interrupted, and the sequence already deposited was subsequently plicated (Canberra Phase of the Benambran Orogeny), uplifted, and eroded. The resulting land was shortly afterwards inundated again, as is testified by the presence of sediments of the upper Llandovery (Camp Hill Sandstone and State Circle Shale) transgressing the Benambran land.

The interval was, therefore, only of short duration, covering no more, probably even less, than the lower and middle part of the Llandovery (Lower Silurian) Epoch. The Orogeny had no consolidating effect on the earth's crust in Canberra. This is substantiated below, in the chapter on the tectonics of the Canberra area. Within the Acton Shale and the Pittman Formation the type of movement is surface folding; the Black Mountain Sandstone is involved in the Benambran structure, but its tectonic response has not yet been worked out: a disharmonic structural relationship of the Pittman Formation against the Black Mountain Sandstone obscures the situation.

#### LOWER SILURIAN SEQUENCE

Lower Silurian units in Canberra are:

(1) Camp Hill Sandstone, and

(2) State Circle Shale, which together represent the beginning of the Silurian marine transgression; and

(3) the Canberra Group.

The Camp Hill Sandstone (Fig. 4, 17) and the State Circle Shale (Fig. 16) are preserved on the surface as outliers on the Black Mountain Horst only. The Canberra Group forms the surface of the Canberra Plain. The name "Canberra Group" is a transcription of the "Canberra belt" and "Canberra Series" of Mahony & Taylor (1913, p.10), and of the "Canberra Beds" of David (1932, Table B), although it is impossible to discover to what extent the two units coincide. Evidently the "Canberra Beds" also cover an essential part of the Ordovician and an unknown part of higher Silurian strata, which are now assigned to other units. The other unit names applied here for the Lower Silurian sequence in Canberra were first used by the author (Öpik, 1954), though the "Acton limestone" was recognized by Mahony & Taylor (loc. cit., p.21). The presence in Canberra of Lower Silurian shales with *Monograptus exiguus* in the locality south of Black Mountain was already known in the Bureau of Mineral Resources when the author's study of the area began.

*Camp Hill Sandstone* (Slc)

The Camp Hill Sandstone is a flaggy, originally calcareous, quartzose sandstone, up to 40 feet thick, forming the basal, transgressive, deposit of the Silurian in Canberra. The type locality is Camp Hill, just south-west of Parliament House (Fig. 17). The Sandstone also outcrops on Capital Hill, unconformably over the Black Mountain Sandstone, and on the Acton Ridge, unconformably over the Acton Shale.

The Camp Hill Sandstone itself is overlain, apparently conformably, by the State Circle Shale, whereby its age is determined as the beginning of the upper third of the Lower Silurian. The Camp Hill Sandstone is abundantly fossiliferous and contains a shelly fauna with corals, brachiopods, and trilobites. Notable is the pentamerid brachiopod *Rhipidium*, previously known only from the Lower Silurian of north-eastern North America. Outside Canberra the Sandstone occurs west of Queanbeyan, but deposits of the same age are not known elsewhere in New South Wales.

The Camp Hill Sandstone is a shallow-water deposit; even ripple marks are present. In conformity with its transgressive character, it forms no continuous blanket over large areas; perhaps it was deposited in a sheltered and topographically low area where the inundated ridges and hills were kept free from sediment by the action of waves and currents.

*State Circle Shale* (Sls)

The State Circle Shale consists of non-calcareous sandy shale and black shale, with beds of fine-grained sandstone, and is about 200 feet thick. The type locality is the north-western road-cutting on State Circle ("State Circle Rift").

On Camp Hill and the north-eastern slope of Capital Hill the State Circle Shale overlies the Camp Hill Sandstone, but in northern outliers on the Black Mountain Horst the latter seems to be missing and the Shale overlaps various units of the basement.

The age is upper Lower Silurian, Zone 22, determined by the occurrence of the graptolites *Monograptus turriculatus, M. spiralis, M. exiguus*, etc. A well-known locality is the southern foot of Black Mountain. The State Circle Shale may be correlated with the Jerrara Series (Naylor, 1935) of the Goulburn area.

Upwards the Shale passes into the Turner Mudstone, which is calcareous.

**Fig. 17.** Camp Hill Sandstone in Camp Hill, State Circle, between Parliament House and Capital Hill.

**Fig. 18.** Bedding in Silurian soft calcareous mudstone (City Hill Shale) in trench at Olympic Pool, Constitution Ave. The pencil is on a bedding plane (dip 32° E.).

**Fig. 19** (opposite). Woolsheed Creek crossing at Fairbairn Aerodrome. Silurian calcareous shale dips steeply to left. Mt. Majura in background on left. The historic locality from which the first Silurian fossils were collected by W. B. Clarke and described by de Koninck. Majura Plain (depositional) and the ridges of the Cullarin Horst on the skyline on the right. See also Fig. 20, 44 and 45.

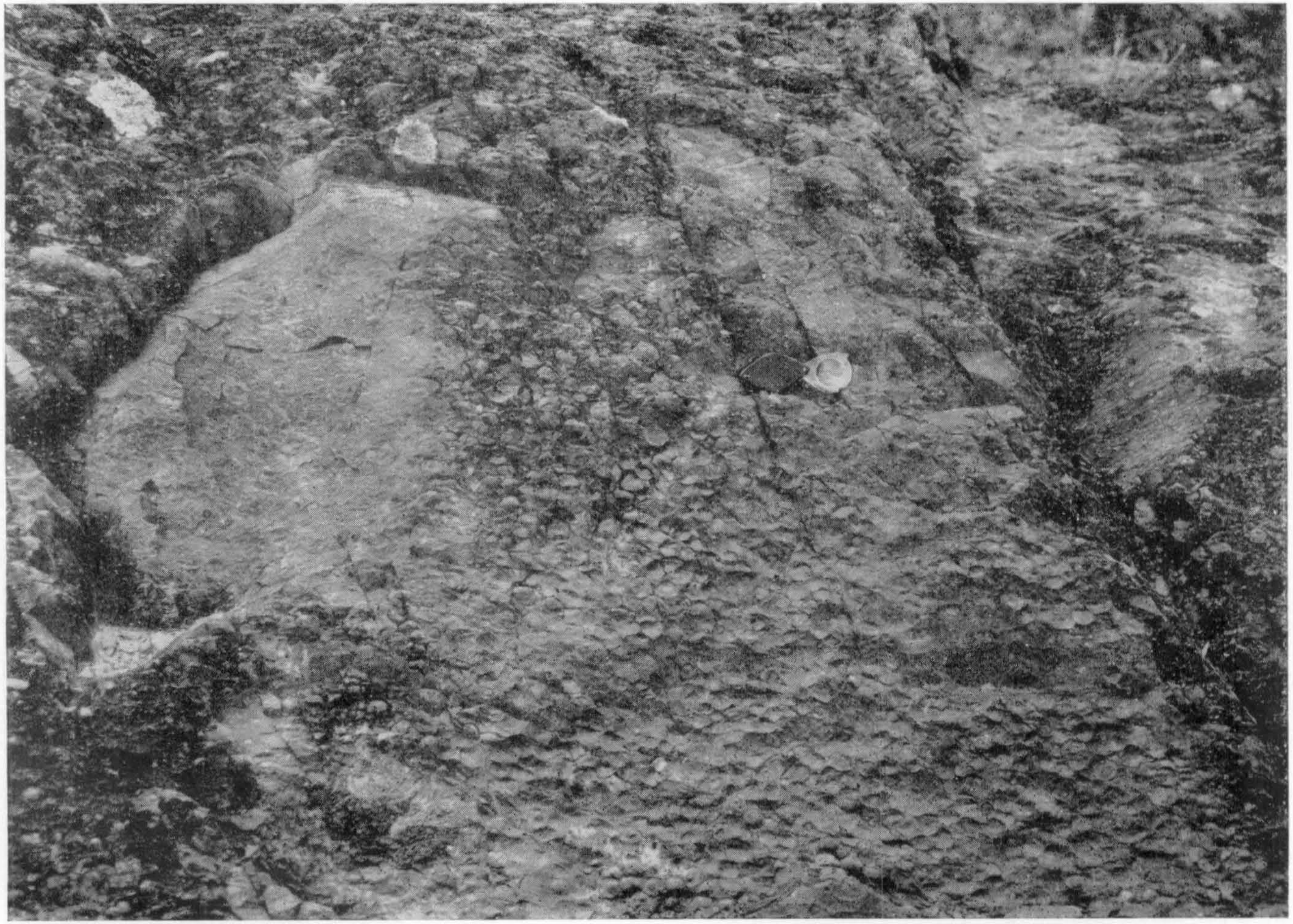

**Fig. 20.** Woolshed Creek (same locality as Fig. 19), Silurian Shale with **Atrypa duntroonensis** Dun on a bedding plane.

**Fig. 21.** View from Acton, at Racecourse, over Golf course to south. Red Hill on skyline on left. Grassy hill in background is Westlake outlier (Silurian). The trodden path on the foreground is on fossiliferous Acton Shale.

**Fig. 22.** Silurian outcrop at Scott's Crossing. Low lichen-covered crests of calcareous shale (City Hill) surround a sinkhole marking a larger limestone lens.



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**Fig. 23.** Mt. Ainslie, view from Mt. Russell. Bald hill in centre is Mt. Pleasant. On skyline on left is One Tree Hill, which links this picture with Fig. 1.

The State Circle Shale represents a temporary recurrence of the conditions of the Ordovician Pittman Formation; even rhythmic intervention of sandstone beds is present. The absence of carbonate may indicate either cool water or no limestone in the provenance of the sediments.

The areal distribution of the State Circle Shale is wider than that of the Camp Hill Sandstone, deposition covering terrains not blanketed by the preceding formation. It is thus a transgressive unit and indicates a general deepening of the Silurian sea. It still seems that major hills of the subsurface (for example, Black Mountain) were not covered by the Shale.

### *Canberra Group*

The Canberra Group consists of three conformable formations, in ascending order: Turner Mudstone, Riverside Formation, City Hill Shale.

Changes in the environmental conditions of the Silurian deposition, as compared with the facies of the preceding Ordovician time in Canberra, are significant. In the Silurian the sedimentation was faster because, for example, more than 1,000 feet of sediments were built during a fraction of lower Silurian time as against 700 feet of the whole Middle Ordovician pile of deposits. Consequently the subsidence was also faster, because the bathymetric conditions within the Silurian were persistent. Calcareous matter is common in the Silurian, which may indicate warmer water and a change of the provenance. From now on volcanic activity is common and steadily increases with the advance of time. Fossils, including benthos, are abundant, indicating normal marine conditions in euphotic depths (not beyond the reach of light). Most significant in this regard are the calcareous algae in limestones and the abundance of corals in the Riverside and later formations. Bioherms, however, are not present.

The *Turner Mudstone* ("Turner Shale" on the geological map) (Slt), approximately 200 feet thick, consists of calcareous mudstone with thin layers of siltstone, fine-grained sandstone, and occasional thin tuffaceous bands. Impure limestone laminae are observed also. The type locality is Sullivan's Creek in Turner. Fossils are rare.

*Riverside Formation* (Slr) consists of calcareous shale and mudstone, current-bedded, fine-grained sandstone, prominent limestone lenses, tuffaceous sediments, tuff, and acid flows (rhyolites). The thickness is 600 feet. The type locality is Riverside, Division of Barton. The Riverside Formation is very fossiliferous; several fossils from this formation, all from Woolshed Creek Crossing (Duntroon) (Fig. 19, 20), were collected by Rev. W. B. Clarke (1878) and described by de Koninck (1876/7). Additions have been described by Etheridge & Mitchell (1916); and Mitchell and Dun (1920-1924).

Above the Riverside Formation follows the *City Hill Shale* (Slh) with its *Acton Limestone Member* (Sla)*. The boundary against the Riverside Formation

* **Acton Shale** (Ordovician) and **Acton Limestone Member** (Silurian) are homonyms. For the Acton Limestone Member a new name will be proposed when such a name becomes available in the City of Canberra. Both names were first used as rock-unit names by Öpik (1954). The informal reading **Acton limestone deposit** (Mahony & Taylor, 1913) is preferable.

is marked on the surface by a change in colour; the Riverside Formation is mostly weathered, yellow and brown, whereas the City Hill Shale is mostly dark grey, nearly black. The City Hill Shale is a calcareous shale with limestone bands and lenses (Acton Limestone Member) and without any volcanic matter (Fig. 18, 22). The upper contact against the St. John's Church Beds is everywhere concealed by alluvial deposits. The visible thickness is 350 feet. The City Hill Shale is very fossiliferous, rich both in the number of individuals and in species. Fossils from the City Hill Shale (eastern slope of City Hill) are mentioned by Pittman ("immediately west of Glebe Farm") and by Woolnough (1938, "just south-west of St. John's Church containing *Halysites*". This locality is at the ruins of the old bakehouse).

The total thickness of the Canberra Group is 1,100-1,200 feet. The age is essentially upper Llandovery (lower Silurian), but the City Hill Shale may represent the passage to middle Silurian as well. This can be decided only after the fossils have been described. The Canberra Group (Canberra Beds) has been correlated with the Bango Series of the Yass region (David, 1932, Table B); the correlation is approximate only.

Middle Silurian Sequence

The middle Silurian sequence in Canberra consists of the St. John's Church Beds, the Mt. Pleasant Porphyry, and the Fairbairn Group.

The depositional environment in middle Silurian time in Canberra differs little from the conditions observed in the lower Silurian Canberra Group. It is a full-scale marine environment, euphotic, well supplied with oxygen and food. Compared with the lower Silurian Riverside Formation, submarine volcanic activity has increased considerably, and becomes a significant factor in lithogenesis.

*St. John's Church Beds* (Smi — St. John's Beds on map)

The St. John's Church Beds (Fig. 36) consist of volcanic rocks (tuffs, porphyries) interbedded with tuffaceous mudstone, sandstone, limestone, shale, and tuff, with limestone nodules, and are about 300 feet in thickness. The type locality is just south of St. John's Church. The name was first used by the author (Öpik, 1954).

Most of the unit is concealed by the volcanic rocks of Mt. Ainslie, so that its sequence is not yet completely known, and the term "beds" therefore seems more appropriate than the definite designations "formation" or "group". It is a fossiliferous unit. The lower contacts of the unit are obscured, but the position within the sequence, as determined here, is demanded by structural relationship and lithological composition.

*Mt. Pleasant Porphyry* (Smp — Mt. Pleasant Rhyolite on map)

On the geological map is a suite of altered acid volcanic rocks (dacite, "spherulitic felsite" or "nodular felsite" of Pittman, loc. cit., map and p.5) outcropping on Mt. Pleasant as a Silurian inlier within the the Lower Devonian Ainslie Volcanics. Most probably it is a member of the St. John's Church Beds. The name was first used by Öpik (1954).

On Mt. Pleasant itself (Fig. 23) and its northern slope, green (chromium-stained) damourite (determined by W. B. Dallwitz) occurs as an alteration-product of the groundmass of the rock. Externally it has some resemblance to serpentine.

The pre-Ainslie age of the Mt. Pleasant Porphyry is deduced from its being tectonically strongly affected, and from the overlap of the Ainslie dacites over it. A quartz reef is present which is not continued into the Ainslie rocks. Lithologically the Mt. Pleasant suite may be compared with the acid Deakin Volcanics. On the north-eastern slopes of Mt. Pleasant, toward the main road to the aerodrome, old pits and other remnants of small goldmines are preserved. The mines are mentioned by Pittman. The alluvial gold occurs in the bottom of gravels against the Mt. Pleasant rocks, and gold is also present in the quartz reef. In Canberra the occurrence of gold is apparently connected with fractures and quartz reefs of the Silurian Painter Phase, which might be additional evidence for the Silurian, pre-Painter, age of the Mt. Pleasant igneous rocks.

*Fairbairn Group*

The names of the group and its formations were used by Öpik (1954). The group-name is derived from Fairbairn Aerodrome in Canberra. The group covers approximately the middle and upper portions of the middle Silurian. The formations of the Fairbairn Group are:

(1) Molonglo Ford Hornfels,
(2) Molonglo (Village) Sandstone,
(3) Molonglo (River) Formation,
(4) Mahon Formation.

Both contacts of the Mahon Formation and the lower contact of the lowermost unit, the Molonglo Ford Hornfels, are obscured by faults. The repetition of the name "Molonglo" in the names of separate units may be regarded as temporary until other official geographical names are available for the area.

The *Molonglo Ford Hornfels* (Smf) is a calcareous hornfels, with bands of impure marble, exposed in a low hill just south of the ford across the Molonglo River in Fyshwick. The visible thickness is about 250 feet. The contact metamorphism originates in a sub-surface intrusion, from which dykes protrude into the hornfels.

The *Molonglo Sandstone* (Smn), flaggy, quartzose, calcareous, and about 150 feet thick, conformably overlies the Molonglo Ford Hornfels. The sandstone is fossiliferous.

The *Molonglo Formation* (Smr) conformably overlies the Molonglo Sandstone. It consists, in its lower part, of calcareous shale and limestone beds and, in its upper part, of tuffaceous sediments, tuffs, and porphyries (the "sheared porphyry" along Sullivan's Line). In Canberra only the lower beds (80 ft.) are represented; the other parts are present just east of Mt. Majura and Mt. Ainslie.

Within the boundaries of Canberra the formation is very fossiliferous. The fossils named by Chapman in Mahony & Taylor (1913) from Miss Cameron's Farm, the old mill, and the western slope of Mt. Majura, were all collected from the Molonglo Formation. The corals are abundant and well preserved.

The *Mahon Formation* (Smh) consists of calcareous shale with limestone lenses up to 5 feet thick, calcareous shales and limestones in a near-rhythmic lamination, and impure limestone beds and tuffs. Its superficial part is 200 feet thick. The type locality is Mahon Hill and its slopes. The main rock (thinly-layered laminated shales and limestones) was described, but not named, by Mahony & Taylor (p.18).

The structure of the hill is an anticline, the crest of which is capped by a flow of the Ainslie suite (Fig. 35), uncomformable against the Mahon Formation.

A correlation of the Fairbairn Group, especially its Molonglo Formation, with the Yass Series, the Bowspring Limestone, the Silurian deposits at London Bridge, and many others, including, perhaps, the limestone at Uriarra Crossing, seems to be possible. A more accurate correlation can be undertaken only after the fossils are studied.

The time of deposition of the Fairbairn Group most probably corresponds to the widest distribution of the Silurian sea in the southern parts of New South Wales.

UPPER SILURIAN SEQUENCE

### *Red Hill Group*

The Red Hill Group consists of:

(1) Deakin Volcanics (below), and

(2) Yarralumla Formation (above).

The units are conformable and all names applied were first used by the author (Öpik, 1954). The depositional environment of the Red Hill Group differs little from the environment of the Silurian of Canberra as described above (see Canberra Group, p.31). Still, within the Red Hill Group volcanic rocks attain their maximum development, and the activity was submarine. Sandstone beds, up to 100 feet in thickness, occur as well, with signs of deposition in shallow water. It seems that in the region islands arose above the surface of the sea, shedding unconsolidated material into the shallow water, together with fresh pyroclastics from the active volcanoes.

The *Deakin Volcanics* (Sud) are a formation of acid volcanic rocks (tuffs, rhyolites) interbedded with tuffaceous sandstone and in places tuffaceous shales with limestone bands, and jasper, in a thickness of 350 feet. The type locality is the Division of Deakin in Canberra. West and south of Canberra the unit covers large areas. As prominent marker-rocks may be mentioned the "purple tuffs" and rhyolites, e.g. in the Red Hill Quarry (Fig. 24, 32, 33).

Woolnough (1938, p.113) describes the "purple tuff" as follows: It "consists of a fine textured, laminated base of dark purplish colour, crowded with intensely rounded and polished grains of quartz and glassy felspar of remarkably uniform dimensions (about 2 mm. diameter). From its association with more normal volcanic types this rock may represent the crater beds of a gas volcano, the intense rounding of the crystalline grains being due to attrition in gas and/or steam blasts". In addition the quartz grains reveal bedding, whereas in the matrix some flowage seems to be present. The deposit may, of course, be an ignimbrite; it is a bed, and not deposited in a crater. The "normal volcanic types" refer to a tongue, or a swarm of tongues, of a porphyry (Painter Porphyry), intruded into the "purple tuff" (Fig. 24), which in parts covers the tuff on the surface also. The structure seems to have been originally an anticline trending north-north-east and overturned to the south-south-east. The porphyry is clearly intruded into the

**Fig. 24.** Red Hill quarry. A recumbent fold intruded by the Painter Porphyry. The "purple tuff", thick bedded on left (Deakin Volcanics) and in centre (see Fig. 25). The Porphyry is completely weathered, red and yellow.

**Fig. 25.** Red Hill quarry, detail of centre of Fig. 24. A folded piece of the "purple tuff" is partly replaced by the porphyry. Above it (upper right quarter) diagonal fractures indicate cleavage and the axial plane of the fold.

