

SOUTH



AUSTRALIA

Department of Mines

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA

---

Bulletin No. 34

---

# Regional Geology and Mineral Resources of the Olary Province

---

By B. CAMPANA, D.Sc., Senior Geologist,  
and D. KING, M.Sc., Geologist

---

Part I—Regional Geology

*By*

B. CAMPANA

Part II—Mineral Resources

*By*

D. KING

*Issued under the authority of*  
THE HONOURABLE SIR A. LYELL McEWIN, K.B.E., M.L.C.  
MINISTER OF MINES

PRICE 7s. 6d.



Department of Mines

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA

---

Bulletin No. 34

---

# Regional Geology and Mineral Resources of the Olary Province

---

By B. CAMPANA, D.Sc., Senior Geologist,  
and D. KING, M.Sc., Geologist

---

Part I—Regional Geology

*By*

B. CAMPANA

Part II—Mineral Resources

*By*

D. KING

*Issued under the authority of*  
THE HONOURABLE SIR A. LYELL MCEWIN, K.B.E., M.L.C.  
MINISTER OF MINES

---

W. L. HAWES, Government Printer, Adelaide

1958

PRICE 7s. 6d.

## LETTER OF TRANSMITTAL

---

Geological Survey Office, Department of Mines,  
Adelaide, 2nd July, 1957.

Sir,

I have the honour to submit herewith, a report on the regional geology and mineral resources of the Olary Province, by Dr. B. Campana (Senior Geologist) and Mr. D. King (Geologist).

Mineral prospecting in the Olary Province began many years ago, about the time of discovery of the great Broken Hill lode of New South Wales. Although many discoveries were made, and a number of mines worked, no significant producers survived from the early period. Geological investigations were initiated by Prof. Sir Douglas Mawson some forty years ago, but the more recent work has been done almost entirely by officers of the Geological Survey of South Australia. The new stimulus for prospecting was the urgent need, in 1944, for uranium, followed later by the exploration and development of the Radium Hill mine for production. The discovery of thorian-brannerite (absite) in the Crocker Well area in 1951 led to the establishment of an exploration camp and to a geological survey investigation which has extended over the past five years. The results of this investigation are set out in the present report.

The text has been prepared in two parts. In Part I, Dr. Campana has dealt with the regional geological setting in the Province, and has presented a new concept of the relationships between the Archaean crystalline basement rocks and the sedimentary succession of the Proterozoic. Intensive study of the Archaean formations has enabled their subdivision into three stratigraphic units, for the first time in this area.

Conclusions reached in the regional investigations have been applied in Part II of the report by Mr. King, dealing with the mineral resources of the area. These have been covered systematically, with emphasis on the uranium deposits of Radium Hill and Crocker Well, which because of their economic significance, have been dealt with in considerable detail. Other mineral occurrences have been covered exhaustively, both in the field and by a search of early literature, so that the present compilation will serve as a complete reference work for some time to come.

Acknowledgment is made to the assistance rendered by Mr. R. K. Pitman, Mr. M. L. Reyner, and Mr. W. Peterson of the U.S. Atomic Energy Commission; to the Deputy Government Geologist, Mr. L. W. Parkin; to officers of the Geological Survey who assisted in the field, and to Mr. A. W. G. Whittle for petrological and mineralogical studies which were a valuable contribution to the report. Finally, thanks are due to the exploration staff of the Broken Hill mining companies for stimulating discussions on problems common both to the Olary Province and to the Broken Hill area; and to the pastoralists of the area for their friendly co-operation with the field parties.

I remain Sir, etc.,

T. A. BARNES,

Government Geologist.

To the Hon. Sir A. Lyell McEwin, K.B.E., M.L.C., Minister of Mines.