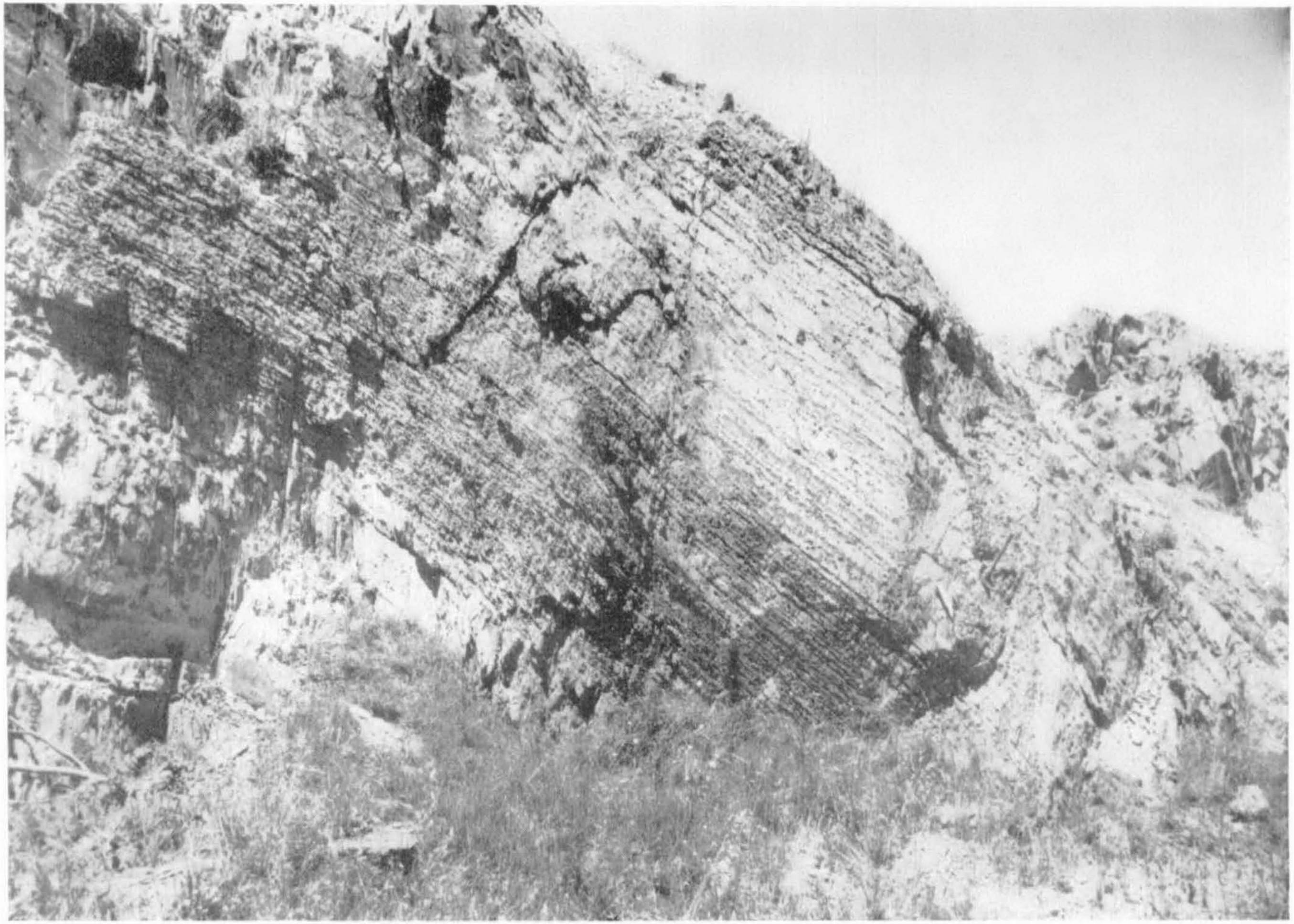

**Fig. 26.** Yarralumla Quarry. Impure limestone on flank of an anticline.

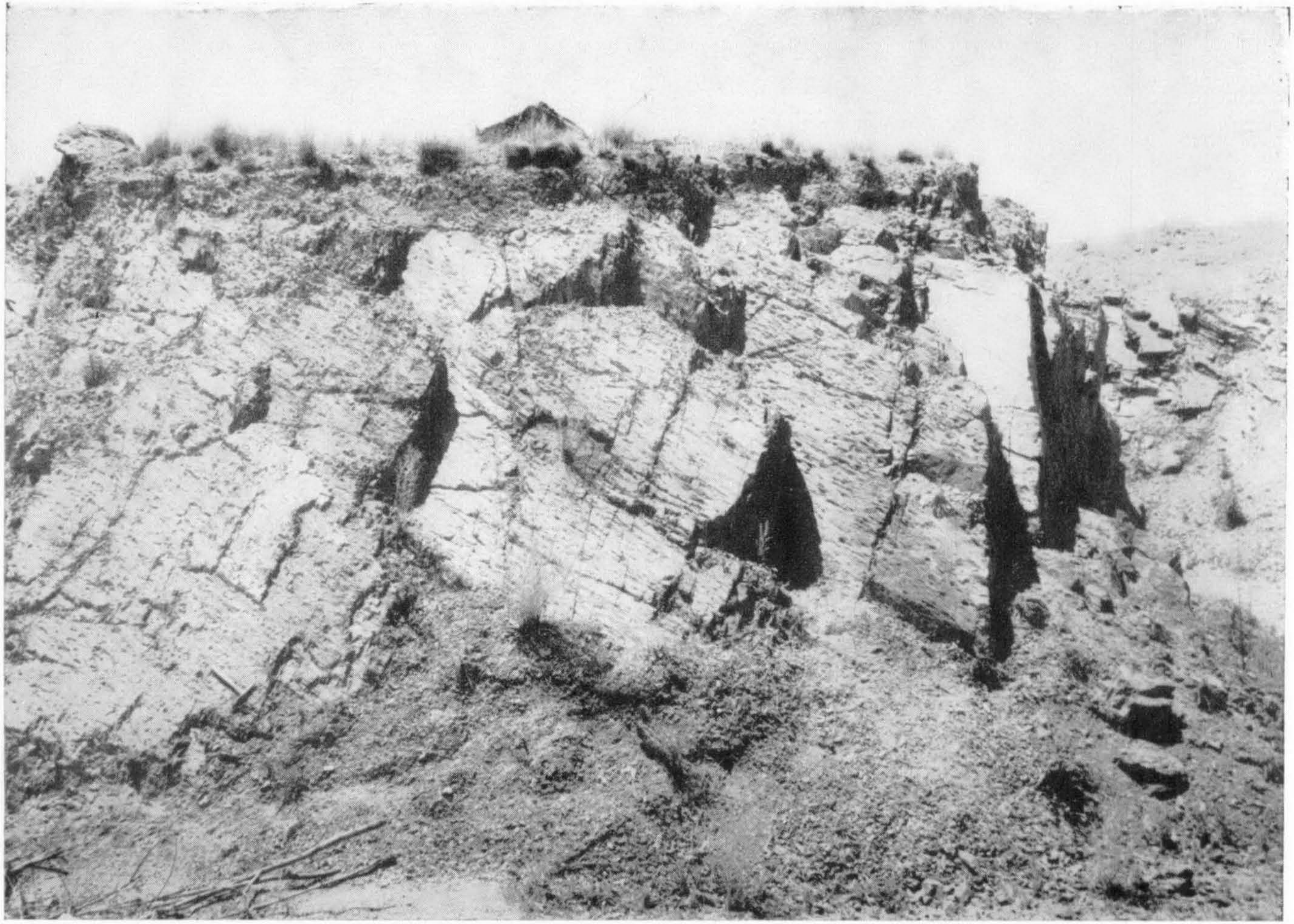

**Fig. 27.** Shale and tuff of Yarralumla Formation in Quarry south of Adelaide Ave., Deakin. Plunge south.

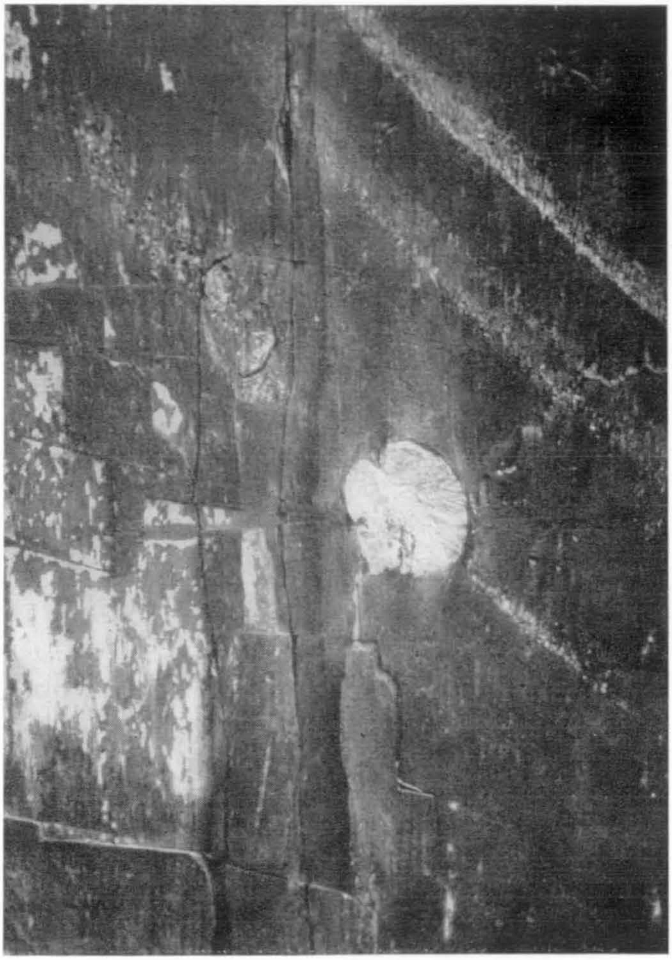

**Fig. 28.** Yarralumla Quarry: a fossiliferous calcareous shale of the Yarralumla formation. Vertical cleavage well developed just at a fault. The bedding (fossil bands) dips to right. An incipient grading in the distribution of the fossils is apparent. **Favosites** is in the middle.

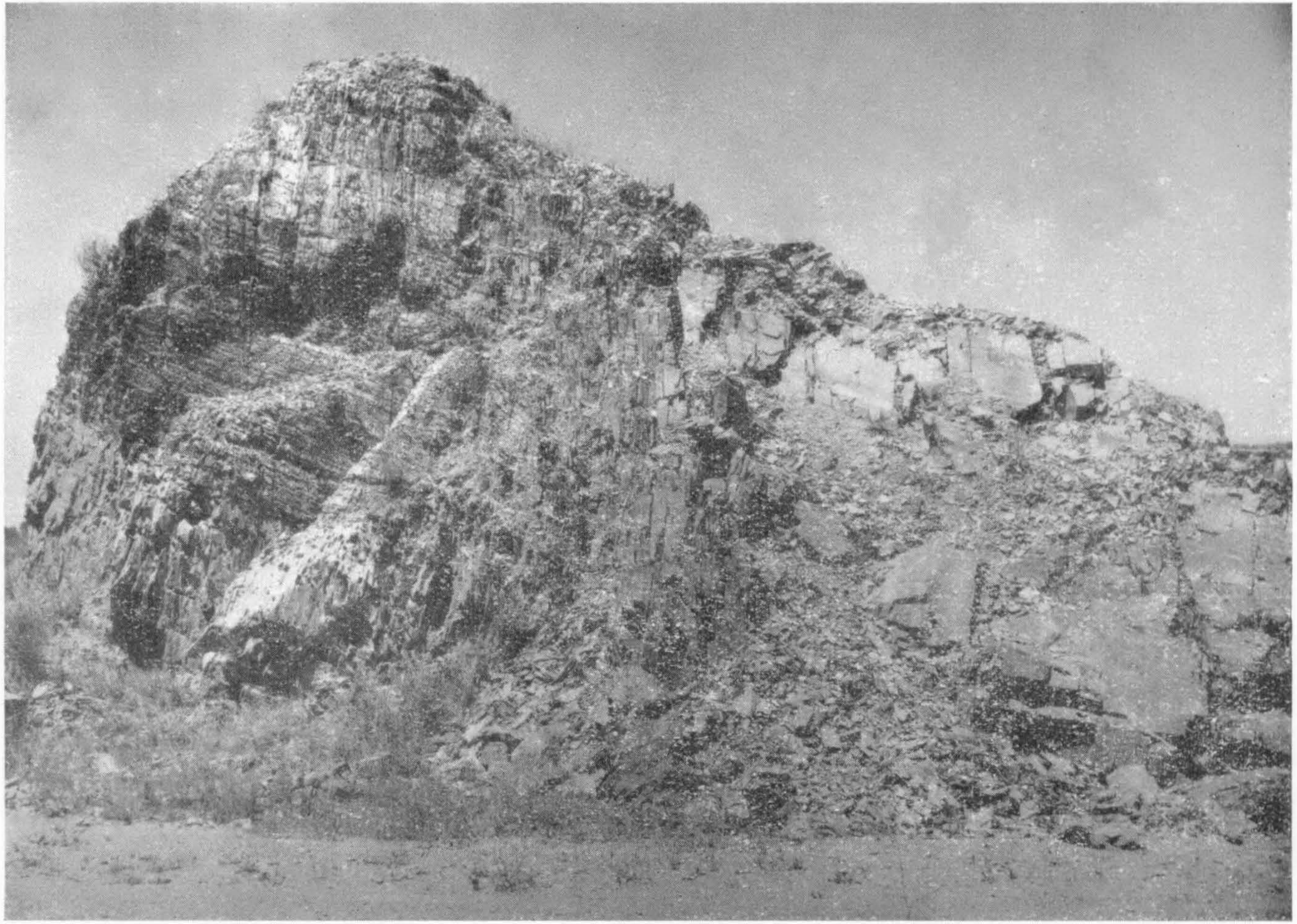

**Fig. 29.** Yarralumla quarry: a near-vertical fault has brought together impure limestone (left) and shale (centre).

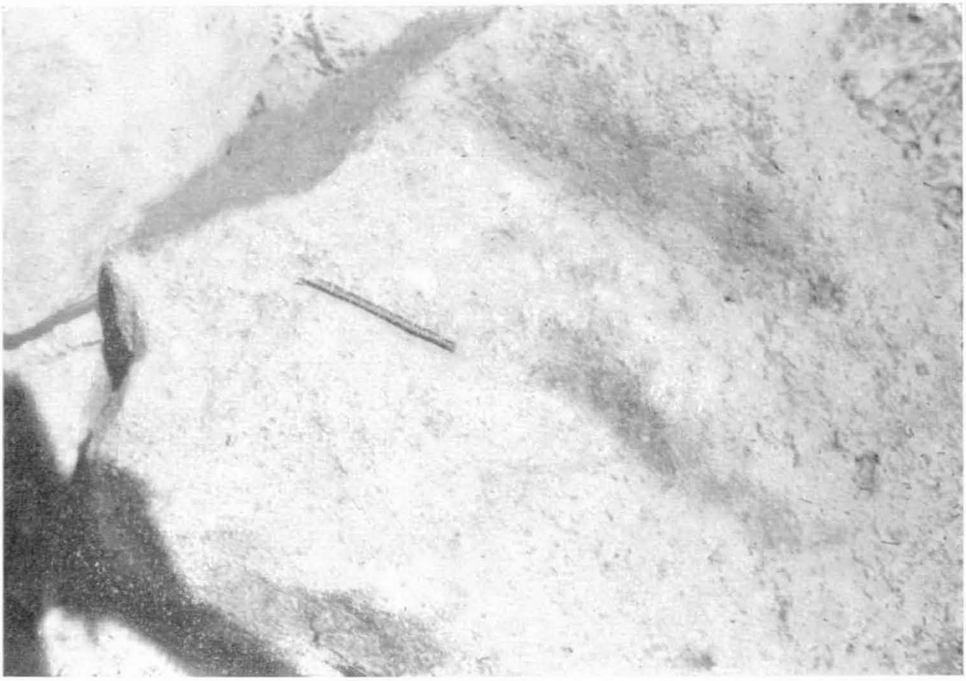

**Fig. 30.** Painter Porphyry: a fresh face showing abundant inclusions. Coppins Crossing, 8 miles west of Canberra.

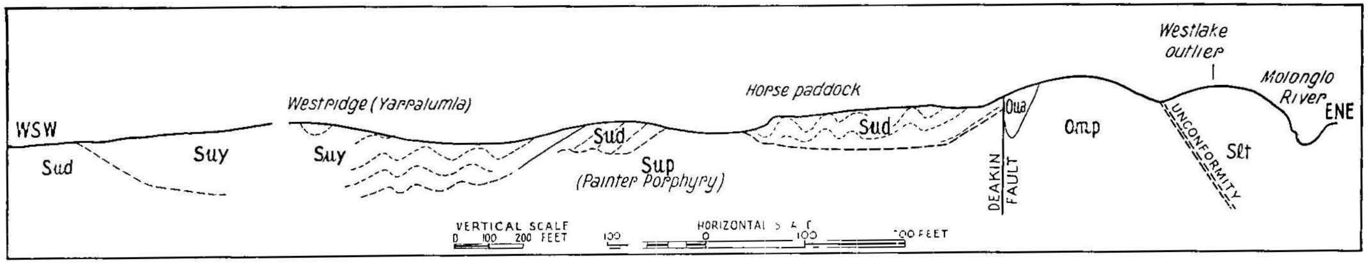


**Fig. 31.** Diagrammatic section between Molonglo River and the Westlake outlier and Westridge, for ¾ mile. West of Westridge the other flank of the Yarralumla Syncline is indicated. Oua (Acton Shale) and Omp (Pittman Formation) represent the Ordovician rocks of the Black Mountain Horst. Slt is a deep infold of Silurian rocks in the Horst. The unconformity in between is folded. Sud—Deakin Volcanics; Suy—Yarralumla Formation. Both are strongly folded and fractured by minor faults and afterwards intruded by the Painter Porphyry (Sup). The Deakin Volcanics (Sud) in the west flank of the syncline contain tuffs, flows, and interbeds of red jasper and fossiliferous limestone. See also Fig. 21 and Fig. 33.

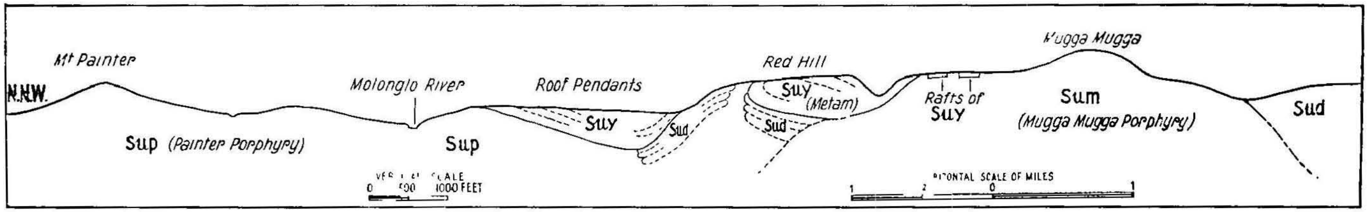


**Fig. 32.** Diagrammatic section of western part of Canberra, to show relationship between roof pendants and intrusions of Painter (Sup) and Mugga Mugga (Sum) porphyries. Suy—Yarralumla Formation, metamorphosed in Red Hill; Sud—Deakin Volcanics. Rafts of metamorphosed Suy on Mugga Mugga porphyry exaggerated. Note the anticline in the north slope of Red Hill cut by a tongue of Painter Porphyry.

core and cuts the flanks also. However, the intruded porphyry shows a lineation parallel to the axial plane of the fold (Fig. 25), indicating, perhaps, that the folding and intrusion were at least very close in time. The structure was interpreted as a culmination of the Painter Porphyry (a cross-fold) developed during the intrusion and therefore of local significance only. By mistake it was omitted from the Tectonic Map, and is therefore not specially mentioned in the alphabetical "Explanation of the Tectonic Map" (below).

The "purple tuff" is fairly fresh and comprises also beds of a hard pinkish tuffaceous sandstone. The intrusive porphyry, however, is completely decomposed, with a claylike matrix as seen in the faces of the quarry, although on the surface it is represented by floaters of fresh rocks in the form of boulders or even tors. It is mostly pink in colour, and therefore all the rocks of the quarry, even the "purple tuff", are termed "pink" by the quarrymen.

The roof-pendants (see "Explanation of the Tectonic Map" below) consist essentially of folded Deakin Volcanics (Fig. 32, 33). In the "High Pendant", the rocks are strongly compressed and transformed into sericitic schists. In Narrabundah, a hill south of the Narrabundah Infants' School, between Sturt Avenue and Jerrabomberra Creek, consists of similar compressed rocks, which are converted into a kaolin-like mass. On the maps this occurrence is marked by a trend-line (silicified fault) only; the kaolinic patch of the Deakin rocks became apparent in trenches after the completion of the map.

The *Yarralumla Formation* (Suy) about 500 feet thick, contains calcareous shale and sandstone, with limestone beds, all more or less tuffaceous (Fig. 26-29). The type locality is the brickpit at Yarralumla.

Red Hill itself consists of the same sequence of rocks as at Yarralumla, except for the contact metamorphism. The calcareous sediments are transformed on Red Hill into a hard hornfels by the intrusive *Mugga Mugga Porphyry.*

By virtue of its stratigraphical position the Red Hill Group belongs to the lower Ludlow (lower Upper Silurian), and by fossils may be correlated approximately with the Barrandella Shale of the Yass area.

The Yarralumla Formation of the Red Hill Group is the uppermost preserved Silurian marine deposit in Canberra.

A number of fossils from Yarralumla were collected by Rev. W. B. Clarke (1878) and described by de Koninck (1876/77).

*Yarralumla Phase of the Bowning Orogeny*

Soon after, or perhaps immediately after, the deposition of the Yarralumla Formation, the Canberra region was folded in a phase of the Bowning Orogeny. The name Yarralumla Phase is derived from the youngest known unit involved in the movement. The present distribution of the structures of this Phase is shown on the tectonic map. The dating of the orogenic phase is quite accurate, for it happened before the Mt. Painter intrusion which also occurred in lower Ludlow time.

The term "Yarralumla Phase" designating an episode of the Bowning Orogeny (Browne, 1950) was used for the first time by Öpik (1954). The Phase and the Orogeny itself are discussed in the section on tectonics below.

*Mt. Painter Porphyry* (Sup)

The Mt. Painter Porphyry is a dark, massive porphyry with numerous xenoliths of sedimentary and igneous origin, amongst them fragments of vein quartz (Fig. 30). The quartz alone, however, is not diagnostic, because quartz xenoliths also occur in the younger Ainslie dacites. Garnet is present in places. The thickness is more than 650 feet. The type locality is Mt. Painter, north-west of Black Mountain. The name was introduced by the writer (Öpik, 1954).

The porphyry is an intrusive rock, a sill, traceable in a northerly direction far beyond Canberra and the A.C.T.

Volcanic rocks intruded by the Painter Porphyry show no direct metamorphism; the sediments, however, were slightly altered near the contacts.

The porphyry is relatively little affected by tectonic stress, although the Silurian rocks of the Red Hill Group, which are intruded by the Painter Porphyry, and which are preserved only as roof-pendants of the latter, were strongly plicated during the preceding Yarralumla Phase. Obviously the Painter sill was intruded after the Yarralumla Phase. In the next section (Painter Phase of the Bowning Orogeny), it is shown that another phase of movements followed the intrusion, so that the Painter Porphyry, intruded between two phases, is a synorogenic intrusion. The ubiquity of xenoliths in the porphyry indicates a large-scale fragmentation of the country-rocks by and during the process of intrusion, and hence the event can be interpreted as a synkinematic emplacement.

As explained above, the Painter Porphyry has, as an event, a paramount significance in reading the structural history of Canberra, and much depends on its interpretation as an intrusive body rather than a supracrustal volcanic rock. It therefore seems appropriate to discuss the diverse interpretations and to substantiate the interpretation here presented.

*Mt. Painter Porphyry as part of the Deakin Volcanics.*

At an early stage of the study of the geology of Canberra, the Deakin Volcanics and the Painter Porphyry were regarded as a single unit, whose age as a whole was derived, according to the principle of superposition, from its position in the sequence beneath the Yarralumla Formation. Even at that stage the Painter Porphyry was not understood to be strictly supracrustal but was recognized as an intra-volcanic, intra-pyroclastic intrusion of the same age as the stratified volcanic rocks of its roof. This concept explained even the numerous abrupt and violent contacts of the porphyry tongues cutting and crossing the pyroclastic strata and the interbeds of sandstone. An example of this discordant behaviour of the Painter Porphyry within Canberra is seen in the above-mentioned quarry (p. 34) at the north-western end of Red Hill, where a tongue, or swarm of tongues, from the main body of the Porphyry cuts in various discordant ways the "purple tuff" and associated sandstones. Similar though less spectacular relationships have been observed along the eastern foot of Red Hill, where the Porphyry is, however, in contact not with the Deakin Volcanics but with rocks of the younger Yarralumla Formation, which show here a low-grade contact metamorphism along the junction. Numerous similar discordant contacts have also been observed in temporary outcrops in the western part of the suburb of Westridge (Division of Yarralumla), and small but instructive outcrops have been seen in the creeks west of Jerrabomberra Creek at Bonshaw (not marked on map). Thus, some evidence collected indicated that the Porphyry is in reality younger than the Deakin Volcanics and even younger than the Yarralumla Formation and cannot be a volcanic event within these formations; at the same time the possibility that the Painter Porphyry was an intrusion became apparent.

*Mt. Painter Porphyry as a possible cause of folding of sediments and pyroclastics (Pittman's interpretation).*

In all the examples mentioned above, the intruded rocks are folded, but it was not yet evident whether the folding took place before the intrusion, at the time of the intrusion, or even as an immediate consequence of the intrusion, as had been suggested by Pittman. The last was, of course, the most plausible explanation, because contortion of tuffs by an intravolcanic intrusion seemed logical. However, the case could not be closed, because the attitude of all the contorted rocks coincided in the main with the general Bowningian grain of the country, and a lineation of similar direction (but not necessarily of the same age) was in some places observed to affect the Painter Porphyry as well. Moreover, the above-mentioned contact of the Painter Porphyry with the sediments of the Yarralumla Formation along the eastern foot of Red Hill already contradicted the volcanic version under discussion.

*Evidence that the Mt. Painter Porphyry is intruded after the folding.*

In the meantime, the foundations of the residence of the High Commissioner for the United Kingdom, south of Adelaide Avenue, revealed that here the Deakin volcanic rocks were highly compressed and even transformed into sericitic schists or slates, whereas the surrounding and intrusive porphyry was free from any marks of tectonic stress. The same relationships were also observed north of Adelaide Avenue ("Horse Pendant"), which facts permitted only one explanation: the porphyry was emplaced after the plication of the Deakin Volcanics. The matter is discussed again in the "Explanation of the Tectonic Map" (below, p.68) under the heading "Adelaide Ave. Roof-Pendants" and "Roof-Pendants".

The findings above, that the Mt. Painter Porphyry is not connected with the Deakin Volcanics and that the folding is regional and not caused by the emplacement of the Porphyry, necessitate discussion of all the connected observations and testing the evidence for the Porphyry's being an intrusion, perhaps a sill. Thus, the coincidence of a younger, intrusive porphyry sill with older, even folded, pyroclastic rocks is not accidental: in a sequence of compact sediments and tuffs, intrusions very often move into such contacts of lithological contrast and show a preference for tuffs, seemingly because such contrasts represent conditions of structural weakness. Examinations of specimens of Painter Porphyry, collected from various places on a line eighteen miles long and parallel to the course of the Deakin Fault, shows that local variations depend only on the quantity of xenoliths; in slides a uniformity of composition and texture is recognized. No pyroclastic or stratified development within the body was detected. The body is referred to as a sill. Its intrusive character has been discussed above, and other forms (e.g. a dyke, a laccolith, etc.), are not evident at all. The interpretation of the Porphyry as a



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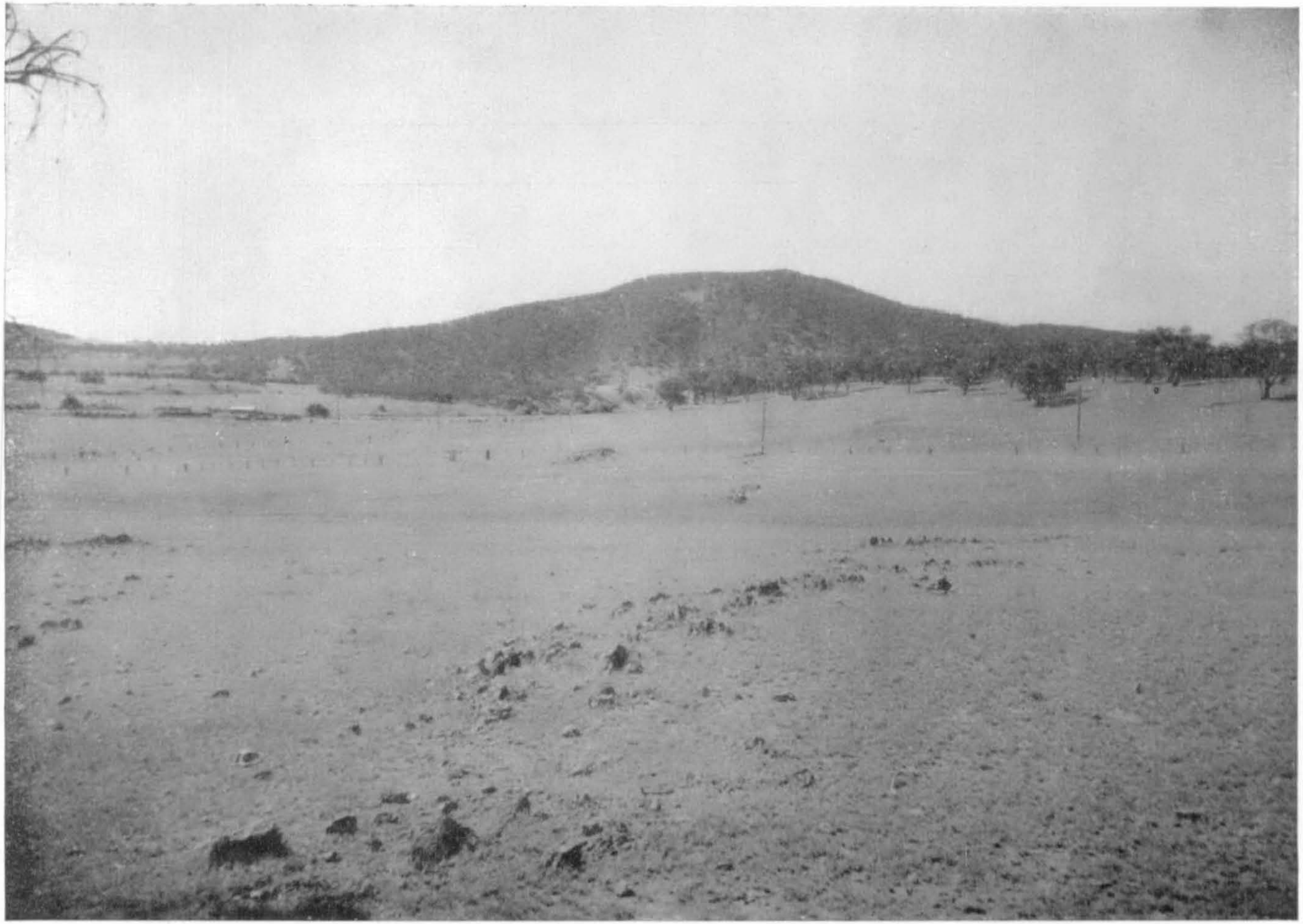
sill results, of course, only from the examination of the upper contacts (all that is visible), which, in turn, are irregular. The junction of the Yarralumla and Deakin Formations is a depositional contact — therefore originally horizontal. When referred to this junction, which at the time of the emplacement was already folded, the surface of the Painter sill shows deviations of up to 300 feet, which is an estimation of the thickness of the roof-pendants. In relation to the geographical extension of the intrusive body and its volume these deviations are very small, and the upper contact of the Porphyry appears to be the surface of a sheet. The lower contact is unknown, being eliminated from the surface by faulting, and so the real geometry, whether the Porphyry is an irregular sill or something else, remains a matter for further enquiry.

The lithological map of Pittman (1911) depicts quite accurately the distribution of the Painter Porphyry in Canberra, although the limiting Deakin Fault was for example unknown to him. Pittman obviously associated the porphyry with the Deakin Volcanics because both rock types are igneous rocks, and at the same time his map shows a number (ten or eleven) of sandstone patches within the igneous rocks separated because they are sediments; but on the map itself the rocks are classified as intrusive ("crystalline intrusive rocks chiefly quartz porphyries and quartz felsites"). According to the present interpretation, the sandstones, the felsite, and the tuffs and flows, belong together in the one unit, the Deakin Volcanics, and the massive crystalline porphyry is the Painter. The sandstones of Pittman's map are now under buildings and shifted material, but their number shows that there are in reality more roof-pendants than it has been possible to trace in the course of the present studies. In this sense the present map is and will remain incomplete. Structural relationships of the Painter Porphyry and the Deakin Volcanics are also reflected on a general scale in the topography. Thus most of the outcrops of the Painter Porphyry in Canberra occur along the Deakin Fault, evidently because the Porphyry as a body dips off the fault and has retained there a higher structural position. North of the Molonglo River the belt of the Painter Porphyry widens towards the structural culmination at Mt. Painter itself. There is a distinct southerly plunge, and south of the river the roof of the Porphyry is preserved in the form of pendants. The Red Hill and Yarralumla roof-pendants contain the youngest rocks and are in reality the remnants of the core of a syncline; west of these pendants the Deakin Volcanics once more emerge on the surface, and east of the Red Hill and Yarralumla pendants the Deakin Volcanics indicate the other flank of the syncline. Here the Adelaide Avenue Pendants and an unmapped pendant of volcanics south of Collins Park form hills whose height increases towards the south in accordance with the increase in thickness of the resistant pendant rocks down the direction of the plunge. From here on, along

**Fig. 33.** Black Mountain and Horse Paddock, view toward west-north-west. Black Mountain in the background. At the first of the spurs between the two gullies on the slope of the Black Mountain is the fault block with the **Monograptus exiguus** shale. On the left edge of the picture the slope of Mt. Painter is just visible. The Deakin Fault trends from right to left along the line of timber. In the foreground are the contorted pyroclastics of the Deakin Volcanics cut off by the fault. The South Black Mountain Fault is indicated by the lower line of timber on the slope of the mountain.



Red Hill, the Deakin Volcanics form an uninterrupted belt which widens south of Canberra and dominates the country. However, the Painter Porphyry also remains on the surface along the full length of the Deakin Fault, but the roof-pendants in the south, as for example, at Bonshaw, are no longer marked topographically as hills, because here the Porphyry seems to have intruded a higher level of the Volcanics, so that the thickness of the pendant rocks (resistant volcanics) was small from the beginning. Nevertheless, the structural plunge of the Painter Porphyry remains consistent; its belt (a plain) along the Deakin Fault narrows and finally disappears about eight miles south-east of Yarralumla, under a solid (hilly) cover of Deakin Volcanics and, perhaps, younger volcanic rocks (Fig. 32).

It is now obvious that the Painter Porphyry can be explained and understood only if viewed on a wider scale and that its outcrops within Canberra are insufficient for an exhaustive study. Moreover, the country west of the Deakin Fault in Canberra is a fragment of an area different in its structure and rocks from that of Canberra itself and has to be investigated as a structural unit of the region on its own merits.

The discussion can be summarized as follows:

(1) the Painter Porphyry is a rock of great uniformity of lithological composition and texture without pyroclastic or stratified material in its body;
(2) the Porphyry shows intrusive contacts with both the formations of the Red Hill Group;
(3) sediments in contact with the Porphyry show contact metamorphism;
(4) the Painter Porphyry crops out along the north-eastern flank of an asymmetrical syncline faulted down along the Deakin Fault;
(5) judging from the attitude of the Painter Porphyry this syncline shows an axial plunge to the south-south-east and a culmination near Mount Painter;
(6) tracing the upper and only visible contacts of the Painter Porphyry, it seems apparent that the Porphyry within the syncline is a sheet following the attitude of the syncline;
(7) the Porphyry is stratigraphically younger than its roof.

The general conclusion is that, as far as can be seen in the field, the Porphyry is a shallow intrusion of great extent.

A multitude of possibilities remain, which cannot be settled without adequate facts from the field. Thus, a shallow intrusion could also be represented on the surface by volcanic rocks. Perhaps the Yarralumla Formation is not the youngest preserved Silurian unit in the region, but was followed after the first plication by volcanic activity from Painter-like sources, not yet distinguishable lithologically from the stratigraphically older Deakin Volcanics. Great petrological similarity dominates the Silurian volcanic rocks and intrusives and also the Lower Devonian Ainslie rocks. No marine bands are known in the greater part of the volcanic field west of Canberra and none younger than the Yarralumla Formation. Hence the folded and disrupted mosaic of the igneous rock bodies west of Canberra must be tested once more in the field.

## *The Painter Phase of the Bowning Orogeny*

Numerous large faults cut both the Painter Porphyry and the lineation of the Yarralumla Phase in Canberra. The Painter Phase (name proposed by Öpik, 1954) was a movement of regional significance accompanied by subordinate plication. This second phase of the Bowning Orogeny is named after the youngest rock unit involved in the disturbance — the Painter Porphyry. The time between the two phases was short, but covers the events of the intrusion itself and of the consolidation of the intruded magma. At the time of faulting it was already consolidated, as it is clean-cut by the Deakin Fault. The contact of the Painter Porphyry along the Deakin Fault against the Ordovician and Silurian rocks is structural only, without any signs of metamorphism and without dykes, etc.

## *Mugga Mugga Porphyry* (Sum)

The Mugga Mugga Porphyry is a medium-grained dark massive porphyry constituting the intrusive stock of Mugga Mugga ridge. A chilled margin is present, especially along the western contact, and rafts of metamorphosed sediments are found on the crest of the ridge. The Porphyry was intruded into the Red Hill Group after the Painter Phase and very close to it (Fig. 32).

The author of the name is Pittman (1911).

The long axis of the Mugga Mugga intrusive body is parallel to the Deakin Fault, marking, perhaps, a tensional fracture; the Porphyry, however, is not affected tectonically and was therefore intruded after the Painter Phase. However, it was intruded quite early, before the erosion of the Bowning structures which formed the roof of the subsurface intrusion. Hence the age seems to be Upper Silurian, and the Porphyry can be classified as a postorogenic intrusion.

Pittman described it as "a 'massif' of quartz porphyry" from which offshoots intrude the Silurian sediments.

The interpretation of Mugga Mugga as a massive intrusion is correct. According to Mahony & Taylor (p.53), the rock of Mugga Mugga is a "dacite tuff", with "unequivocal evidence of a pyroclastic origin" and with "optical evidence of strain". The only explanation for such a discrepancy is the possibility that Pittman is speaking of Mugga Mugga proper, whereas the specimens described by the later authors belong to the envelope of the intrusion and represent the folded Deakin Volcanics.

Moreover, Mahony & Taylor (p.12) speak of a "Mugga Series", by which a concept different from Pittman's massive Mugga Porphyry is introduced. Furthermore, Mahony & Taylor, disputing Pittman's (p.67) "belt of igneous rocks [which] stretches from north-west to south-east across the city area [and which] intruded the sedimentary series . . . .", because they thought he was describing Mugga Mugga, could see from his map that he was referring not to Mugga Porphyry, but to another porphyry (Painter Porphyry) intruding the Yarralumla rocks and the Deakin Volcanics. Obviously, a final deciphering of the statements of Mahony & Taylor can be made only if their localities can be precisely fixed, without which the field relationship of the rocks they describe cannot be identified.

**Fig. 34.** Quarry in columnar dacite at Ainslie Hotel. The rock is weathered and friable, with residual floaters and tors of fresh rock on top. South slope of Mt. Ainslie in the background.

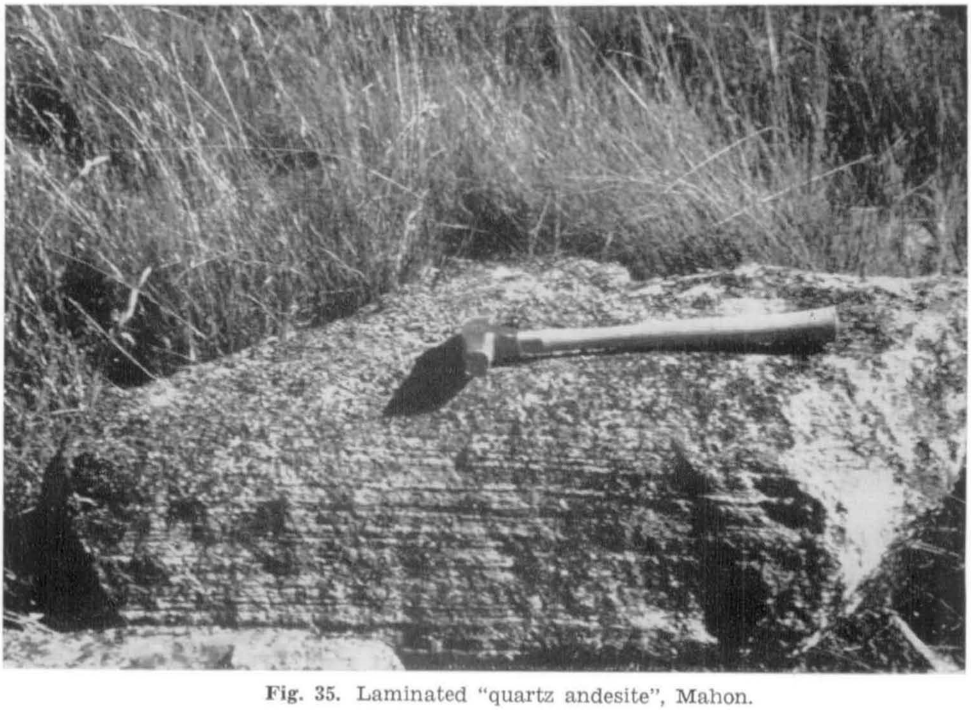


**Fig. 35.** Laminated "quartz andesite", Mahon.

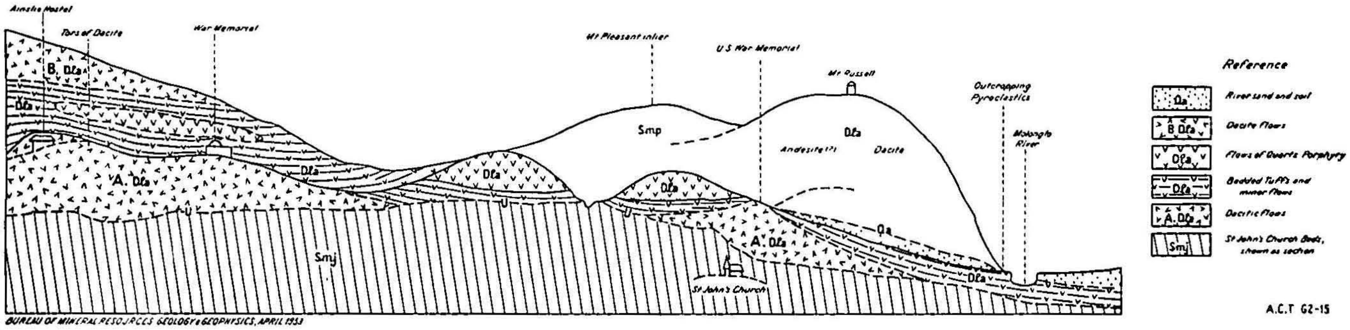



**Fig. 36.** Panorama and section of western slopes of Ainslie Volanics between Ainslie Hostel (north) and Molonglo River (south), on a north-south line for approx. 3,500 yards.

Distribution of landmarks to the left from the church as observed from the eastern slope of City Hill, and to the right from the church as seen from Parliament House. Direction of the left side of the section is about south, of the right side is south-east. Vertical scale exaggerated. St. John's Church Beds (Smy) and the nearer Ainslie rocks are shown in section. U is the contact (unconformity) of Ainslie Volcanics against the folded middle Silurian; A (Dla) represents the dacite flows at the base of Mt. Ainslie, outcropping at Hotel Ainslie, the War Memorial, the foundation of the U.S. War Memorial, etc. Topographically and stratigraphically above it follows the belt of the bedded Ainslie tuffs with flows of a dark quartz porphyry (field definition). It is overlain in turn by dacites (B-Dla). Mt. Russell belongs also in the suite of Ainslie rocks, but remains in the background. Mt. Pleasant consists of a middle Silurian porphyry, and is an erosional inlier.

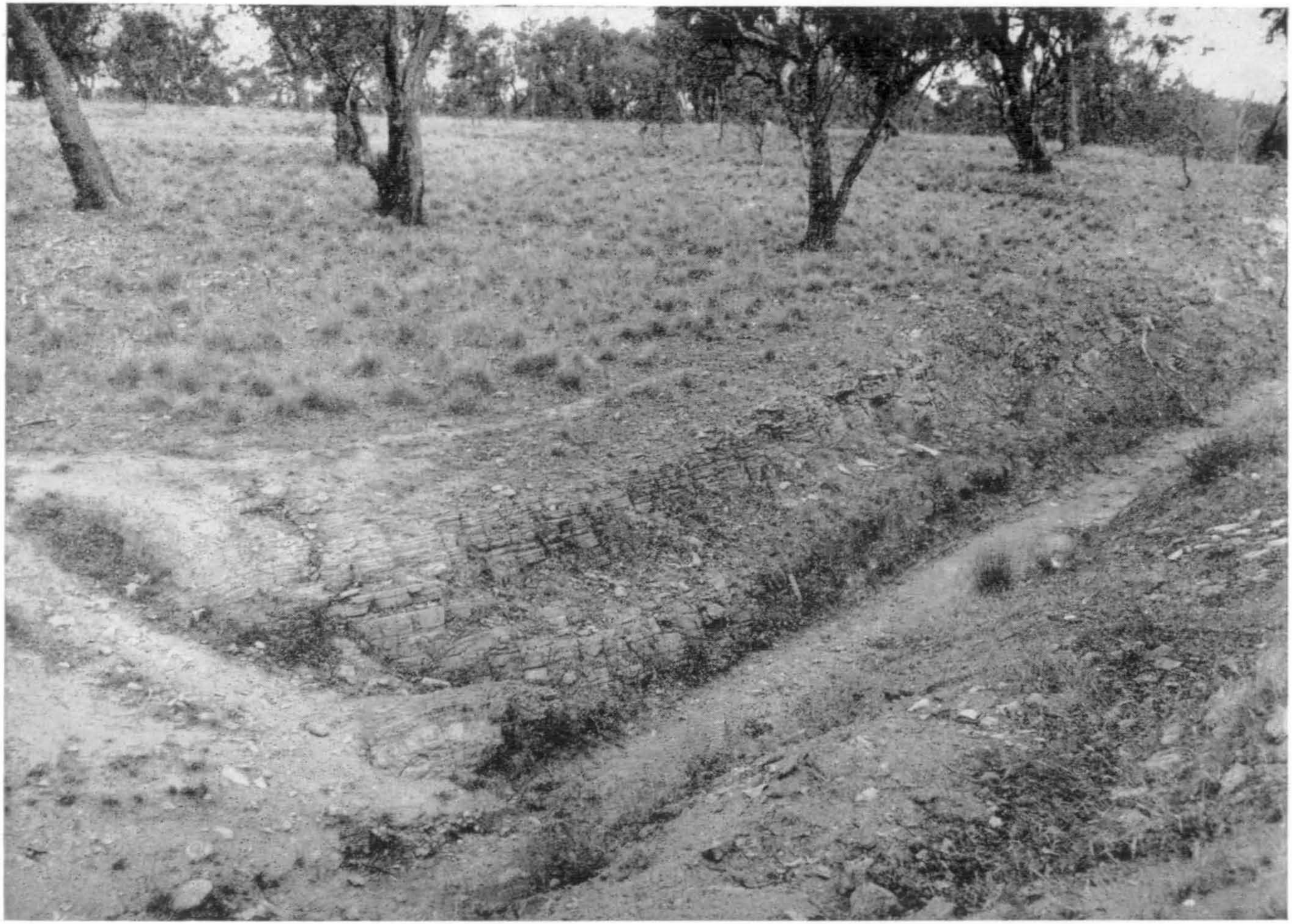


**Fig. 37.** Stormwater drain, south-east of War Memorial. Coarse pyroclastic sediments of the Ainslie Suite. See also Figs. 36 and 38.

**Fig. 38.** Detail of an acid flow replacing pyroclastics of Fig. 30. The dark spots arranged in bands are lava fragments externally suggesting "sphaerulites". Locality the same as Fig. 37.

*Consolidation and Erosion after the Bowning Orogeny*

As is explained below (p. 56), the Ainslie Volcanics, believed to be of a Lower Devonian age, are unconformably superimposed on the eroded surfaces of Silurian rocks and the structures of the Bowning Orogeny (Fig. 36).

The Bowning Orogeny consolidated the Canberra belt, because after it no depositional or tectonic events of major importance are recorded. The mountains of the Bowning Orogeny were eroded during the Downtonian (uppermost Silurian) Epoch and at the beginning of Devonian time. During this erosion the present topography of Canberra was developed, except for the Ainslie-Majura-Gooroo ridge, which was a later, Lower Devonian, development.

DEVONIAN

No marine sediments younger than Silurian are known in Canberra: the Devonian is represented only by the Ainslie Volcanics and the Narrabundah Ashstone. The Ainslie Volcanics are believed to be Lower Devonian in age, for the following reasons: (1) they are lithologically similar to the Victorian Snowy River Porphyries, for a part of which the age is established; (2) they are unconformable against the Silurian, overlapping, for instance, the St. John's Church Beds, the Mahon Formation, and some of the faults of the Painter Phase, and are therefore post-Silurian in age; and (3) the Ainslie Volcanics show tectonic structures that might be explained as a result of the Middle Devonian Tabberabberan Orogeny. The Narrabundah Ashstone may also belong to the suite of Ainslie rocks.

*Ainslie Volcanics* (Dla)

The Ainslie Volcanics consist of acid to dacitic pyroclastic rocks and volcanic flows (Fig. 34) composing the Ainslie-Majura-Gooroo ridge and resting unconformably on the eroded surface of folded Silurian rocks (Fig. 36). The thickness is 700 feet. The type locality is Mount Ainslie. They were recognized by Pittman (1911).

On the correctness of the age-interpretation of the Ainslie Volcanics depends the deduction of a Silurian age of the Bowning Orogeny in Canberra and, to some extent, the dating of the topography of the region. Therefore, some additional remarks on the relationship of the Ainslie Volcanics to their substratum may be necessary. On Mahon Hill a flow, most probably dacite, or a quartz andesite (Fig. 35) according to Mahony & Taylor (1913), with regular flowage lamination, rests on various beds of folded Silurian sediments, and the unconformable relationship is evident from the map. On the slopes of Mount Ainslie itself, however, the Ainslie Volcanics are in contact with Silurian volcanic rocks (St. John's Church Beds) of a somewhat similar lithology, and thus the difference between the two volcanics and their unconformable relationship are not immediately deduceable and not evident in every outcrop. The general relationship along the west-south-western border of Mount Ainslie is shown in Figure 36. Here, in the middle part of the section, laminated tuffs and even flows of quartz porphyry of the Ainslie suite are in contact with tuffs of the St. John's Church Beds. The latter are folded and, in parts, calcareous and fossiliferous. The Ainslie rocks are only volcanic and mostly subhorizontal (Fig. 37-38), and can be traced to the north, where they occur sandwiched between dacites. On the slopes of Mount Ainslie near-horizontal tuff beds occur. On the north-western slope of Ainslie the contact of a flow-laminated dacite against west-dipping fossiliferous St. John's Church Beds is exposed in a watercourse. At Duntroon, a V-shaped gully, eroded into tuffs and tuffaceous limestone of the St. John's Church Beds and filled by a quartz porphyry attributed to the Ainslie suite, was exposed in an extensive excavation. Moreover, on the eastern slopes of Mount Majura and Mount Ainslie, near-contacts against the rocks of the Fairbairn Group are evident, and on the western slope of Mount Majura (compare Mahony & Taylor, 1913, p. 11) an erosional inlier of strongly folded limestone and metamorphosed shale of the Molonglo Formation is surrounded by tectonically unaffected porphyry (dacite?). Finally, the fault of Sullivan's Line, which cuts the Silurian rocks, is concealed in places by rocks of the Ainslie suite.

The comparison of the Ainslie rocks with the Snowy River Porphyries is based on a suggestion of Mahony & Taylor. At the present stage, however, it has to be substantiated by further study.

The volcanic origin of the Ainslie suite was recognized by Pittman (1911), as is seen from his description (on the map): "Complex series of crystalline volcanic tuffs and lavas. Some of the former much resemble quartz porphyries but show occasional evidence of bedding". Later, Mahony & Taylor (1913, map) described the Ainslie rocks as "laminated porphyry, tuffs, etc". The massive appearance of some of the rocks and the absence of vesicular structure may imply the presence of some intravolcanic minor intrusions. However, even such rocks show very regular flowage-lamination and have to be regarded as volcanic. It is essential to think of Mount Ainslie as the ruin of a volcano; its pyroclastic roof and subaerial flows have been eroded away, and only the core is preserved. This also explains the predominance of flows, because only in a preserved volcano are the pyroclastic rocks the dominant material. The relatively coarse flowage-lamination may be interpreted as a property of a rather viscous magma at a relatively low temperature. The lavas preserved in the ruin of the Ainslie-Majura-Gooroo volcanoes are very near to dome-flows, and in some of them the shapes of small cumulo-domes can be inferred. As a contrast, the Lower Devonian Black Range rhyolites of the Taemas region west of Canberra and Yass may be mentioned. These rhyolites are, within the limits of an epoch, contemporaneous with the Ainslie rocks but are minutely laminated. They are interpreted as the product of a hotter and more fluid magma, extruded not on a consolidated block but in a subsiding belt. The petrological characters of the two suites have not been compared.

The duration of the volcanic activity is unknown, but the Ainslie-Majura-Gooroo ridge consists of a variety of rocks, which is a sign of intermittent activity. The erosional intervals between the active stages cannot be reconstructed, except the very last, which is documented by the Narrabundah Ashstone.

Inliers of older rocks (e.g. Mt. Pleasant, Fig. 23) occur on the ridge of Mt. Ainslie; not all these inliers are yet known. Mt. Ainslie itself, and the volcanic rocks believed to be Lower Devonian in age, are not yet mapped in detail nor studied petrologically.*

* I. A. Browne, in a recent paper (1954, p.6), regards the igneous rocks of Mt. Ainslie, Yarralumla, and Uriarra Crossing, as part of a belt of Silurian age extending from the vicinity of Cooma to Canowindra. This belt is characterized by the occurrence

*Narrabundah Ashstone* (Dln)

The Narrabundah Ashstone is a very fine-grained hard volcanic rock, laminated in places, and grey and greenish in colour. Thicknesses of 50 feet have been observed in residuals of an original blanket of ash. The type locality is the quarry at Narrabundah, at the big bend of Jerrabomberra Creek. The name was proposed by the author (Öpik, 1954).

The Ashstone lies on the eroded surface of the Silurian rocks of the Canberra Plain and on the slopes of Mt. Ainslie, with an erosional contact against the Ainslie dacite. Obviously at the time of the ashfall the topography coincided essentially with the present land-surface. The land-surface buried under the Ashstone was re-excavated by subsequent erosion but no further dissection took place.

The Ashstone may be interpreted as a product of the final explosion of the already reduced, and otherwise nearly extinct, Lower Devonian Ainslie volcano.

Petrologically, the Ashstone is similar to some fine-grained bedded tuffs interbedded with the Ainslie Volcanics.

*Ainslie Orogenic Phase*

The Ainslie bedded tuffs are not quite horizontal, but show moderate dips (maximum 20°) in various directions, and the strikes, though also variable, seem to be arranged in near-meridional directions. Cleavage is generally not developed but occurs only in separate zones of stress. The Ainslie Volcanics are also affected by faulting (Fig. 39). Some of the structures may be merely local results of the volcanic events themselves. Still, the general lineation, combined with the faulting, is an indication of a regional tectonic unrest during, and also after, the volcanic activity. On this evidence is based the Ainslie Orogenic Phase (name proposed by Öpik, 1954). Even the Narrabundah Ashstone has been slightly affected by the unrest. It is assumed, therefore, that the Canberra area passed through an essentially post-volcanic tectonic phase of the Middle Devonian Tabberabberan Orogeny, which is documented by the structures recognizable in the Lower Devonian volcanics. The Tabberabberan is chosen here, because it is the nearest in time and place to the Silurian and to Canberra. The faults of the Painter Phase, however, were not revived during this Phase.

## Dykes of Various Ages

Only a few dykes are known in Canberra, and they are all small.

The dykes in Fyshwick (Smd), composed of a hybridized porphyry, are believed to be of middle Silurian age and have already been mentioned in connexion with the Molonglo Ford Hornfels (p.33).

The Tolldale dyke (Sut), in O'Connor, is a quartz porphyry, cutting the folded Silurian rocks; it may be of postorogenic age.

of "intrusive tuffs"; "much of this material is coarsely crystalline and shows some resemblance to quartz porphyry in hand specimen, but its clastic character is apparent under the microscope". It appears to the present author that the uniformity of this belt is interrupted in Canberra, where igneous and pyroclastic rock-bodies of different ages occur. Further discussion, however, is reserved, and more evidence as to the continuity of the belt in time and space is awaited. The author believes that the Mt. Painter Porphyry, as described above, may be the largest rock-body of this belt.

A small dolerite dyke occurs on the top of Mt. Ainslie (compare Woolnough, 1938). Its age is unknown, though it may be Lower Devonian, which is the age of the Ainslie rocks themselves.

Dykes occur also on Red Hill, but are not yet mapped. The rocks here seem to be of intermediate to basic type. They are probably connected with the Mugga Mugga intrusion.

## PERMIAN

Upper Devonian and Carboniferous times have left no geological records in Canberra. The Permian is represented by terrestrial fluvioglacial deposits (Fyshwick Gravel), which are preserved only as small residuals on the Canberra Plain.

A Carboniferous age should also be considered (as for example the Namurian Burindi and Kuttung Series), but is less probable. Generally, the age is within the "Permo-Carboniferous Glaciation". Permian is selected because it is the latest possible date, and a Permian glaciation may have obliterated traces of earlier glaciations. Permian terrestrial ice deposits had also the greater chance of preservation because the time of erosion is less than that from the Carboniferous.

### *Fyshwick Gravel* (Pg)

The Fyshwick Gravel (Fig. 40,41) consists of quartzose conglomerate and coarse sandstone with boulders of local Silurian rocks; it is up to 30 feet thick. The deposits are plicated. The type locality is the gravel-pit in Fyshwick. The gravels were observed by Pittman and interpreted as high-level gravels of Tertiary age, and, according to Mahony & Taylor (1913), lithologically similar gravels in the Canberra region are even younger. According to Öpik (1954), the Fyshwick Gravel is of fluvioglacial origin; its folding is produced by the presence of the over-riding glacier; and the boulders in the Gravel are erratics. The presence of glacial Permian deposits on the present surface of the Canberra Plain suggests that the topography is ancient.

In matters of dating, glacial deposits have the value of fossils. The glacial origin of the Fyshwick Gravel and its probable Permian area have therefore to be substantiated, because even geologists familiar with the area regard the interpretation given in the A.N.Z.A.A.S. Handbook (Öpik, 1954) as unconvincing.

No unequivocal dating of the age of the gravel is possible, of course, because it is unfossiliferous. But it is certainly younger than Silurian, because it contains fragments of fossiliferous Silurian rocks. The author suggests that the gravel is of Permian age if it is a fluvioglacial deposit and if the age is not Pleistocene. The following discussion refers essentially to the gravel-quarry in Fyshwick, and is arranged as follows: (1) reasons why the writer considers the gravel to be of fluvioglacial origin; (2) impossibility of a Pleistocene age of the deposit; (3) deduction of a Permian age of the gravel; and (4) evaluation of other aspects of the age of the gravel and origin of the folding ("high-level" gravel, fault-scarp deposit, plication by a lava flow).

#### *Glacial origin of the Fyshwick Gravel*

The glacial origin of the Fyshwick Gravel can be demonstrated as follows:

(1) Boulders up to 7 feet in diameter of local Silurian sandstone are embedded in the conglomerate and sandstone: they are regarded as erratics shifted into their

present position by ice. The sandstone is the local Molonglo Sandstone, which is the substratum of the gravels at the locality under discussion.

(2) Large slices (up to 10 feet in diameter) of soft, leached Silurian shale (with *Encrinurus*) float in the gravel. They have been introduced from elsewhere. The transport of solid blocks of shale is thinkable only if they were saturated with water frozen to ice which protected them from otherwise inevitable disintegration.

(3) The gravels are incompetently plicated, and the folding affects the total visible thickness of 30 feet. Dips of 70 degrees and overturning and involution of conglomerate beds are seen. In normal conditions a gravel or conglomerate is not likely to respond in such an incompetent manner; an ice-saturated bed, however, will have no clear-cut boundary against the ice-sheet on its top, and the flowage-plication of the creeping ice will also be reflected in its overridden basement of rock fragments cemented by ice. An alternative explanation of the plication is local slumping on a subaquatic slope triggered by an earth-tremor, which may explain the folding in similar gravels observed at St. John's Church and at Gorman House, but not the occurrences of boulders.

(4) The absence of tills and of other periglacial deposits such as varved clays is no evidence against the glacial origin of the rock now preserved only as erosional residuals, because we do not know what was present in the complete sequence. Varved clays could well be absent altogether in the terrestrial conditions prevailing in the area. True subglacial tills are not seen, but south of the Fyshwick gravel-quarry, in another excavation, a till-like rock was observed included in the stratified gravels. It was not sorted nor stratified and consisted of quartz pebbles and angular sandstone fragments, sand, and silt. It is interpreted as a slice of local till shifted by ice.

(5) The gravels within the sediments are classified as fluvioglacial deposits of stratified rudites with boulders, formed near the margin of a glacier, in a terrestrial environment.

(6) The predominance of quartz pebbles (subangular to rounded) in the Fyshwick Gravel can be understood on the principle of the inversion of a sequence of rocks in the course of erosion. It is expected, and observed, that in a derived sequence the basal bed contains the fragments of the top beds of the source and is followed by material from gradually older beds exposed in the course of erosion. The Fyshwick Gravel is the basal, initial, part of an incipient glacial deposit and consequently contains the material of the land surface at the time of the first ice. At the beginning the ice had to shift the existing surface scree. This scree was composed of vein-quartz accumulated on the surface as the debris of the most resistant rock in conditions of chemical and mechanical decomposition.

The quartz of the pebbles is vein-quartz and quartzite derived from the Ordovician rocks of the Cullarin Horst in the east. Nevertheless, pebbles of non-metamorphosed sandstone and shale, all angular, are also present in the deposit. Completely weathered and friable pebbles of igneous rock are observed also, but they disintegrate into sand and clay at the first touch. Of course, in conditions of subsequent continuous leaching and lateritization, fragments of igneous rocks had little chance of preservation. They disintegrated, thus augmenting the predominance of quartz-pebbles in the coarse fraction of the sediment. However, even pebbles originally weathered and friable have been shifted by the ice and glacial streams without disintegration, because they were again saturated by ice as a secondary bonding. Such pebbles and boulders had, of course, even less chance of survival.

(7) The absence (as yet) of identified long-range erratics is inconclusive against the glacial origin of the beds, as long as the concept of a basal, initial, deposition is accepted. The observed conditions satisfy the concept of a "local moraine" as observed in Pleistocene glacial deposits elsewhere. In eastern Australia glacial deposits are known from upper Palaeozoic (Permian) time, but only as marine "tillites"; terrestrial, fluvioglacial, development may be present in Carboniferous (Kuttung) time. Thus a Permian age of the Fyshwick Gravel is possible by geographical proximity to marine glacial deposits, and the Pleistocene glaciation is the only alternative, because there are no other (Mesozoic) glaciations known in the region.

*Pleistocene glaciation excluded*

The Pleistocene glaciation is impossible for the following reasons:

(1) the Fyshwick Gravel is lateritized, with all the colours of the mottled zone and remnants of the ferruginous crust on top. Lateritization implies a pre-Pleistocene age of deposition of the gravels.

(2) the elevation (c.2,000 feet) is too far below the lower topographic limit of Pleistocene glacial deposits in Australia. According to Browne (in David, 1950, Vol. 1, p. 628), the lower limit of the ice is found at altitudes of 4,800 feet of the present topography in southern New South Wales.

(3) Pleistocene glacial deposits, being very young, ought to be present as undissected cover, and even better preserved than in the higher altitudes of Tasmania and the Australian Alps. But all that is preserved in Canberra are small erosional residuals of a basal, initial, portion of an otherwise completely extinct sequence, whose glacial origin is not immediately obvious from their present morphology.

*Permian Age*

The possibility of a Pleistocene age of the Fyshwick Gravel is eliminated above. If the gravel is not of a glacial origin, it must be regarded, nevertheless, as a pre-Pleistocene deposit on account of its lateritization. The next youngest age possible is Permian. The Permian age is conditional, of course, and is correct if the Fyshwick Gravel is of glacial origin. In any case it is not a discovery of a new glaciation and has no bearing on the palaeo-climatological understanding of the history of the region. Palaeogeographically it would indicate land conditions in the Canberra area during upper Palaeozoic time, a conclusion already inferred from the absence of marine sediments.

*Evaluation of other aspects of the age of the gravel and the origin of its folding.*

Other geological explanations are high-level river-gravel and fault-scarp, or even piedmont, conditions. The river-gravel concept explains the stratifications and, in combination with the above-discussed seismic slumping, the plication. The

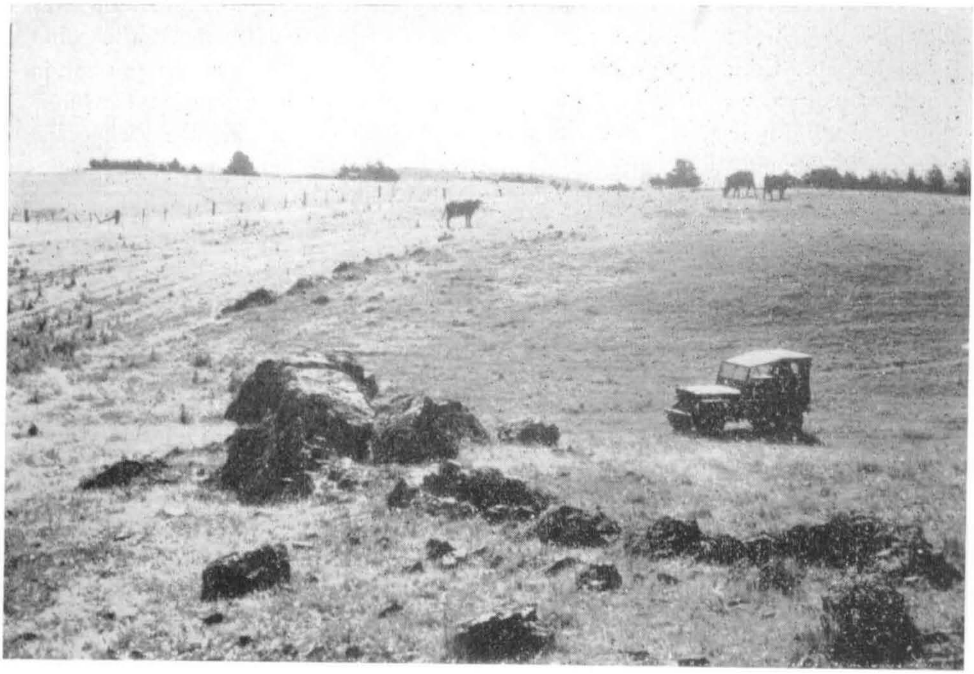


**Fig. 39.** South Fyshwick Fault. The fault is contorted, and its quartz reef dips south (to left). The vehicle is on Silurian sediments, the cattle are on the downfaulted and sheared dacite.

**Fig. 40.** Fyshwick gravel quarry, at western end of North Fyshwick Fault. Irregularly interbedded conglomerate and friable sandstone, red, white, yellow, mottled.

**Fig. 41.** Detail at eastern entrance of Fyshwick gravel quarry. Locality the same as Fig. 42. Contorted conglomerate and sandstone, light brown. The hammer is on a large block of leached Silurian shale which extends to left, beyond the picture. The colour of the block is white (pallid). The top bed is brown and red and richly ferruginous.



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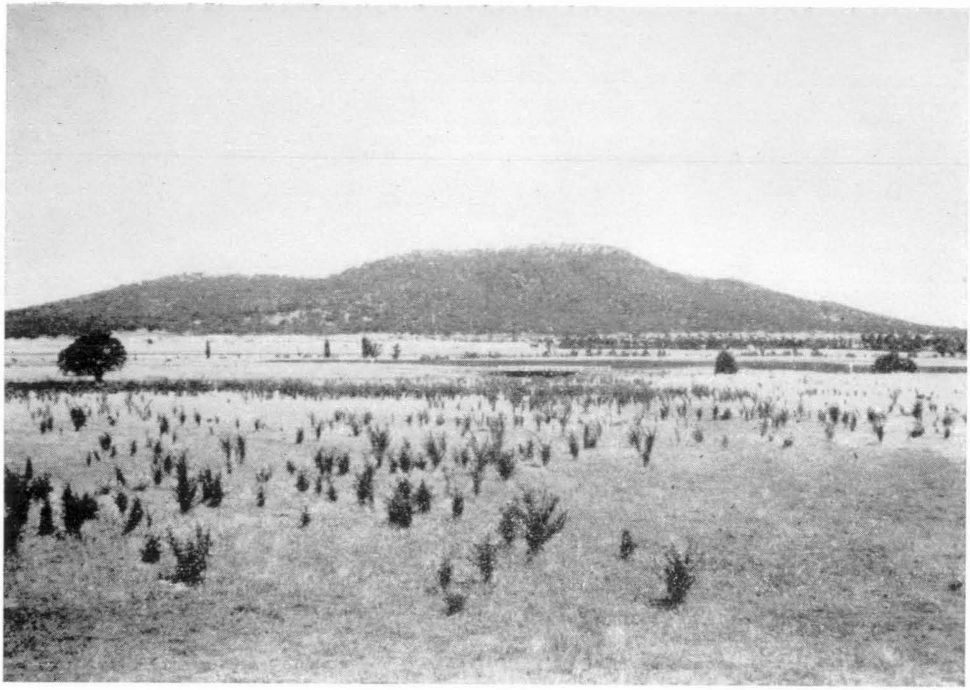

**Fig. 42.** Pleistocene depositional plain (Lyneham Lake), northern part of Canberra. View looking south-east. Mt. Ainslie in the background. See also Fig. 43.

**Fig. 43.** Woolshed Creek: a break-away in Pleistocene sediments of the depositional plain east of Mt. Ainslie (Majura Plain). Grey sandy clay with two bands of calcareous nodules in its upper part, followed by a ferruginous buckshot horizon (dark), and topsoil. Similar sections have been seen in Canberra (Lyneham Lake deposits). See also Fig. 42.

**Fig. 44.** Gravel quarry, eastern slope of Black Mountain (Tourist Camping area). Black Mountain in background. Fanglomerate of the slope of the mountain. Crude bedding and poor sorting of the angular material derived from the Black Mountain Sandstone.

erratics, however, remain unexplained. Moreover, there is no major difference, stratonomically, between river-gravel and fluvioglacial gravel except for the erratics. Piedmont deposits of course contain large blocks of rocks, which might be mistaken for erratics, but the plication observed is certainly not caused by drag along a fault; the occurrence is on an established horst with a fault exposed as a quartz-reef just north of it. The slickensides dip approximately 70 degrees north, and on the downthrow side no comparable sediments are seen. Hence the gravel is not a fault-scarp conglomerate, as is also obvious from the widespread occurrence of similar gravels in Canberra, which are arranged in accordance with no tectonic line or trend.

Another explanation is plication by a transgressive lava-flow of a substratum composed of gravels of unknown age. If the lava were the Ainslie dacites and rhyolites the stratigraphically impossible Silurian or Lower Devonian age of the gravels would have to be introduced. This is recognized, of course, and thus a former cover of "Tertiary Basalt" in Canberra is a necessary inference. The basalt explains the plication and the plication in turn points towards the basalt. The argument at this stage is a *petitio principii.*

However, there is no geological evidence, as yet, for basalt-sheets in Canberra. The basalt might have been lateritized and rapidly eroded, just as the ice melted away, but the traces of ice are preserved, whereas the basalt has left none. It is true that at the base of a lava-flow the substratum can be contorted by, and mixed with, the lava to depths of a few feet, but a flowage-plication of competent conglomerate and sandstone to depths of 30 feet by a lava-flow, perhaps with a thickness of the same magnitude, has never been observed and is not likely to exist at all.

The boulders also remain unexplained. Besides, an unknown thickness of the gravels has already been eroded away, which is an additional pile of plicated rocks below the postulated contact against the basalt. A basalt flow could be spread over any rocks of any date and origin and, if it existed, would still not explain the peculiarities of the substratum.

In a discussion of the possible role of "basalt", the question of "billy" has to be reviewed also. The general argument is that "billy" represents quartzites formed from sandstone at the contact against a basalt flow above it, and that the presence of billy is therefore evidence of a former basalt cover. However, the sandstone boulders at Fyshwick cannot be classified as billy from their texture; they are rather leached calcareous sandstones with a weak and surficial siliceous bonding only. Besides, the boulders are unevenly distributed through the whole of the section, and the base is a similar Silurian sandstone, whereas true billy is to be expected on the surface. Billy-like fragments occur as pebbles in the gravel also; but they can be derived from silicification at the base of the Palaeozoic Ainslie volcanic rocks, for which ample evidence has been seen in accidental outcrops along the fringe of Mount Ainslie. The author attributes the incipient silicification of the sandstone at the base of the Fyshwick Gravel, and its leached non-ferruginous appearance, to lateritization; but even this is not necessary, because surface silicification could take place at any time, and coincidence in a section is not always evidence of common cause. For example, at the unconformity on Capital Hill, the Silurian sandstone is not silicified, but its subsurface (the Black Mountain Sandstone) is. On the other hand, the whole of Black Mountain has a surficial silicified crust, which would hardly be identified as the one seen at the unconformity.

The question of basalt and billy in New South Wales deserves more comments. Many existing basalts over lacustrine sands and deep leads have no billies at their base, as for example at Kiandra; hence silicified sandstone is no evidence for a former basalt cover, nor is its absence evidence against it. Moreover, besides the two generally known, and of course real, modes of formation of billy — by lateritization and by contact with a basalt (or lava) flow — there is a third, not less important, type that has not been considered before. This is the fresh-water or swamp quarzite, whose purest and commercially important variety is ganister. Every case of a quartzite in fresh-water sediments, even under a basalt cover, must be tested for such a possibility, until a definite conclusion as to its origin can be reached. Therefore, occurrences of billies without a visible basalt cover cannot be taken as evidence of the missing basalt, from which usually geomorphological speculations of great attractiveness and obscure reality may result.

In the light of the above discussion, the question of a temporal correlation of the Fyshwick Gravel with the Tertiary gravels and sands of New South Wales (deep leads and lacustrine sands and gravels) seems to be inconclusive, the more so as all such deposits are not necessarily of the same age ("Tertiary"), which in most cases is inferred from geomorphological considerations, as well as applied to geomorphological reasoning.

The interpretation here suggested and defended — that the deposits are Palaeozoic glacials — arose from the evidence preserved in the rock itself and its environment, without any intention of proving or refuting the current schools of thought, and there is now ample justification for submitting the Tertiary gravels, the billies, and the basalts, to another test, each on its own merits.

Outside Canberra (but within its region) no rocks occur that can be interpreted as glacial. Gravels and conglomerates on the hill-tops, as for example in the Lake George area, may contain redeposited fluvio-glacial material.

*Summary.*

An observer experienced in the study of Pleistocene glacial deposits, and also familar with contacts of lava-flows with unconsolidated sediments or tuffs as seen for instance in Iceland, has in the case of the Fyshwick Gravel no alternative but to attribute a fluvioglacial origin to the rock, and it seems that, unless fossils contradicting the Permian age are found in the gravel, as, for example, Mesozoic or Tertiary plants, the fluvioglacial origin and consequently the Permian age remain the answer.

If the gravels are high-level gravels in the popular sense, their pre-lateritic age and position on the floor of a mature valley prescribe a radical revision of the current concepts of the geomorphology of Canberra and the Canberra Rift.

Finally, if the glacial origin of the Fyshwick Gravel is not accepted, the age of the deposits can be anything between upper Palaeozoic and Tertiary, which is, of course, a reasonable first approximation and leaves the way open for further inquiry.

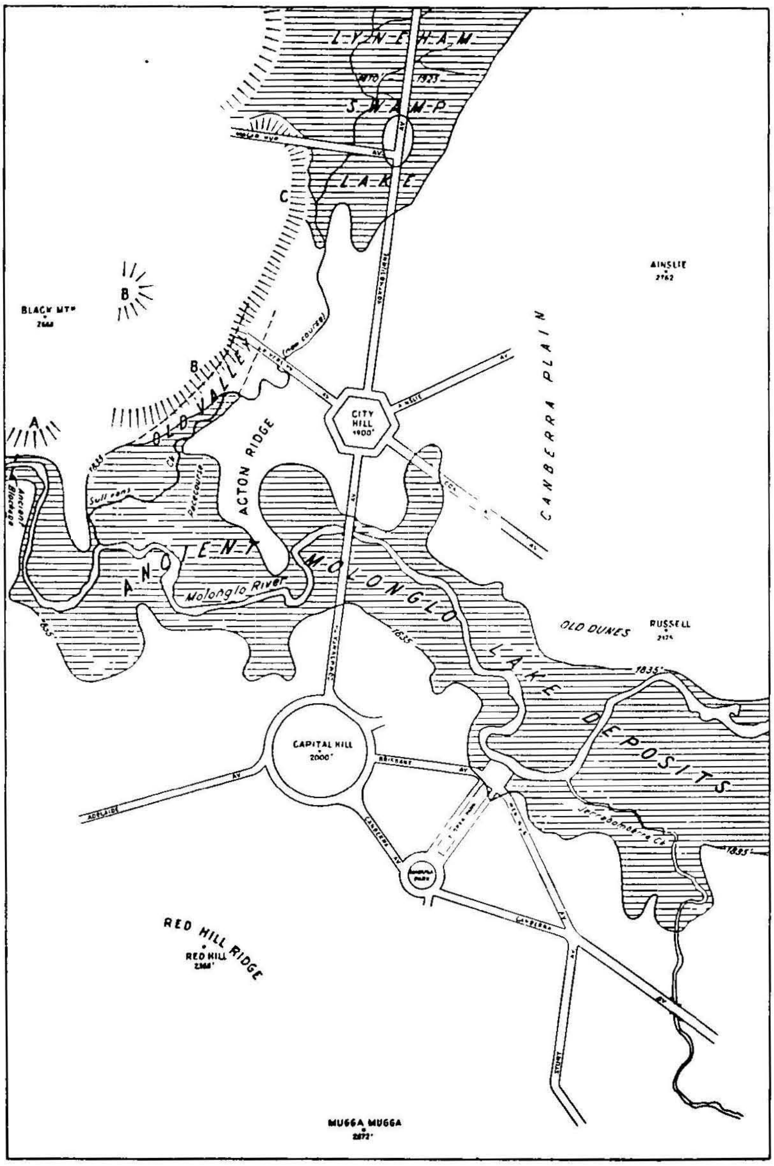


**Fig. 45.** Diagrammatic sketch-map of Pleistocene lakes, fanglomerates, and old valleys, in Canberra.

A—Fanglomerate of the south slope of Black Mountain; B—Fanglomerates of the south-eastern slope; C—O'Connor fanglomerates. The ancient "dam-site" or blockage of the Molonglo Lake was formed by the fanglomerate A, which is now broken through by the river. "Old Valley" refers to the ancient valley of Sullivan's Creek, now filled up by fanglomerate B. "New Course" refers to the Sullivan's Creek bed as an outlet of the Lyneham Swamp Lake, after the main valley was filled up by the fanglomerate. The outlines of the Ancient Molonglo Lake are determined by the 1835 ft. contour-line. The shores of the lake consist of undissected country-rocks.

## Post-Palaeozoic Deposits

No rock record is preserved in Canberra for the whole of the Mesozoic Era and the Tertiary Period. The time passed in conditions of retarded erosion and local deposition.

The idea of Pleistocene freshwater lakes was put forward in a general way by Legge (1937) and is developed below.

The sediments of the swamp-lake of Lyneham in the northern part of Canberra are interpreted as a local deposit of Pleistocene age. The lake was caused by the scree (fanglomerates) of Black Mountain, which filled a part of the ancient bed of Sullivan's Creek (see Fig. 45). The lake had to develop a new outlet — the present Sullivan's Creek — in consequence, and even today the area of the former lake is still subject to deposition rather than erosion. The same fanglomerates, perhaps at a later date, temporarily blocked the bed of the Molonglo River at the south-western slope of Black Mountain, raising the river level 35 to 40 feet. Thus, in prehistoric time the bed of the Molonglo formed a lake within the limits of Canberra. After the river had broken through the obstacle, this lake also disappeared, leaving behind the sandy river-flats. Evidently no tectonic movements of, for example, Pleistocene or later date are needed to explain the present topography, the distribution of the alluvial deposits, or even the surface drainage system in the Canberra area.

Details of the post-Palaeozoic rock cover in Canberra, however, have not yet been studied. In many places, as, for example, in a channel at the Kingston Sports Ground, a coarse reddish friable sandstone occurs on top of the Silurian rocks. The sandstone, up to 2 feet thick, differs in its consolidation and red colour from the alluvial deposits on top but cannot be dated as yet. A similar bedded sandstone occurs on weathered porphyry in trenches south-west of the United States War Memorial and was exposed in the foundation of the Memorial itself. In this area it is four to six feet thick and is preserved as erosional residuals beneath the unconsolidated Pleistocene sand and clay.

The following sections may illustrate the composition of unconsolidated surface deposits in Canberra.

*Trench at the former site of Tolldale*

(O'Connor, about 100 yards north of MacArthur Avenue)

| | | |
|---|---|---|
| 1. | Grey soil | 8 in. |
| 2. | Reddish subsoil, with ironstone peas (buckshot) increasing in number towards the base | 2 ft. |
| 3. | Grey and brown gritty clay with pebbles and angular fragments of Black Mountain Sandstone and Ordovician chert and siliceous shale | 7 ft. |
| 4. | Pale grey, even white, clay grading into weathered Silurian mudstone | 1 ft. |

A deposit of ironstone, 8 feet thick, was observed nearby, resting on an irregular surface of weathered Silurian rocks. Similar ironstone is widespread in Canberra and to the north. The ironstone is post-Palaeozoic, but its origin is obscure. The observed relationships suggest a pre-Pleistocene age of deposition.

*Foundation pit in Civic Centre*
(Brisbane Building)

| | | |
|---|---|---|
| 1. | Shifted material | 4-5 ft. |
| 2. | Grey topsoil | 10 in. |
| 3. | Sandy subsoil with ironstone buckshot resting on an uneven surface of | 20 in. |
| 4. | Brown clay with a columnar partition and scattered pebbles and a few boulders | 3-5 ft. |
| 5. | Consolidated conglomerate with densely packed pebbles of quartz, sandstone, and Ordovician cherts | 2 ft. |

The material in the conglomerate may be derived from redeposition of rocks similar to the Fyshwick Gravel. There are indication that below it follows a red sandstone comparable with some of the rocks of the Fyshwick Gravel which were temporarily exposed in the foundations of the Australian National University.

## TECTONICS

### Explanation of the Tectonic Map

The tectonic map is essentially constructed to present the stratigraphy of the structures; or, in other words, to present the succession of tectonic events superimposed on pre-existing rock bodies and in relation to rock bodies *in statu nascendi*. The present map is incomplete; it shows only prominent structures and trends, illustrating the main grain of the country and some deviations thought to be important. Only those faults are shown which by their magnitude displace boundaries of rock units, and which therefore obscure — or perhaps help to decipher — the sequence. A great number of "minor" faults and fractures which do not extend beyond the boundaries of a single unit were intentionally omitted from the present map.

The following text is arranged alphabetically, to help in the use of the map in the field.

*Acton Anticline.* The western limb is exposed in numerous outcrops at Lennox Crossing, around the Canberra Community Hospital, e.g. as a low cliff at the bend of the Molonglo River. The eastern limb is seen in the "Bakehouse Block" (with supplementary folds), in the cutting north of the Commonwealth Bridge, and on City Hill. The latter represents a flanking segment of the anticlinal nose. The eastern limb is the steeper, indicating a push from the west. The Lennox Syncline complements the fold in the west. The Acton Anticline must not be confused with the Acton Syncline, which is an older structure, not related to it.

*Acton Fault.* Because of its unusual shape the Acton Fault was referred to in the fieldnotes as the "snake fault". Geometrically unpredictable, its course became apparent only after examination of a number of temporary outcrops, not all of which existed at any one time. The best outcrop was in a tunnel under Liversidge Street near the Australian National University Bus-stop. At present the fault can be demonstrated at the Tourist Camp and, less clearly, on the Acton ridge itself.

The fault dips east at various angles (between 75° and 85°), and the downthrow of the Silurian (Canberra Plain) is about 3,000 feet. The Black Mountain Sandstone and the Ordovician rocks are clean-cut by the fault with a narrow gouge along the contact. The Silurian rocks, however, are strongly dragged in a wide zone, with numerous quartz-veins and minor displacement-fractures trending parallel to the main fault. It may be interpreted as a compound slip-fault. The fault has been traced to the north-north-east for several miles, disintegrating into a system of quartz reefs and smaller faults *en echelon*. The eastern slope of Black Mountain is the receding fault scarp, morphologically prominent as far as Gungahlin in the north (see Fig. 1).

*Acton Syncline.* The core consists of the Upper Ordovician Acton Shale partly concealed by the unconformable lower Silurian Camp Hill Sandstone, which is not involved in the structure. The trough-line of the syncline is sharply bent; the northern segment is intensely contorted, with overturning of contacts and even axes of the folds. The upper part of the Pittman Formation is also greatly involved. A thrust from the north, conducted by the mass of Black Mountain, may be the cause of the structural complications. A slip from the pre-existing slope of Black Mountain may be considered also.

*Adelaide Ave. Roof-Pendants* (Fig. 31, 32, 33). The carrier of the pendants is the Painter Porphyry; the pendants consist of the Deakin Volcanics. There are three main pendants altogether: (1) at the road-cutting at Prime Minister's Lodge (the "Lodge Pendant"); (2) south of Adelaide Ave., at the site of the residence of the High Commissioner for the United Kingdom ("High Pendant"); and (3) north of the Avenue ("Horse-Paddock Pendant"). The intrusion of the Painter Porphyry into the previously folded (Yarralumla Phase) Deakin Volcanics is most obvious in the pendants. The "High Pendant" is strongly sheared; the volcanic rocks here are mostly transformed into sericitic schist. The pendant itself reveals a rotation on a vertical pivot. A quartz reef marks the eastern edge of this pendant. The "High Pendant" is larger than was originally thought: from a recent trench along Melbourne Avenue, it was concluded that the volcanic rocks extend several hundred yards south-east from the boundary shown on the map and even cross Melbourne Avenue. This portion shows the usual lineation but is less sheared than the northern end of the pendant. The "Horse-Paddock Pendant" (Fig. 33) shows drag-folds near the contacts against the Deakin Fault.

*Bakehouse Block.* The name refers to the site of the first bakehouse in Canberra, which was burned in the early days of the City. The fault separating the block is a minor sag-fault accompanied by quartz-veins on its northern side.

*Belconnen Synclinorium.* The name Belconnen refers to the Belconnen wireless transmitter. In relation to the Black Mountain Axis it is generally a syncline of Ordovician rocks with small discordant outliers of lowermost Silurian sediments. In detail it consists of crowded anticlines and synclines, the latter with the Acton Shale in the cores. North of Canberra the Synclinorium plunges under Silurian rock within the boundaries of Gungahlin Station along the Yass Road. About 200 yards south of the Belconnen water reservoir a quartz porphyry dyke represents the only igneous rock known within the Ordovician Black Mountain Horst.

*Black Mountain Axis.* A remnant of a major anticline greatly distorted by subsequent tectonic movements. It is pre-Silurian, earlier even than the Canberra Phase, because in the Middle Ordovician it functioned as a local barrier, separating the north-western basin with radiolarites from the south-eastern basin without radiolarites in Canberra itself. The folds of the Belconnen Synclinorium are definitely disharmonic in relation to the Black Mountain Axis and show the features of surface folding (decollement). However, the Black Mountain Sandstone, stratigraphically below the rocks of the Synclinorium, and by itself a competent mass, is folded so intensely (Fig. 8) that its structures cannot all be understood as a result of the Canberra Phase and the Bowning Phases. Hence a movement earlier than Middle Ordovician may have initiated the Black Mountain Axis. The contact of the Black Mountain Sandstone against the next higher Pittman Formation (Middle Ordovician) is as yet obscure, but the cartographic relationship between the units, as observable in the section across Southwell's Quarry and in the north-western corner of the map, suggests an angular unconformity between them and a gradual overlap of the Pittman Formation over the Black Mountain Axis. Moreover, no infolds of younger rocks into the Black Mountain Sandstone are found. The foundation of the Black Mountain Horst, the backbone of which is the Black Mountain Axis, is, perhaps, the result of a locally-preserved consolidation-block, rooted in the tectonic conditions established before Middle Ordovician time. Such a condition would furnish a mechanical explanation for the type of folding (decollement) of the Canberra Phase (Fig. 11), which passed on and broke against the pre-existing axis. On the other hand in the west, in the Cotter Horst, the Canberra Phase possibly acted as a major orogeny, in a style different from that in Canberra.

*Black Mountain Fault.* The fault separates Black Mountain from the downthrown Belconnen Synclinorium; it is clean-cut in the pre-Silurian rocks but has caused intense drags in the Silurian. In the north-east (Northern Node) it is a vertical wall. The throw is several hundred feet. (Fig. 15, 16.)

*Canberra Plain.* (Not marked on Tectonic Map; see Figure 3.) Originally a morphological term introduced by Taylor. Here it covers the portion of the Canberra Rift east of the Deakin Fault, consisting of Silurian rocks obviously below the level of the eroded Painter intrusion, and forms a structural unit different from the roof-pendants west of the Deakin Fault. The rocks of the Canberra Plain show the shear-cleavage and open folds of a buried sequence, whereas in the roof-pendants close folds and a certain amount of fracture-cleavage indicate a near-surface position during the orogeny. (Fig. 1.)

*Causeway Structure.* The structure is completely concealed and buried by alluvial deposits. Its existence is recognized from the fact that, in the area, the lower Silurian Riverside Formation and the middle Silurian Molonglo Formation are in near contact on the surface without enough space between them for the St. John's Church Beds and the City Hill Shale. A short-range thrust from the east, or an interformational break, or even a concealed high in the substratum, may be the cause.

*Crace Axis.* The name is derived from Crace Hill, just at the northern end of the Canberra City District, outside the map. The "axis" is traced within approximately one and the same horizon of the Riverside Formation, with a uniform dip to the east and a uniform cleavage. It represents the most continuous line of outcrops on the Canberra Plain, illustrating the considerable meridional extent of individual Bowning structures. Although the line is selected for a particular horizon, it touches a variety of rocks. At Crace itself they are tuffaceous calcareous shales and a rhyolite, and south of it limestones and calcareous shales, and farther south tuffaceous rocks again are met. In reality it is a "trend-line", and the term "axis" has been used here for brevity.

*Deakin Fault.* A major fault (Fig. 31, 32, 33) with a downthrow to the east of not less than 4,000-5,000 feet. It separates the Canberra area from the main Rift in the west. The Deakin Fault joins the fault of Sullivan's Line opposite Mt. Jerrabomberra at Letchworth (off the map), a railway siding three miles southwest of Queanbeyan; the structure, however, is here obscured by an intrusive porphyry of Mugga-Mugga type, a significant coincidence with local structural conditions. In the north, and outside the Capital Territory, the fault is concealed under younger, perhaps Lower Devonian, volcanic rocks. Silurian rocks on both sides of the fault are dragged, but the pre-Silurian ones are clean-cut. Quartz reefs occur within the Silurian rocks at the fault, and its southern end and some sections in the north are also prominent quartz reefs. The fault is practically vertical. Sections of the fault are concealed by Lower Devonian volcanic rocks (Narrabundah Ashstone) and thus no younger movements are involved. The fault cuts both the Silurian rocks folded in the Yarralumla Phase and the Painter Porphyry, which, in addition, shows some signs of folding. In the north, east of Mt. Painter, the Deakin Fault has brought the Black Mountain Sandstone into contact with a small block (see "Roof-Pendants" below) of Deakin Volcanics floating in almost massive Painter Porphyry (section, Fig. 10). However, Mt. Painter itself is a culmination of an areal structure of clearly orogenic origin, which first suggested the existence of the Painter Phase as a late event of the Bowning Orogeny in Canberra. Faulting is still the main feature of this Phase, with the Deakin Fault the best-studied example.

Morphologically some sectors of the fault form low sloping scarps, which, remarkably enough, considering its Palaeozoic age, nearly coincide with the fault-line itself (Fig. 33). This can be seen where the fault cuts the Black Mountain Sandstone or the Ordovician rocks, which were obviously already petrified at the time of faulting. The erosion of the fault-scarp most probably proceeded not as a general recession but as a stripping and lowering of the narrow Black Mountain Horst. The line of scarps begins at St. Andrew's Church and can be followed in a north-north-westerly direction, with several interruptions, of course, to the north-western corner of the mapped area. The main breaks in the scarp-line are the Molonglo River and the Pittman Valley.

*Fyshwick Dome.* Situated in the south-eastern portion of the District. The dome developed in three phases:

(1) At the end of the middle Silurian and before the folding started, an intrusion rose to a near-surface position and sent dykes upwards. An aureole of competent contact-metamorphic hornfelses was created. This

event can be interpreted as a forerunner of subsequent major orogenic events. The author believes that such events indicate the advance of intrusions generally interpreted as both Benambran and Bowning, and that the nearby granites (Sutton, Greenwood, and White Rock) in the Cullarin Horst are also "forerunners".

(2) During the Bowning Orogeny the area of the hornfels, by its competence, was structurally only moderately affected (dips up to 15 degrees only) and attained its dome structure.

(3) In Middle Devonian time the dome was accentuated once more by faulting. (Fig. 39.)

*Hidden Fault.* The name is arbitrary because the fault is mostly concealed by Ainslie Volcanics. It is a strike-fault of considerable displacement within the St. John's Church Beds. It outcrops in a creek as a ferruginous zone 6 - 7 feet wide.

*Lennox Syncline.* The name is derived from Lennox Crossing on the Molonglo River at Acton. The syncline is situated between the Acton Fault and the Acton Anticline, completing the fold. It has a steep western, and a more gentle eastern, flank, indicating a push from the west. The core is City Hill Shale and its Acton Limestone Member. The pitch is to the south, and the Riverside Formation emerges at the northern nose. It is a favourable structure for reckoning the thickness of the City Hill Shale.

*Mahon Anticline.* A well-exposed structure in the south-east of Canberra. The eastern limb has a dip up to 50 degrees; the crest is exposed. The western flank and a portion of the crest are covered unconformably by a flow of the Ainslie suite (Lower Devonian) (Fig. 35).

*Node.* The term "node" is applied within the Canberra area for localities where several major structures meet and bring together rocks of extremely different age and composition. They are keys for structural and even morphological relationships.

*N-Node.* Stands for "Northern Node". The meeting of the Black Mountain Fault and the Acton Fault, as well as of the Black Mountain Axis and folds of the Canberra Phase and the Yarralumla Phase, forms this node. Within a few hundred yards Silurian graptolites (*Monograptus exiguus*, in the creek near the fault wall) (Fig. 15) and Ordovician graptolites (Acton Shale, south of Prof. Oliphant's house) can be collected. Morphologically a gully, now buried by fanglomerates, was cut here through the Acton Fault. Upstream, in Etheridge Creek, Middle Ordovician graptolites, conodonts, and radiolaria occur.

*North Fyshwick Fault.* See also "Fyshwick Dome". The fault is represented at its western end by a prominent slickensided quartz blow, dipping at about 75 degrees north. Immediately south of it, in the gravel-pit, is the main locality for the Permian fluvioglacial deposits.

*Oakes Fault.* The name refers to Oakes Crescent, Division of Ainslie. The fault is developed as a reef, partly quartz and partly ferruginous, with drags on both sides, and with the downthrow in the south-south-east. The Riverside Formation and St. John's Church Beds are brought into contact; the City Hill Shale is eliminated. Details, however, are obscure. It is perhaps a sag-fault, because the metamorphics (contact hornfels) may represent in reality an upper horizon of the City Hill Shale. Still more complications are involved (cf. the geological map), because some hundred yards to the east the Molonglo Formation (stratigraphically above the St. John's Church Beds) is found, coming in without visible structural cause. The rocks are here abundantly fossiliferous, especially the Riverside Formation, from which fossils have to be won by digging in soft, weathered, dragged shales. The hornfels mentioned above is seen in small outcrops in a watercourse on the stock-route immediately south-west from the plantation near the north-eastern end of the fault. The hornfels is fossiliferous.

*Powerline Fault.* The name refers to a place in the north-eastern corner of the area where the powerline crosses a creek. It is a small fault, by which basal agglomerates of the Ainslie Volcanics, containing unaltered fragments of calcareous shale and limestone, are brought up. West of it another, unnamed, fault reveals limestone in the substratum of the Ainslie Volcanics.

*Roof-Pendants* (Fig. 31, 32, 33). The name refers to occurrences of the Yarralumla Formation and the Deakin Volcanics west of the Deakin Fault. Three of the pendants are discussed separately under "Adelaide Ave. Roof-Pendants". The two remaining are the largest: (1) Red Hill, which is a pendant in the Painter Porphyry and Mugga Porphyry, and is metamorphosed; and (2) the Yarralumla Pendant, intruded only by the Painter Porphyry, and slightly metamorphosed near the contacts. At its northern edge, along the Molonglo River, the Painter Porphyry emerges from beneath the Yarralumla rocks and shows a culmination in Mt. Painter itself, whose position is shown in Figure 32.

There are more such pendants in Canberra than are represented on the map. Thus, at the Monaro Crescent Bus-shed, south of Collins Park, in foundation pits of houses, banded lavas and tuffs have been exposed. The rocks are folded and sheared and show a moderate cleavage. The occurrence is noteworthy because it is a vesicular lava, generally very uncommon in the Palaeozoic volcanic rocks of Canberra. Again, the little roof-pendant (Sud) shown in the Section (Fig. 10) west of Black Mountain exists in this position although it is not on the map. It is situated in the extreme north-western corner of the map at the outcrop of the Black Mountain Sandstone. It consists of vertical pyroclastics cut and shattered on one side by the Deakin Fault, and surrounded by Painter Porphyry on the other sides. The strike is west-north-west, not coinciding with the direction of the fault. In the discussion of the Painter Porphyry (above), the roof-pendants are regarded as the core of a syncline west of the Deakin Fault. This syncline is most probably a structure of the Painter Phase, contemporaneous with the faulting (Fig. 3 and 32).

*S-Node.* Stands for "Southern Node". At the Manuka Oval the Acton Fault joins the Deakin Fault and the following rocks are brought together: (1) the Pittman Formation, at Manuka Oval, where it is now concealed by shifted material, although good outcrops still exist around the Forrest Methodist Church; (2) the Painter Porphyry, several good outcrops along the Deakin Fault; and (3) the Riverside Formation, here very fossiliferous, in the creek south of the Oval. South of the Node the Deakin Fault cuts Silurian rocks; both sides of the fault went down in the course of faulting, but the western side has a deeper throw.

*South Black Mountain Fault.* The abrupt southern slope at Black Mountain is a preserved, and not yet receded, fault scarp (Fig. 33). The fault is directly observable near its western end, with drags in a downfaulted erosional outlier of the lower Silurian State Circle Shale (a locality for *Monograptus exiguus*). It is perhaps a reverse structure, possibly a thrust. See also "Acton Syncline".

*South Fyshwick Fault.* Well exposed, and developed as a quartz reef dipping steeply to the south (Fig. 39). The eastern end of the fault is folded, and the axes pitch steeply south, following the dip of the fault. It is, perhaps, a sag-fault, because the throw is negligible on its western end but increases rapidly to the east. The fault throws the Ainslie Volcanics and is therefore later than Lower Devonian.

*State Circle Rift.* A local structure subsidiary to the major Deakin Fault. Both faults are exposed on the surface. The eastern fault cuts the Black Mountain Sandstone cleanly, but causes intense drags in the downthrown State Circle Shale. The western fault is partly silicified.

*Sub-Ainslie Syncline.* As the name indicates, the structure is buried under the Ainslie Volcanics, which cover it unconformably. The existence of the syncline is postulated from the following observations:

(1) North of the Ainslie Reservoir the St. John's Church Beds dip to the west at about 40 degrees, representing the eastern limb. The western limb here in the suburb of Ainslie is now concealed by buildings.

(2) South of St. John's Church the same horizons of St. John's Church Beds dip east, the angle increasing to the east. It is regarded as the western limb of the syncline.

(3) In Duntroon the St. John's Church Beds (approximately the same horizon again) show a pitch in a northerly direction, and plunge under the unconformably overlying porphyry of the Ainslie suite. It is understood to be portion of a synclinal nose.

(4) The Mt. Pleasant Porphyry, an erosional inlier within the Ainslie rocks, seems to belong high in the St. John's sequence and represents, perhaps, the core of the syncline. Moreover, east of Duntroon, at the bridge over Woolshed Creek, in the classical locality of Rev. W. B. Clarke and de Koninck, a higher horizon of the Riverside Formation crops out, dipping west towards the axis of the postulated syncline. (Fig. 19 and 20.)

Between the abovementioned outcrops at the Royal Military College at Duntroon and Woolshed Creek, the Ainslie Volcanics cover an area large enough to account for the City Hill Shale under similar geometrical conditions. The relationships along most of the eastern limb of the syncline are unknown owing to the volcanic cover. A meridional fault may be present, because immediately west of Mt. Ainslie and Mt. Majura considerably younger beds (Molonglo Formation) prevail and may even represent fragments of a downthrown anticline. (See also "Oakes Fault".)

*Unconformity.* This word on the map marks the unconformity on Capital Hill, between the Black Mountain Sandstone and the Silurian Camp Hill Sandstone (Fig. 4-7 and 31). Other unconformities in Canberra are: (1) at the base of the Middle Ordovician, as discussed under "Black Mountain Axis"; and (2) the unconformity at the base of the Ainslie Volcanics against the eroded surface of the Silurian, which is best observable north of the Ainslie Reservoir, in two creeks south of St. John's Church, at the Military College in Duntroon, and on Mahon Hill. It is not marked on the tectonic map, as it is well represented on the geological map. (See also Fig. 36.)

*University Fault.* A small fracture subsidiary to the Acton Fault cuts the Ordovician Acton Shale cleanly, with drags in the downthrown Silurian, with a throw of 100-200 feet at the junction of the faults. The fault does not affect the concealing sandstones and conglomerates of Permian age (Fyshwick Gravel, glacial). At present the fault is completely covered by buildings.

*Westlake Outlier.* Amongst all the Silurian erosional and structural outliers on the Black Mountain Horst, this has the greatest thickness, with a middle horizon of the Turner Mudstone at the top. The outlier is violently folded, together with the unconformity at its base. (Figs. 21 and 31.) The general structure is that of a syncline deeply sunk into the basement, which consists of Ordovician rocks of Acton Shale (soft, leached, nearly white) in a quarry west of the outlier, followed by a higher horizon of the Pittman Formation at the eastern edge of the outlier. West of the outlier older horizons of the Pittman Formation emerge from below.

*W-Node.* Stands for "Western Node". Three faults meet here in the form of a letter K. The Deakin Fault here throws the Painter Porphyry into contact with the Black Mountain Sandstone (middle sector of the "K") and the Pittman Formation (upper and lower sectors of the "K"). The slopes of Black Mountain are here very steep and correspond to fault-scarps of the Black Mountain faults. The Pittman Formation north of the Node (upper sector of the "K") is a high anticline exposing the deepest known part of the unit with lower Middle Ordovician graptolites. The eastern flank of the anticline dips against the Black Mountain Fault. At the node the Molonglo River attains a steeper grade, passing through the Deakin Fault into the Painter Porphyry. It is interpreted as the site of a former blockage, now eroded, which dammed up the river and created the "prehistoric Molonglo Lake" of Canberra (Fig. 45). The river-gravel on its southern bank is quarried here for concrete aggregate. It is known as the "golf-ball gravel", because the lost balls from the golf-links upstream usually strand here in large quantities. The gravel is obviously Recent.

## Thickness of the Palaeozoic Sequence in Canberra

The total visible thickness of pre-Silurian sediments in Canberra is between 2,400 and 2,700 feet, depending on the thickness of the Black Mountain Sandstone, which is 1,500 to 1,800 feet.

The lower Silurian sequence is known completely, and is 1,400 feet thick. However, at its top, between the City Hill Shale and the St. John's Church Beds, about 150-180 feet of sediments are not exposed, whereby the total is raised to about 1,600 feet.

The estimated thickness of sediments between the City Hill Shale and the St. John's Church Beds is calculated from the attitude of the two units at the Molonglo River crossing south-west of the United States War Memorial (King's Ave.).

Corresponding sediments have recently been exposed in a trench along Constitution Ave. between Reid House and St. John's Church. At Reid House the trench cuts City Hill Shale (grey mudstone, shale with calcareous layers, as is also seen in the excavation for the Olympic Swimming Pool, north-east of Mulwala House); above it, and interbedded with it for a thickness of about a foot, follow slaty red argillaceous shale and mudstone. The dip is 32° to 45° east-north-east, and the thickness may be greater than the figure given above (150-180ft.). The rock is clearly different from the City Hill Shale and the St. John's Church Beds and cannot be referred to either. It still remains sub-surface, and the name is left open. In February, 1956, the Department of Works investigated by drilling the Molonglo River bed opposite the King's Avenue crossing, in connexion with a bridge project. Below some forty feet of surface deposits, soft red shale was met, grading downward into fresh rock. This is a grey and soft laminated and banded clay-shale with pyrite and brachiopods. Calcareous matter is absent.

The visible thickness of the Red Hill Group in Canberra is 850 feet. The base of the Deakin Volcanics is not exposed here, but from other outcrops in the A.C.T. its thickness has been estimated to be 600-700 feet or more, and the Red Hill Group is therefore 1,000-1,200 feet thick.

The Painter Porphyry has a visible (topographical) thickness of 650 feet. Its lower contact, however, is not seen.

To sum up, the total visible thickness of the Silurian sequence in Canberra is 3,800 feet. The real thickness, however, is over 4,800 feet, which is the depositional compaction thickness.

The total thickness of all Palaeozoic pre-Devonian rocks in Canberra is more than 7,200 feet. Owing to the plication, this rock pile may have attained, in zones of intense folding, a mechanical thickness of up to 9,000 feet, or even more.

## Analysis of the Palaeozoic Orogenies in Canberra

The analysis of the orogenies in Canberra is conveniently presented in tabular form (Table 4) and is condensed from another which might be described as "questions and answers". The questions are given in the left-hand column, and the answers follow separately for each of the phases. The questions arose during the field work, during the subsequent study of the observations, and during the many discussions with colleagues. The discussions helped considerably to formulate the questions, and some of the questions are formulated and answered according to the diverse aspects from which the matter can be looked at. This is the case with the Painter Porphyry, which, depending on the aspect of the questions, is "preorogenic", "synorogenic", or "postorogenic", and its interpretation even as "synkinematic" is possible. The angles of dip and pitch as given are not average numbers but measured quantities. However, they are based on a selection (from a greater number of data) of about a hundred measurements which are thought to be significant for the area. For reasons explained in the introduction, this original material is no longer available.

Geometrical data for Black Mountain are not included here because of its exceptional structural position. The author usually describes the structure of Black Mountain in conservation as "a bag of crushed bones" (Fig. 8), and from a number of measurements (about thirty, and not enough for a definite reconstruction), has thought of it as a greatly distorted anticline plunging ten to fifteen degrees to the east-north-east.

## TECTONIC HISTORY

The tectonic and geotectonic significance of the Canberra structures and theii history are briefly treated below. They have to be discussed in connexion with the framework of the southern part of New South Wales. The main line of inquiry is the mode of consolidation. The concept of tectonic consolidation has been elaborated by Stille (1944) on a grand scale, and here it is tested within narrower limits and for a special case. A knowledge of the mode of consolidation, apart from its own intrinsic value, is desirable because of its bearing on the geomorphological history of the country, and it is the basis of an understanding of the present topography of Canberra.

From the foregoing analysis a general evaluation of the relative intensity of the orogenies in Canberra can be made. Thus, the long history of pre-Silurian sedimentation was interrupted, perhaps more than once, by intervening foldings, though they had little effect on the consolidation of this segment of the earth's crust. The last of them, the Canberra Phase of the Benambran Orogeny, was violent and seemingly surficial, releasing a relatively small amount of "high-tension" energy. The Bowning phases, being of lesser violence, affected a greater pile of rocks, and released energy of a great magnitude and lesser tension, and contributed to the consolidation of the segment. The last (Ainslie) phase resulted in mild structures; but because it affected the already consolidated welt, the energy involved was possibly of greater magnitude than before.

The Canberra Phase was only an "overflow", unable to change the course of events. It was, from a geotectonic point of view, a delaying interlude, but the same Benambran epoch was a time of important rearrangements of the regional lithology. No carbonate rocks from pre-Benambran time are known in the region; the sediments are sandstones, cherts, siliceous shales, and some argillaceous shales (in the Middle Ordovician Pittman Formation). This quartzose and silico-lutitic suite is quite abruptly followed in Silurian time by argillo-lutitic, calcareous sediments. The latter, of course, cannot have been derived from the Ordovician suite, which shed its erosional detritus elsewhere during lower and middle Llandovery time, which is not represented by sediments in Canberra. In this connexion it may be noted that Silurian rocks older than the zone of *Monograptus exiguus* are unknown in southern New South Wales, and the writer has elsewhere suggested (Öpik, 1954) that the Tasmanian Lower Silurian (lower and middle Llandovery) Crotty Sandstone may represent, for example, part of the detritus derived directly from the Benambran land. However, the Camp Hill Sandstone and the State Circle Shale in Canberra may be of mixed origin, the former being calcareous, the latter not. They were deposited at a later stage in conditions of subsidence, and therefore are not derived from rocks of their immediate basement but from lands outside the depositional area of the units.

The change in lithology after the Benambran Orogeny can be understood only as a substitution of one provenance by another, different in composition, and it consequently reflects a fundamental change in the palaeogeographical environment in the course of Benambran events. Nevertheless, Ordovician and Silurian sediments in the Canberra region do coincide in one essential aspect: formations of rudites and greywackes of geosynclinal volume are absent in both suites. If



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TABLE 4. Analysis of the Palaeozoic Orogenies in Canberra.

| Questions. / Phases. | Benambran Orogeny, Canberra Phase. | Bowning Orogeny. | | Ainslie Orogenic Phase. |
|---|---|---|---|---|
| | | Yarralumla Phase. | Painter Phase. | |
| *Age* | Beginning of Silurian (lowermost Llandovery) | Lower Ludlow (lower Upper Silurian) and before the Painter intrusion | Lower Ludlow, but after the Painter intrusion | Most probably Middle Devonian (Tabberabberran) |
| *Duration of movement (plication)* | Short; folding and subsequent erosion accomplished before upper Llandovery | Short; perhaps about, or less than, the duration of a graptolite zone | Main movements abrupt and short; final fracturing dying out before Lower Devonian | Of a longer range than previous movements; starting in Lower Devonian, with a peak in Middle Devonian |
| *Character of deposits involved* | Sandstones, various shales, radiolarites, all marine; Ordovician and older | Marine calcareous lutites, limestone, sandstone, volcanic rocks, of Silurian age, and the previously folded basement | As before, but with additional intrusive rocks | As before, but substantially diminished by erosion, with additional volcanic rocks laid down in epicontinental conditions |
| *Volcanic activity during sedimentation and before movement* | None, except for possibly tuffaceous shales at the base of Black Mountain Sandstone | Submarine acid to dacitic volcanic activity steadily increasing with advancing time | Not observed; not preserved because of absence of sedimentation | Ainslie Volcanics, mostly dacites and quartz porphyries |
| *Synorogenic igneous activity* | None | Intrusion of the Painter Porphyry between the two phases. Perhaps even synkinematic | | Ash-eruptions (Narrabundah Ashstone); no lavas |
| *Pre-orogenic intrusions (fore-runners)* | Not observed | Dykes, and a sub-surface intrusion in Fyshwick (Molonglo Hornfels), perhaps of upper Wenlockian age | Painter Porphyry in relation to the Painter Phase | Not identified |

| | | | | |
|---|---|---|---|---|
| *Post-orogenic igneous activity* | Not observed | Painter Porphyry in relation to the Yarralumla Phase | Intrusion of Mugga Mugga Porphyry before erosion of mountains | Not observed |
| *Preceding movements of Palaeozoic age* | Possibly before the sedimentation of Pittman Formation, as reflected in structural relationship of Black Mountain Axis | Canberra Phase and Fyshwick forerunners | Yarralumla Phase | Benambram and Bowning Orogenies |
| *The problem of orogenic sediments involved in, or derived from, the folded sequences* | No conglomerates, but rhythmic clastic sediments suggest tectonic unrest prior to the Canberra Phase | Camp Hill Sandstone and the rhythmic State Circle Shale reflect an unrest at the beginning of Silurian transgression ; no conglomerates | None in Canberra. The conglomerate at Bowning (Yass basin) may be the material derived from the Yarralumla and Painter Phases | Unknown |
| *The problem of overburden* | Uppermost Ordovician rocks were most probably removed before folding (see *Character of cleavage* below) | Yarralumla Formation was covered by deposits of relatively small thickness | Erosion had already started but had removed only an insignificant part of the folded deposits | A considerable quantity of pyroclastics was spread over the area |
| *State of petrifaction of the sediments* | Compaction complete, but only the radiolarites were petrified; Black Mountain Sandstone was petrified at an earlier stage | Ordovician rocks of the basement already petrified and competent as a whole (clean cut by the faults); compaction of Silurian rocks complete, but generally incompetent (drags on both sides of faults) | | Ordovician and Silurian rocks already in their present state. Ainslie Volcanics rapidly consolidated |
| *Average angles of dip* | 60° ; overturning in small folds common | 40°, but ranging between 25° and 55° | Up to 70° in drags of sediments already folded; overturning in reverse movements | 10° to 15°, maximum 20° |
| *Angle of pitch* | Up to 80°, overturning of axis common | 10° to 15°; up to 25° locally | Not recorded numerically, but cartographically observed | Not recorded |

| Questions. / Phases. | Benambran Orogeny, Canberra Phase. | Bowning Orogeny. | | Ainslie Orogenic Phase. |
|---|---|---|---|---|
| | | Yarralumla Phase. | Painter Phase. | |
| *Additional (±) dip superimposed by subsequent folding* | About 30° by the Yarralumla Phase, observed at two localities | Considerable distortion by the Painter Phase, but not measurable | Seemingly no subsequent distortion | None |
| *Angle of unconformity* | 68° and 90° are observed against Silurian strata | Up to 40° observed against Ainslie Volcanics | Faults concealed by Ainslie Volcanics | Sub-horizontal, and up to 20° against the present land surface |
| *Metamorphism* | No regional metamorphism observed in the Canberra Rift ; normal contact alteration at instrusive bodies | | | |
| *Thickness of deposits involved* | 2,500 feet, and base not seen | Over 7,000 feet, but base not seen | | Over 7,000 feet |
| *Character of cleavage* | Generally slaty, but bedding often preserved. Fracture-cleavage in radiolarites and siliceous shales indicating shallow subsurface position. Superimposed slickensides | Generally slaty shear-cleavage stronger than bedding. Fracture-cleavage near the top (Yarralumla Formation). Local slates | Fracture-cleavage, following approximately the lineation of the faults. Narrow gouge in some of the faults | Undeveloped cleavage-lineation in selective zones of stress. Slickensides |
| *Character of plication* | Folds numerous, crowded, close, contorted, disharmonic against the Black Mountain Sandstone suggesting a *decollement* of the Pittman Formation over the former | Large-distance open folds, harmonically involving the previously folded basement. Disharmonic structures locally present | Major folds recognized cartographically as culminations. In an overturned fold south-east of Canberra the basement is involved | Generally large, gentle folds. Folding of latitudinal faults of the same phase. Some of the dips may be local (compensation of eruptions) |
| *Gravitational plication (slumping)* | Non-tectonic submarine slumping common in Black Mountain Sandstone, less common in higher horizons | Non-tectonic slumping observed in places in sandstones of lower Silurian units | No evidence | Some flowage, and slumping in tuffs of the Ainslie suite |
| *Fracturing* | Minor thrusts and strike-faults | Numerous minor faults in higher levels of the pile of rocks | Major faults of areal and regional significance, throws up to 3,000–4,000 feet. Creation of Canberra Rift | Areal faults with throws up to several hundred feet, preceding the plication |

| | | | | |
|---|---|---|---|---|
| *Strike* | North-north-east | Near-meridional. Main axial direction bulging slightly to west, following the lineation of the Black Mountain Horst | Folding-lineation generally near-meridional, main faults north-north-west. Adjustment to the Black Mountain Axis evident | Near-meridional |
| *Direction of push* | From west-north-west | From western sectors | From western sectors. Backward folding to west at a reverse fault | Not sufficiently evident, most probably from the west |
| *Discordance of strike-directions against preceding structures* | Subparallel to the probably pre-existing Black Mountain Axis | Averaging 20° against the lineation of the Canberra Phase | Locally 15°–20° against the lineation of the Yarralumla Phase. Up to 45° against the lineation of the Canberra Phase | Subparallel to the lineation of the Yarralumla Phase |
| *Discernibility (dating) of structures* | Easily distinguished by the character of folding, unconformity, and cartographical relationship. Subsequent deformations locally measurable | Easily distinguished from the succeeding phase by the presence of the Painter Porphyry, and the character of folding | Easily distinguished by the unconformity against the Ainslie Volcanics and by the regional fault pattern | Easily distinguished within the Ainslie Volcanics. In their absence confluent with Bowning structures |
| *Uplift as reflected in the eroded pile of rocks* | About 2,000 feet of plicated sediments were removed before the Silurian transgression | More than the thickness of the Silurian sediments involved (over 5,000 feet) on the Black Mountain Horst, which was the main mountain range, but considerably less in the rift | | No noticeable uplift and erosion after destruction of the mass of the Bowning mountains |
| *Tectonic classification* | Violent surface folding, deeper folding of an unknown character. A stage in the development of a persistent marine mobile basin | Deep-seated movement of moderate violence, concluding a marine history of very long duration and involving a great pile of rocks. No "geo-synclinal" vulcanicity | | Tectonic unrest within an epi-continental environment, as an echo of orogenic movements elsewhere |
| *Consolidating effect on Earth's crust* | No consolidation or decrease of mobility | Consolidation and stabilization. Transformation of the mobile marine basin into a continental block | | Final readjustment of the continental block. No subsequent movements |

there was a common cause for this persistent deficiency, it may have been the non-metamorphosed, or even non-petrified, state of the rocks in both sources. The *marine* palaeogeography of Ordovician and Silurian times in New South Wales is fairly well known; the two different *lands* are still to be searched for.

A geotectonic classification of the geosynclines represented in Canberra cannot be ventured on the evidence from this small sample. Nevertheless, some aspects encountered in Canberra may contribute towards the understanding of the whole of the region. One may think of an Ordovician miogeosyncline (without igneous rocks) which after the Benambran paroxysm attained the character of a eugeosyncline, but with acid igneous activity only. The absence of igneous rocks in the Ordovician of Canberra was certainly only local, for, in the southern extension of the belt, andesites occur in the Kiandra Beds of the Snowy Mountains.

The Kiandra andesites, however, are volcanic rocks, and nothing is known to suggest an intrusive, basic, ophiolitic activity in the Snowy Mountains and their northern extension. The andesites are of Middle Ordovician age; the Upper Ordovician is free from volcanics, and no volcanics are known in the Llandovery in connexion with the Benambran diastrophism and its subsequent interval. Dykes and other subsurface intrusions are also unknown. The Silurian sequence in Canberra, taken alone, is hardly a post-Benambran eugeosyncline; it is without basic igneous rocks and is of moderate thickness, by itself. It is superimposed on Benambran structures, but these are not of sufficient magnitude to justify the term epi(eu)geosyncline (Kay, 1951) for the subsequent Silurian conditions.

The geosyncline in question seems to consist of a number of segments, each of which may represent a different class. In Canberra, the Ordovician sequence may be miogeosynclinal; but at Kiandra more than miogeosynclinal qualities can be seen, and other segments may even prove to be eugeosynclinal. The geosyncline as a whole, therefore, cannot be readily fitted into any existing classification. The Ordovician and Silurian history of the Canberra region is best understood as an unbroken chain of events. It is the history of a polycyclic geosyncline, or perhaps an orthogeosyncline (for the meaning of terms see Glaessner & Teichert, 1947), evidently ranging from the Cambrian to the end of Silurian time. It shows many individual peculiarities and deficiencies, a long history, and a contrast of final consolidation achieved seemingly by a relatively moderate Bowning deformation. It is, perhaps, an illustration of Kober's (1928) "Australian tectonic style". Kober has not formulated or amplified this concept, which is a conclusion drawn from a brief consideration of the Caledonian, i.e., the lower Palaeozoic, orogenic history and structures of south-eastern Australia. It is also beyond the scope of the present paper to investigate the meaning of the term "Australian tectonic style", but the possibility of its existence is kept in mind during the following discussions of the role of the plication and igneous activity in the consolidation of the Canberra Welt.

The plicated cover of non-metamorphosed sediments in Canberra is certainly not the seat of the consolidation, which belongs to deeper levels of the earth's crust. So the solidity of the Canberra region in post-Silurian time cannot be understood from the structures seen on the surface in Canberra; the surrounding horsts. where deeper tectonic levels are to be seen on the surface, have to be taken into consideration. The statement made above, that the consolidation was "achieved seemingly by a relatively moderate Bowning deformation", refers only to the conditions in the Canberra Rift, where intrusive rocks are insignificant. In the horsts to the east and west of Canberra, whose present surfaces correspond to a mile or more beneath the level of the Canberra Rift, granitic bodies are dominant so that in the Rift beneath the plicated cover of Silurian rocks, granite may be present also. Evidently, not the plication alone, but the granites also, are the consolidators of the Welt.

If "orogeny" refers primarily to folding or plication of rocks, the consolidation of the Canberra Welt was not the result of an orogeny, but of what one might call a "granitorogeny", of the Bowningian epoch. On the other hand, it is very doubtful if granitic activity accompanied the Benambram disturbance. There are several reasons for such an assumption:

(1) The Benambran movement was essentially a plication not followed by consolidation, which may be explained as a sign of the absence of granitic consolidators.

(2) Volcanic rocks are missing in the Upper Ordovician of south-eastern Australia, which may indicate a general igneous inactivity at that time. This is in marked contrast to the very prominent acid vulcanicity of the Middle and Upper Silurian, that is of the Bowningian epoch.

(3) The granites believed to be Benambran in age (compare Browne, in David, 1950, Vol. 1, p.171) and synchronous with this folding, *are in contact with, and have metamorphosed, the already-folded uppermost Ordovician rocks,* as for example, the black shales with *Pleurograptus linearis* in the Cooma region. Such granites must have had a roof of Silurian rocks and are post-Ordovician.

(4) Where metamorphosed Silurian rocks are seen in contact with granites, they are not older than Middle Silurian if compared with the sequence in Canberra.

It seems, therefore, that only the Bowningian epoch was a "granitorogeny". There may have been forerunners, as discussed above for the Fyshwick Dome (page 71), where an advance of the granites is indicated as early as middle Silurian time. This advance contributed to the mobilization of the crust, which, in turn, resulted in plication. In the wake of the compressional phases of the Bowningian epoch, numerous spearheads of granites rose into higher levels of the crust. To conclude, the granites mobilized the earth's crust; the folding was a by-product of the granitic mobilization; the solidification of the subsequent granites finally demobilized the affected belt; and the consolidation of the Welt was accomplished.

It is generally accepted that phases of folding require a fraction, of a magnitude of $10^5$ years, of a geological period. This applies strictly to the compressional phases, and is once more illustrated by the Canberra Phase, where the erosion before folding, the folding itself, and the subsequent erosion and inundation, took place in the lower and middle ages of the Llandoverian Epoch. The consolidating Bowning events, however, cover not a small fraction, but nearly the whole of the upper half, of the Silurian Period, and may even have reached into the Lower Devonian.

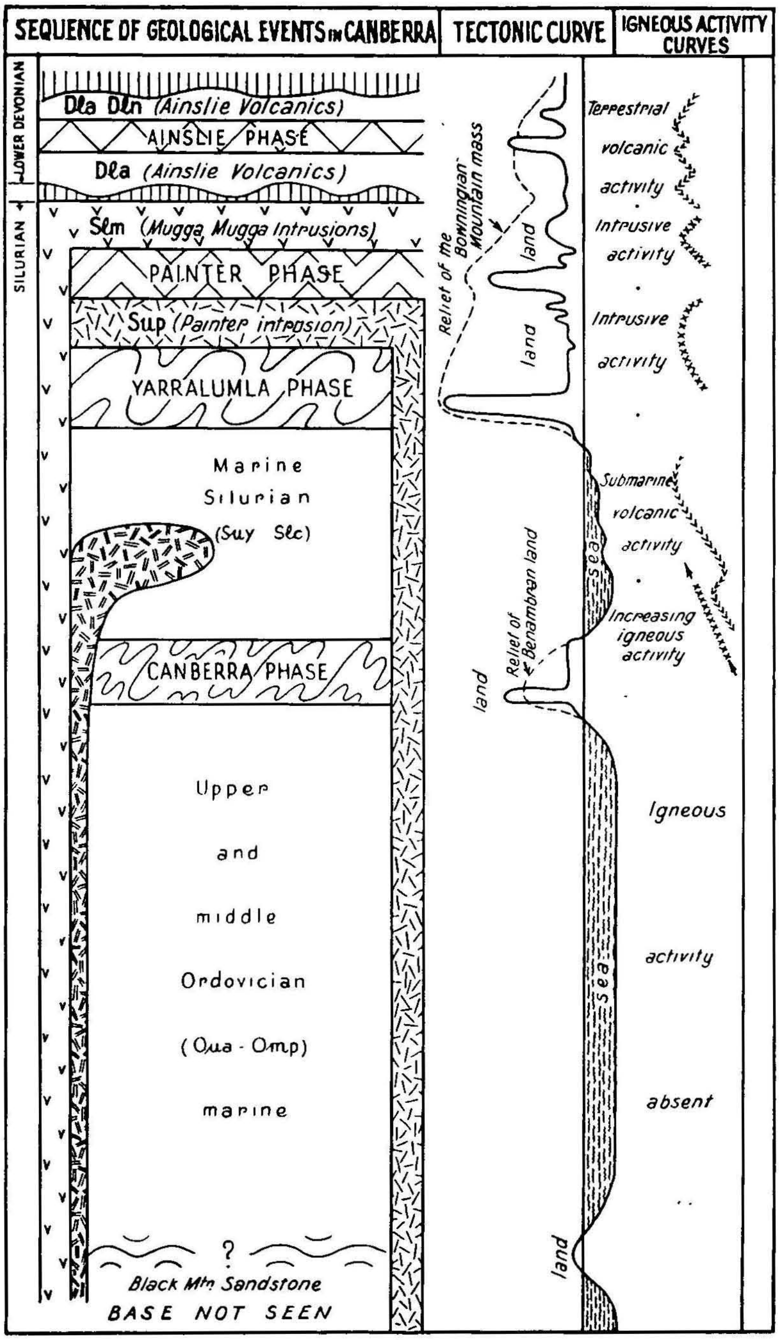


**Fig. 46.** Summary diagram of Palaeozoic history of Canberra.

# CORRELATION

## Stratigraphical Correlation

### *Ordovician*

The Ordovician sequence of Canberra, comprising the Pittman Formation and the Acton Shale, contains graptolites of universal significance. The correlation of these units is given in their description (pp.12, 13, 15-18); it is based on index-fossils and characteristic assemblages and is accurate.

Notwithstanding the last statement, the Pittman Formation is dated only by two graptolitic horizons — the lowermost observed horizon and the uppermost horizon; the zoning of the intervening sequence cannot be ventured until all the fossils are determined. Present evidence indicates continuity of sedimentation within the Pittman Formation in its main area (the Belconnen Synclinorium), but two possible exceptions may be noted: first, the possible overlap of the lower beds of the Pittman Formation over the Black Mountain Axis, and secondly the contact of the Acton Shale against radiolarites of the Pittman Formation at the Belconnen Reservoir, north of Canberra (off the map). In all other areas, radiolarites mark the middle of the Pittman Formation, and, if this observation is geologically significant, upper beds of the Pittman Formation may be missing here. On the other hand, no evidence for a break or strike-fault is known, and, moreover, the distribution of radiolarite beds is somewhat erratic — locally they may have been developed in higher horizons as well as the known horizons about the middle of the Pittman sequence.

Table 5 shows a correlation by graptolites of the pre-Silurian sequence in Canberra with the British Ordovician sequence and the Victorian Ordovician stages; a tentative correlation with the sequence of the Snowy Mountains is also shown. The formations in Canberra cannot be comprehensively correlated with corresponding rocks in New South Wales, because the Middle Ordovician of that State is not adequately known. Nevertheless, as Canberra and the Snowy Mountains region belong to the same depositional belt, a comparison between the two may illustrate what can be expected in the subsurface in Canberra.

The Snowy Mountains sequence was originally established and published by Fairbridge (1953), but two modifications of his interpretation appear in Table 5: first, the name "Kiandra Beds" in Fairbridge's interpretation also covers the Bolton sequence, which is here considered as a separate formation; and, secondly, Fairbridge's original designation "Bolton Greywacke" is altered to "Bolton Formation". The second change was made by the present author (Öpik, 1952a) because of the wide range of rock types; (below) chert, slate, quartzite, and even limestone, followed (above) by a more-or-less uniform rhythmic sequence of grey, fine-grained quartzite and dark slate; the upper quartzite contains a visible amount of dark minerals which may be of volcanic, as well as clastic, origin. The writer considers that none of the many definitions of "greywacke" corresponds to the diversity of well-stratified, sorted, and very fine-grained Bolton rocks; besides, "a greywacke formation 8,000 ft. in thickness" is a description of quite formidable consequences in the interpretation of the folded belt, suggesting conditions of sedimentation similar to established greywacke formations elsewhere.

Only within the limits of the Eastonian and Gisbornian is the correlation



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TABLE 5. Ordovician correlation between Canberra and the Snowy Mountains region (modified from Öpik, 1952a).

| British zone nos. | Victorian stages. | Canberra formations. | Graptolites in Canberra and Snowy Mountains sequences. | Rock sequence in Snowy Mountains region. |
|---|---|---|---|---|
| 13 | Bolindian | | *Pleurograptus linearis* | Wambrook Creek, |
| 12 | Eastonian | *Acton Shale* (over 200 feet) | *Dicranograptus hians*, *Climacograptus caudatus*, *Dicranograptus nicholsoni*, *D. ramosus spinifer*, *Dicellograptus elegans* | and in black shales, upper part of *Adaminaby Beds* |
| 11 | | | | |
| 10 | Gisbornian | | *Dicellograptus sextans*, *D. divaricatus salopiensis* | Upper part of *Kiandra Beds* |
| 9 | | | | |
| 8 | Darriwilian | *Pittman Formation* (700 feet) | *Climacograptus* cf. *scharenbergi* | *Kiandra Beds* (chert, tuff, lava, shale, etc.), comprising the Temperance Chert and Nine Mile Shale (perhaps over 10,000 feet) |
| 7 | | | | |
| 6 | | | *Trigonograptus ensiformis*, *Phyllograptus anna*, *Pterograptus*, *Isograptus*, *Didymograptus* | |
| 5 | | | | |
| | | ? break | | |

| | | | | |
|---|---|---|---|---|
| | | *Black Mountain Sandstone* | | Upper part of Bolton Formation |
| | | (1,500-1,800 feet) base not seen | No diagnostic fossils | *Bolton Formation* (about 8,000 feet) |
| | | | | *Bald Mountain Creek Portal Beds* (position in sequence inferred) |
| | | | | *Tumut Pond Beds* |

between Canberra and the Snowy Mountains completely based on fossils; from here downwards no fossils are known in the Snowy Mountains except worm-tracks. The correlation of the lower part of the Pittman Formation, which is dated by fossils, and the Kiandra Beds, which are not, and which are, moreover, nearly twenty times as thick, is suggested only by the presence of cherts and the absence of breaks in both sequences. Deeper down, no real basis for a correlation exists, and, as with the Black Mountain Sandstone in Canberra, the question of the lower limit of Ordovician rocks in the Snowy Mountains sequence and the presence of not-yet-detected breaks becomes unavoidable. This question has been discussed to some extent by the author (Öpik, 1954), who concludes that a Cambrian age of the lower part of the Bolton Formation and the Tumut Pond beds (sandstone and green phyllitic shale) is possible.

*Silurian.*

The correlation of the Silurian rocks of Canberra is less accurate than the Ordovician. They are referred to as lower, middle, and upper Silurian, but these subdivisions are not to be regarded here as standard epochs. It is a general time-scale, without defined boundaries, and therefore only of an arbitrary character.

The geological age of the basal part of the Silurian sequence in Canberra is alone free from ambiguity, owing to the occurrence in the State Circle Shale of an association of *Monograptus turriculatus, M. spiralis,* and *M. exiguus.* Above the State Circle Shale the uncertainty of the age-interpretation increases with increasing stratigraphical distance from the *exiguus* shale.

The Riverside Formation, for instance, contains fossils which show a relationship with the shelly fauna of the Victorian "*Illaenus* Band" at Heathcote (Öpik, 1953), which, by its graptolites, is dated as upper Llandovery (though not the uppermost). Consequently, to cover the upper part of the Llandovery, the City Hill Shale is regarded here also as "lower Silurian". It may be mentioned that the fauna of the Riverside Formation, in its ostracods and some brachiopods, resembles the Amber Slate (Shale) of north-western Tasmania (Gill & Banks, 1950), which is also very near in time to the Victorian "*Illaenus* Band".

It is perhaps significant also that in the Canberra Group the Lower Silurian *Pentamerus* s. str. occurs, and *Rhipidium* is common in its lowermost unit (Camp Hill Sandstone). These pentamerid brachiopods are significant in the Lower Silurian of the Northern Hemisphere.

The purpose of middle Silurian deposits above the City Hill Shale is beyond doubt, but the boundary cannot be delimited accurately. No graptolites occur, and an estimation of the age has to be based on shelly fossils which are not yet described. Accordingly, the Molonglo Formation is regarded as being high in the Wenlock, because it contains an abundance of the coral *Halysites,* which is unusual in the Ludlow, and a pentamerid, *Conchidium* (near "*C. biloculare*"), has its first appearance here. The *Conchidium* indicates approximately an upper Wenlock to lower Ludlow age, and the abundance of *Halysites* gives preference to the former. The above observations apply also for the Mahon Formation.

The next higher unit, the Red Hill Group, is interpreted as lowermost Ludlow (Upper Silurian). This is important because the Red Hill Group (its upper, Yarralumla Formation) is the last marine deposit in Canberra, on the age of which depends the age of the beginning of the Bowning Orogeny in this area. The age-determination of the Red Hill Group is based on the following palaeontological observations; first, in the Deakin Volcanics, at a locality known as "Sewer Hill" approximately four miles west of Canberra, a brachiopod very near to *Atrypella prunum* (Dalman) of the lower Ludlow of Europe has been found — this form goes as high as the middle of the Yarralumla Formation; and, secondly, *Atrypella* is also present in the Silurian of Yass; it occurs above the Bowspring Limestone (with *Conchidium*), in the "*Barrandella*" Shale, the top of which grades into the coralline Hume Limestone. The *Atrypella*-assemblage, however, does not extend into the latter. It seems, therefore, that the Red Hill Group, according to the present state of knowledge, is likely to be roughly contemporaneous with the "*Barrandella*" Shale and the Hume Limestone of Yass. Both the above-mentioned units of Yass, however, are clearly below the graptolite beds with *M. bohemicus* and *M. nilssoni*, which are also lower Ludlow. The Silurian of Yass is the best-known in New South Wales owing to the work of Brown (1941); and a correlation with another, less well known, area would be even more tentative.

### Tectonic Correlation

The tectonic correlation of the Canberra area may be discussed from the following aspects: first, the spatial extent of the structures of Canberra outside the area and the relationship with belts of structures perhaps not directly connected with Canberra; secondly, temporal correlation of the phases in Canberra with similar events in southern New South Wales; and thirdly, the correlation of the orogenies within an Australian and a general geotectonic time-scale.

The Yass basin contains the type-area of the Bowning Orogeny (Browne, 1949), and in view of the stratigraphic correlation between Yass and Canberra, a similar correlation of orogenic events betwen the two regions may be ventured also.

Marine sedimentation was interrupted considerably later in the Yass basin than in Canberra, and considerably later than the lower Ludlow graptolite zone with *Monograptus nilssoni*. The final sediment here is a coarse conglomerate with pebbles of Silurian igneous rocks and, most probably pre-Silurian, quartzite. This conglomerate can be regarded as being derived from a Silurian orogenic belt which arose somewhere in the vicinity. The author considers that the Canberra upper Silurian orogenic belt extended in a north-north-easterly direction, perhaps towards Goulburn, leaving untouched the Yass basin west of it. This orogenic belt, built up in Canberra essentially by the Yarralumla and Painter Phases, was the source of the conglomerates preserved in the centre of the Yass basin. A later movement, however, produced the structures of the Yass basin itself, and is responsible for the unconformity of the Lower Devonian rhyolite of Bowning Hill against the gently folded Silurian rocks, which include the final conglomerates as well. Hence the concept of Bowning Orogeny refers to a type area in which a conglomerate derived from the erosion of the structures of the two early phases (Yarralumla and Painter), and a third late phase testified by an unconformity, represent the record.

The Yass basin, although so close to Canberra, nevertheless shows a development of sediments so different that the question arises as to whether there existed a barrier of older rocks between them. The faunal picture is also different, rendering a correlation rather difficult. The plication of the Yass basin is mild; shear-cleavage is undeveloped, though fracture-cleavage is general in the shales. The latter may be an indication of a shallow overburden at the time of the orogeny. The western limb of the syncline is more strongly folded, suggesting, as in Canberra, a push from the west. However, the folding of the Taemas Middle Devonian orogenic belt, only a few miles west of the Yass Syncline, may have subsequently distorted the edge of the previously folded Yass Syncline.

It seems that in the Yass region the Bowning Orogeny was not a consolidating event, because the region was already nearly consolidated before the Silurian transgression. Therefore, the Silurian of Yass was deposited on a semi-consolidated block of earlier date, whereas the Canberra belt of Silurian rocks had a considerable mobility. At the beginning of the Bowning Orogeny (Yarralumla Phase) the Yass block was a part of a conductor of the tectonic push, but after the consolidation of the Canberra belt it was itself deformed by a late Bowning paroxysm, because at that time there was left no mobile belt to receive alone the full force of the tectonic stress.

The Yass and Canberra regions represent two clearly different tectonic environments, and it may also be expected that the volcanic history of the two was different. Consequently a coincidence in time of individual Silurian volcanic events in Yass and Canberra is doubtful, and the volcanic rocks, even where they are petrologically similar, are a treacherous ground for stratigraphical correlation, unless a continuity of the rock-bodies in space is verified.

For a correlation between Canberra and the Goulburn district, information found in the paper of Naylor (1949) seems most significant. According to Naylor, graptolites of an extreme Upper Ordovician age are present in the Goulburn district; an horizon which is assumed to have been eroded away in Canberra partly before, and partly after, the Benambran disturbance. The Silurian Jerrara Series of the Goulburn district corresponds lithologically and palaeontologically to the State Circle Shale in Canberra. A palaeontological break between the uppermost Ordovician and the Jerrara Series (upper Llandovery) is evident in the Goulburn district, but, according to Naylor, the two were folded together in late Silurian time, and no evidence is present as yet for a Benambran folding there. The absence of an early Silurian orogenic phase and the possibility of a corresponding temporary consolidation may explain the subsequent violence of the structural deformation of the Goulburn Siluro-Ordovician belt in Bowning time. Moreover, according to Naylor, rocks with *Monograptus bohemicus* are involved in the Bowning structures of Goulburn, which indicates phases of a later date than the Yarralumla Phase in Canberra. The dating of orogenic events in the Goulburn district presents some difficulties: a long break between the folded Silurian and the Upper Devonian rocks renders the dating of the Bowningian movements on this area less precise, and, in combination with the observations cited above, suggests that the Bowning Orogeny may extend into the Devonian in this particular area.

It is hoped that detailed stratigraphical, palaeogeographical, and tectonic analysis of the lower Palaeozoic belt of Goulburn will greatly help the understanding of conditions in Canberra as well.

Comparison of the tectonic histories of Canberra, Yass, and Goulburn, within the available information, supports the concept of the Bowningian Orogeny as an epoch of regional tectonic mobility of considerable duration, culminating in the form of localized compressional paroxysms (phases), which did not coincide in time, but which may have occasionally overlapped geographically.

An approximate correlation of the orogenies of early Palaeozoic time in eastern Australia and the Northern Hemisphere has been treated by many authors, and very little can be added to the discussion from the experience gained in Canberra. The oldest disturbance, that between the Black Mountain Sandstone and the Pittman Formation, which is only postulated, might be Lower Ordovician in age. This would correspond in time to an early Taconic, where "Taconic" means only "within the Ordovician", without further implications. It might even have been the Tyennan Orogeny of W. R. Browne, which, according to him (1953), took place in Upper Cambrian time. The Tyennan Orogeny refers originally to the unconformity of Lower Ordovician rocks against the Precambrian in central Tasmania, where non-deposition, or erosion of previously deposited Cambrian rocks, may be the alternatives. However, no structures that could be regarded as evidence of an orogeny in its fundamental meaning are preserved. In north-western Tasmania (Öpik, 1951a, 1951b, 1951c, 1952b), the Middle Cambrian is well represented, followed by Upper Cambrian deposits, the lower half of which are dated by fossils. Thus, there is some space left for an Upper Cambrian or Tremadocian orogeny, although in its "type" area "Tyennan" refers essentially to the non-deposition in central Tasmania, followed by a marine transgression at the end of the Upper Cambrian or during the earliest Ordovician time. Of the same character is, perhaps, the contact of the Black Mountain Sandstone and the Pittman Formation. To say more is not yet possible from the available evidence.

The Benambran Orogeny, or its (lowermost Silurian) Canberra Phase, has no "contemporaries" in the outer world; but its age, if viewed from a global aspect, halfway between the Taconic sequence of paroxysms and the Upper Silurian phases, makes a demarcation between the Taconic and Caledonian Orogenies somewhat illusory.

The Bowning Orogeny has even been called the Caledonian Orogeny, because of its time-range; but a coincidence in the dates of the phases in Canberra with the Ardennan Phase, or the later Erian (Hibernian) Phases, of northern Europe is not evident, and so even here a real correlation in time is not certain.

Of course, any dating is inaccurate, and even improbable marginal dates, chosen in the pursuit of an otherwise not apparent coincidence of the phases, can be proposed. However, this would add nothing to the solution of the problem of a common cause of events so remote geographically; the common cause might be doubtful even if the timing were perfect. There is still not enough proof that an "orogenic epoch" covers a global entity of events. The crust is heterogeneous in the distribution of material and energy: it is in a state of perpetual preparedness for tectonic action wherever, and whenever, the limits of mechanical resistance are exceeded. This seems to be the ultimate common cause. Regional, not global, developments, however, seem to be responsible for the transgression of the limits, and these may occur in disconnected parts of the world either simultaneously, or apparently simultaneously, or at different times. But they are independent one from another.

Universal application of the names of orogenies or orogenic epochs is not yet the universality of particular orogenic development; it is a nomenclature of a geological time-scale based on tectonic, rather than biological, events. The calibration is imperfect; the dating of the tectonic phases is generally possible only within "epochs", which are not quite compatible with the divisions of the standard time-scale, and therefore tectonic events have to be referred to a scale of such epochs. In this sense the Caledonian Orogeny (the event) and the Caledonides (the structures) may be an entity in Europe, while the Australian Bowningian events and structures are another entity, and so they have different names. The Caledonides, however, became the "type" of the "Caledonian Orogenic Epoch", which is a division of the tectonic time-scale, and a "Bowningian Epoch" is therefore a synonym of the former.

The Ainslie Phase cannot be dated accurately; its dating is based essentially on its geographical proximity to the Tabberabberan trends to the west. The Tabberabberan disturbance is upper Middle Devonian in age, and a number of Middle Devonian phases or "epochs" are already known and available for correlation (for example, Brunswickian in North America; Orcadian in Europe). However, the Middle Devonian orogeny in Australia seems to form a later link in the sequence of the Bowningian phases, as is shown by the following considerations: first, the Tabberabberan belt reveals "epi-geosynclinal" relations with the foregoing pre-Devonian activity, where the time-interval is relatively short; and, secondly, even between the two orogenies, in Lower Devonian time, some unrest seems to have been present. Thus all the phases seen in this part of New South Wales can be viewed as an historical development within the region, without being divided into separate entities. Of course, the recognized orogenic epochs, if regarded as divisions of the regional tectonic time-scale, still remain the convenient "compartments of reference".

## GEOMORPHOLOGY OF CANBERRA

### *Present status of the problem*

The Canberra District, as represented on the present detail maps, is too small a segment to have the history of its land-surface explained from its own geological records and topography alone: but the Canberra region, as outlined in Figure 3, is a large enough unit for geomorphological study. Its peculiarity consists in its being an approximately oval (closed) rift, which determines its erosional history as contrasted with the history of the surrounding uplifted horsts. Moreover, it is to be expected that the tectonic environment of a large rift is in principle different from conditions prevailing in horsts. Therefore any interpretation of the geomorphology of Canberra, or even of the whole of the Canberra Rift, cannot be applied to areas outside the Rift, as was done in the past, although the rift-structure was already recognized (Woolnough, 1938).

The current, and generally accepted, concept of the geomorphology of Canberra was created by Taylor (1910, 1913). Taylor's own reserved evaluation of his concepts is illustrated by himself as follows: "These hills are termed monadnocks by geographers. Something of this nature has probably given rise to the knobs of Ainslie, Mugga, Taylor, etc., but *till the geology of the Territory is investigated, this cannot be satisfactorily proved*" (Taylor, 1910, p. 9; italics AAÖ's). In Taylor's time the geology of the country was unknown, and its topography had to be explained with the aid of a minimum of geological premises. The topography was explained by Taylor, although his premises proved to be unreal. The history of the features of the land-surface of Canberra, as outlined below on the basis of geological evidence, is very different, but the topography itself is still the same. Obviously, similar topographies may arise from very different chains of events, and a given topography may be explained also with the aid of premises different by choice. Thus, another way towards an explanation is the investigation of the geology, as already stated in Taylor's sentence above.

An exhaustive geomorphology of Canberra cannot be produced at the present stage, because the geology of the whole of the Canberra Rift is not yet adequately known. The material collected and partly presented in this paper has also been gathered essentially for a geological purpose, and needs to be greatly extended for a geomorphological treatment of the matter.

However, a criticism of Taylor's premises in the light of these geological investigations will be useful, as will a short recapitulation of the geological history, as reflected in the present topography of Canberra. It seems also that Taylor (1923) abandoned some of his earlier concepts, but did not amplify the modification.

*Criticism of Taylor's premises*

1. To explain the topography of Canberra, two sub-parallel faults were postulated by Taylor: the Murrumbidgee Fault and the Cullarin Fault. The Murrumbidgee Fault exists as a visible major structure (Fig. 3): the Cullarin Fault, along the Cullarin Scarp (Taylor, 1910), still remains postulated, and its magnitude is unknown; it may, however, be omitted altogether from consideration, for it marks the eastern edge of the Cullarin Horst and is clearly outside the Canberra geomorphological region. The second defining fault of the Canberra Rift is not the Cullarin Fault, but Sullivan's Line, which was unknown to Taylor. The faults are not sub-parallel but converge into a closed rift-structure.

No mention of the magnitude of the faults has been made by Taylor, but displacements of the order of five hundred feet are necessary to satisfy his morphological views. Mahony & Taylor (1913, p.17) indeed mention that the movements were "to the extent of hundreds of feet", but the displacements along the faults as presented in the present paper are of thousands of feet — too great to explain the morphology under discussion, because Taylor's theory operates with topographic elevations originally not exceeding 800 feet.

Another interpretation of the structure was later introduced by Taylor (1923, p. 5, fig. 1), where a fault is postulated between the Cullarin Scarp and Canberra, but considerably east of Sullivan's Line. The Cullarin Horst is here separated from the Canberra "tilt-block", and some similarity to the present concepts is apparent.

2. Taylor (1910, fig. 15) shows the Canberra Fault block as being tilted; but at the Murrumbidgee Fault and at Sullivan's Line Silurian rocks of one and the same age occupy approximately the same topographical level. If all possible circumstances are accounted for, an insignificant tilt in the direction opposite to Taylor's may even be present. The tilt is also not compatible with his later concept of the structure as mentioned above (Taylor, 1923, p. 5). However, Taylor has not amplified his new concepts, which are presented only in a text-figure.

3. The Black Mountain Horst of Canberra, as a structural unit, with its faults (Deakin and Acton Faults), was unknown to Taylor.

4. The age of the faults was postulated by Taylor to be Pleistocene or late Tertiary, which implies that the present topography is very young indeed. According to Taylor (1910, p. 10), the Cullarin Fault "is dated at approximately fourteen thousand years ago. Probably this is too recent, and twenty or thirty thousand would be a better estimate". The premise of a sub-Recent age of the topography allows, or even demands, the same age for the faults.

However, the fault of Sullivan's Line and the Deakin Fault are in places concealed under Lower Devonian volcanic rocks, and the Acton Fault is covered by Permian fluvioglacial deposits. All the faults of the region seem to belong to the same structural set as Sullivan's Line and the Deakin Fault (the Painter Phase of the Bowning Orogeny); they are Silurian, and have been inactive since Devonian time. No record of younger differential movements to support Taylor's premises for an explanation of the drainage-system has yet been observed in Canberra.

5. The higher hills in and around Canberra (Mt. Majura, Black Mt., Mt. Ainslie, Mugga-Mugga, Taylor, and One-Tree) represent, according to Taylor, a summit-level, as a residual of an ancient and now dissected late-Tertiary peneplain of a former 3,000-foot elevation. Even a rough computation of the present summits shows that (a) there are six summits with altitudes between 2,650 and 2,900 feet, which, in relation to the plain (altitude about 1,850 feet), represents a considerable irregularity of the relief and not a uniformity of height, as is stated by Taylor; (b) the number of summits increases significantly towards medium and low (1,900 - 2,000 feet) heights, and (c) any chosen arrangement of the summits shows no preference-levels in the sense of a former "peneplain". There is no evidence preserved in the topography of Canberra for any other initial land-surface than the mountain-mass of the Bowning Orogeny.

6. The high-summit hills of Canberra are monadnocks, according to Taylor (pp. 8 and 9, fig. 11), *because they are derived from* an ancient peneplain (italics A.A.Ö). In this case they are in effect residuals of a peneplain, or, more likely, residuals of a mountain mass. They cannot be at once monadnocks and residuals of one and the same peneplain, because monadnocks are hills on a peneplain. The Canberra hills may be monadnocks only in relation to the co-existing present land-surface, if the latter is a peneplain.

The present land-surface has a mature relief but is not yet a peneplain, because its topography reflects the geological structure, even in detail. As long as fault-scarps (for example) can be recognized, as in the Canberra region, the term "peneplain" cannot be applied. Even according to Taylor himself the present land-surface in Canberra is a rejuvenated "late mature" surface.

The theoretical, text-book picture of a peneplain implies a land with a rolling surface and a wide horizon, with few, if any, widely isolated hills, the monadnocks. The landscape has another aspect in Canberra. Here the view is crowded with hills, which stand close together, with the mountain ridges of the horsts in the distant east and west (Fig. 1). From an elevated point also the observer will be able to recognize the hilly plainlands of the floor of the rift, and the surrounding mountains of horsts. As long as the Canberra Rift as a structure is morphologically recognizable it is not a peneplain. Woolnough (1929; 1938) has developed the ideas of Taylor, but the criticism above covers his ideas also, which therefore need no additional discussion.

*History of the Topography in Canberra*

Land conditions have twice been created in Canberra. The first existed in Lower Silurian time as a result of the plication and uplift during the orogeny of the Canberra Phase. It is a fossil land-surface, fragments of which are incorporated in the next land-surface, which arose at the end of Silurian time and from which the present topography is inherited.

For brevity, the first land is referred to as "Benambran", the second as "Bowningian".

The Benambran land-surface is visible in the present Black Mountain Horst, north and south of the mountain, and is therefore a part of the present surface. Its existence in the area is recognized from the presence of outliers of basal Silurian sediments. The Benambran fragments are distorted, of course, and are in the process of erosion, but so also is the surrounding land. Black Mountain itself was already in existence as a prominent hill at the end of the erosional time of the Canberra Phase, and, if the Benambran land reached the state of a peneplain, the mountain was a monandock in the Lower Silurian. Therefore Black Mountain is the oldest hill of the present topography. Only Mt. Jerrabomberra near Queanbeyan may be of the same age and origin. The Benambran land was subsequently buried under Silurian marine sediments.

The Bowning orogenic phases built up a mountain range and generally destroyed the buried Benambran land-surface. However, fragments of the latter retained, accidentally, a horizontal position in the earth's crust and were re-excavated later by erosion.

The present topography is derived essentially from the Upper Silurian Bowningian mountain mass, and a rough guess can be made as to the magnitude of the latter within the Canberra Rift and Canberra itself.

The Yarralumla Formation, west of the Black Mountain Horst, is the youngest deposit known to be involved in the Orogeny. It shows marks of surface folding, indicating that during the Orogeny the pile of rocks above it was not very thick. Most of the surface of the Rift west of Canberra consists of the Deakin Volcanics and the Painter Porphyry, which also belong to the uppermost part of the Silurian sequence. Obviously the Bowningian erosion removed only the top layers of the plicated rocks, somewhat levelled the surface, and left the greater part of the pile untouched. Therefore, the mountains here were not very high with altitudes averaging the present height of Canberra above sea-level (2,000 feet) plus the plicated thickness of rocks eroded away. In Canberra itself, however, Lower Silurian rocks are on the surface, indicating a greater uplift of the mountains, and in the Black Mountain Horst the Silurian pile is removed completely. The latter was the highest mountain ridge in the Rift, with a maximum potential altitude of 7,000 feet above sea-level. But with the erosion working against the orogeny in action, this altitude was, of course, never attained.

From the mountain mass of the Bowning Orogeny a land-surface was modelled, with the following, still-existent, topographic features :

(1) the Black Mountain Horst, and the mountain itself, which may, or may not, have been monadnocks once, at one or another stage between the end of the Silurian and the present time;

(2) Mugga Mugga and the Red Hill ridge, which are nothing but small residuals of resistant rocks without the characters of a monadnock (e.g. the residual of a dividing range of several rivers) ;

(3) the Canberra Plain with a rolling topography, owing to the softness of the non-metamorphosed calcareous shales, but with low hills of Silurian igneous rocks such as, for instance, Mt. Pleasant.

The Bowningian land in Canberra was temporarily buried under terrestrial volcanic rocks (Ainslie Volcanics) in Lower Devonian time. The subsequent erosion removed most of the pyroclastics and left behind, as a residual, the Ainslie-Majura-Gooroo ridge.

The Ainslie ridge is not derived by erosion from an initial regional juvenile mountain mass but marks only an episode on a pre-existing land-surface without any genetic connexion with the original erosional topography; the volcanic ridge can hardly be called a monadnock. The volcanic event was, moreover, too small to be regarded as an interruption of the normal course of erosion.

The distribution of the Ainslie volcanic rocks (including the Narrabundah Ashstone) on the Canberra Plain is the main evidence that the present topography was already in existence in Lower Devonian time except for the volcanic ridge itself. The latter is the youngest addition to the topography of Canberra and is still Palaeozoic.

The Permian glaciation had little effect on the topography. Its deposits were seemingly of small thickness and became eroded, but the erosion was unable to rebuild the established pre-glacial topography. What followed was a retarded erosion and recession of the hill slopes, mainly in the form of removal of weathered material, and, in the plains, local and temporary sedimentation which went on intermittently with shifting and removal of the same deposits, according to the variations of climate and rainfall.

To conclude, the present topography of Canberra is derived from the Upper Silurian mountain mass of the Bowning Orogeny; it had already attained its maturity in the Devonian, and, owing to its position in the rift, became retarded in its erosional development, retaining the state of maturity more or less indefinitely.

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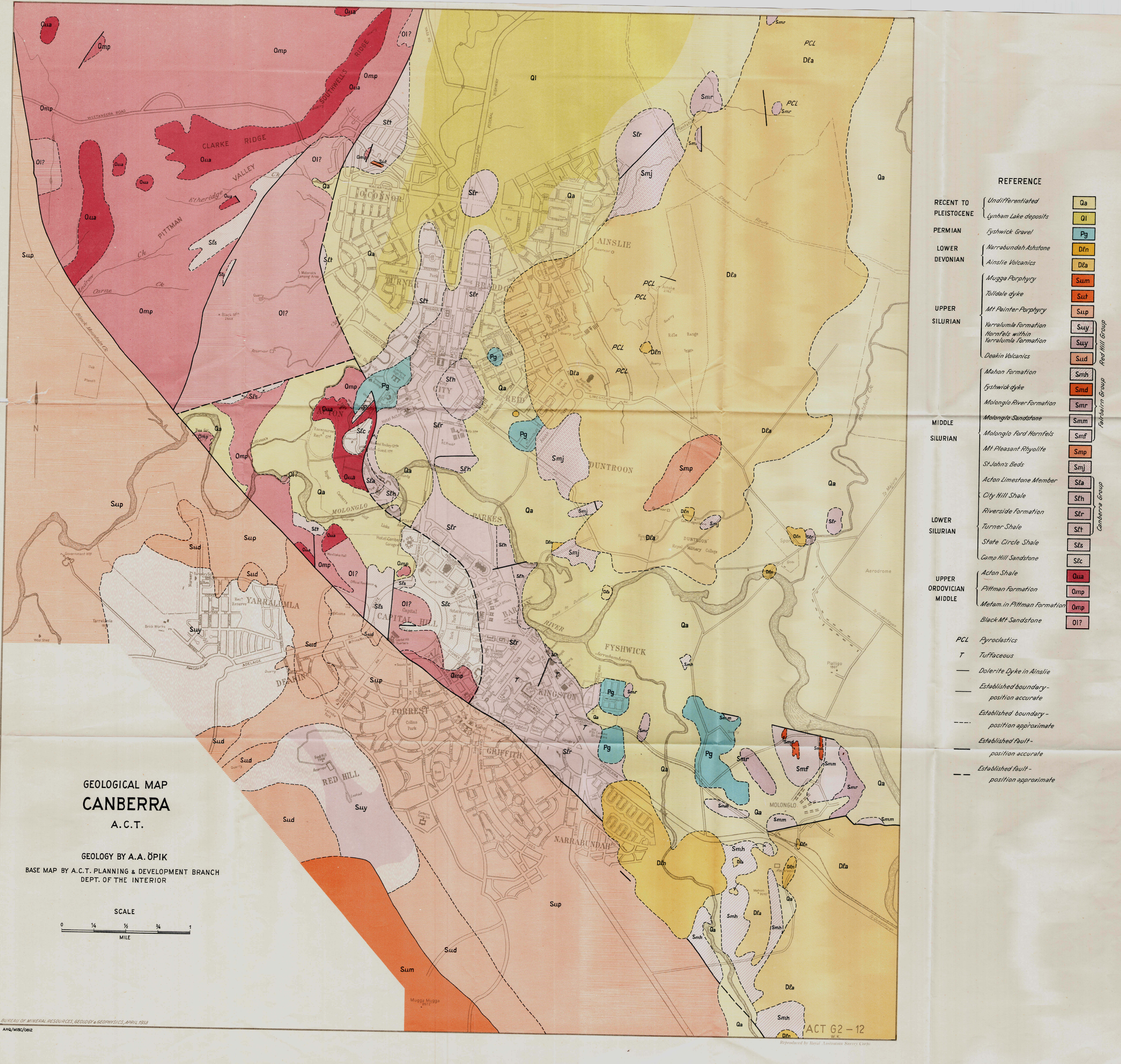
REFERENCE
RECENT TO PLEISTOCENE
Undifferentiated Qa
Lynham Lake deposits Ql
PERMIAN
Fyshwick Gravel Pg
LOWER DEVONIAN
Narrabundah Ashstone Dln
Ainslie Volcanics Dla
UPPER SILURIAN
Mugga Porphyry Sum
Tolldale dyke Sut
Mt Painter Porphyry Sup
Yarralumla Formation Suy
Hornfels within Yarralumla Formation Suy
Deakin Volcanics Sud
Red Hill Group
MIDDLE SILURIAN
Mahon Formation Smh
Fyshwick dyke Smd
Molonglo River Formation Smr
Molonglo Sandstone Smm
Molonglo Ford Hornfels Smf
Fairbairn Group
Mt Pleasant Rhyolite Smp
St John's Beds Smj
LOWER SILURIAN
Acton Limestone Member Sla
City Hill Shale Slh
Riverside Formation Slr
Turner Shale Slt
Canberra Group
State Circle Shale Sls
Camp Hill Sandstone Slc
UPPER ORDOVICIAN MIDDLE
Acton Shale Oua
Pittman Formation Omp
Metam. in Pittman Formation Omp
Black Mt Sandstone Ol?
PCL Pyroclastics
T Tuffaceous
Dolerite Dyke in Ainslie
Established boundary - position accurate
Established boundary - position approximate
Established fault - position accurate
Established fault - position approximate
CLARKE RIDGE
SOUTHWELLS RIDGE
PITTMAN
VALLEY
O'CONNOR
TURNER
BRADDON
AINSLIE
REID
CITY
ACTON
DUNTROON
MOLONGLO
PARKES
CAPITAL HILL
BARTON
YARRALUMLA
DEAKIN
FORREST
KINGSTON
GRIFFITH
FYSHWICK
RED HILL
NARRABUNDAH
MOLONGLO
RIVER
N
GEOLOGICAL MAP
CANBERRA
A.C.T.
GEOLOGY BY A.A. ÖPIK
BASE MAP BY A.C.T. PLANNING & DEVELOPMENT BRANCH
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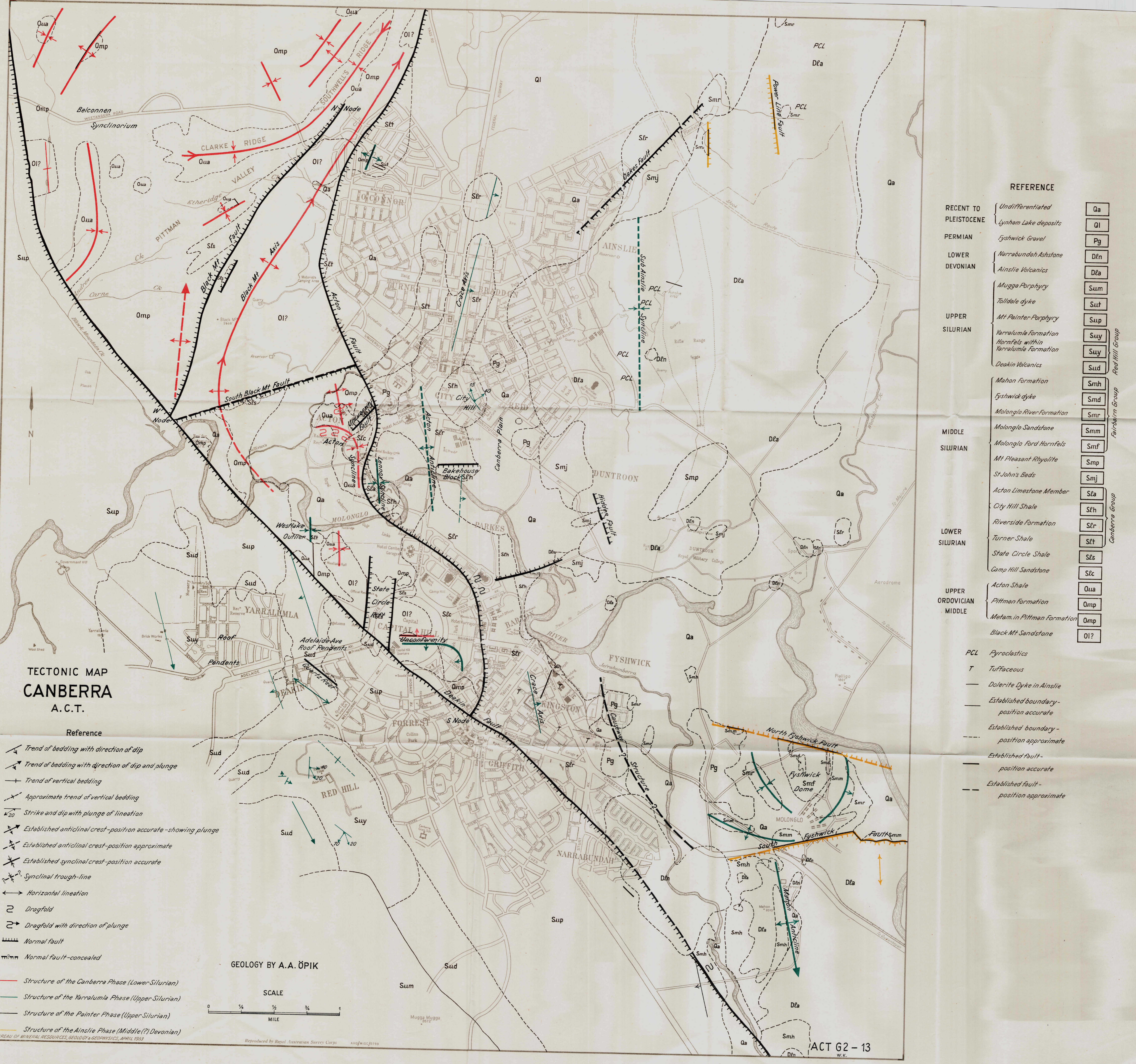
TECTONIC MAP
CANBERRA
A.C.T.
Reference
Trend of bedding with direction of dip
Trend of bedding with direction of dip and plunge
Trend of vertical bedding
Approximate trend of vertical bedding
Strike and dip with plunge of lineation
Established anticlinal crest-position accurate-showing plunge
Established anticlinal crest-position approximate
Established synclinal crest-position accurate
Synclinal trough-line
Horizontal lineation
Dragfold
Dragfold with direction of plunge
Normal fault
Normal fault-concealed
Structure of the Canberra Phase (Lower Silurian)
Structure of the Yarralumla Phase (Upper Silurian)
Structure of the Painter Phase (Upper Silurian)
Structure of the Ainslie Phase (Middle(?) Devonian)
GEOLOGY BY A.A. ÖPIK
SCALE
0 ¼ ½ ¾ 1
MILE
BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS, APRIL 1953
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ACT G2 - 13
REFERENCE
RECENT TO PLEISTOCENE
Undifferentiated Qa
Lynham Lake deposits Ql
PERMIAN
Fyshwick Gravel Pg
LOWER DEVONIAN
Narrabundah Ashstone Dℓn
Ainslie Volcanics Dℓa
UPPER SILURIAN
Mugga Porphyry Sum
Tolldale dyke Sut
Mt Painter Porphyry Sup
Yarralumla Formation Suy
Hornfels within Yarralumla Formation Suy
Deakin Volcanics Sud
Red Hill Group
MIDDLE SILURIAN
Mahon Formation Smh
Fyshwick dyke Smd
Molonglo River Formation Smr
Molonglo Sandstone Smm
Molonglo Ford Hornfels Smf
Mt Pleasant Rhyolite Smp
St John's Beds Smj
Fairbairn Group
LOWER SILURIAN
Acton Limestone Member Sℓa
City Hill Shale Sℓh
Riverside Formation Sℓr
Turner Shale Sℓt
State Circle Shale Sℓs
Camp Hill Sandstone Sℓc
Canberra Group
UPPER ORDOVICIAN
Acton Shale Oua
Pittman Formation Omp
MIDDLE
Metam. in Pittman Formation Omp
Black Mt Sandstone Ol?
PCL Pyroclastics
T Tuffaceous
Dolerite Dyke in Ainslie
Established boundary-position accurate
Established boundary-position approximate
Established fault-position accurate
Established fault-position approximate
Belconnen Synclinorium
Clarke Ridge
Southwell's Ridge
Black Mt Fault
Black Mt Axis
Acton Fault
South Black Mt Fault
Acton Syncline
Acton Anticline
Lennox Syncline
University Fault
Westlake Outlier
Bakehouse Block
Canberra Plain
Crace Axis
Dakes Fault
Sub Ainslie Syncline
Power Line Fault
Hindes Fault
Adelaide Ave Roof Pendents
Roof Pendents
Quartz Reef
Unconformity
Deakin Fault
Structure 2
North Fyshwick Fault
South Fyshwick Fault
Fyshwick Smf Dome
Mahon Anticline
N Node
W Node
S Node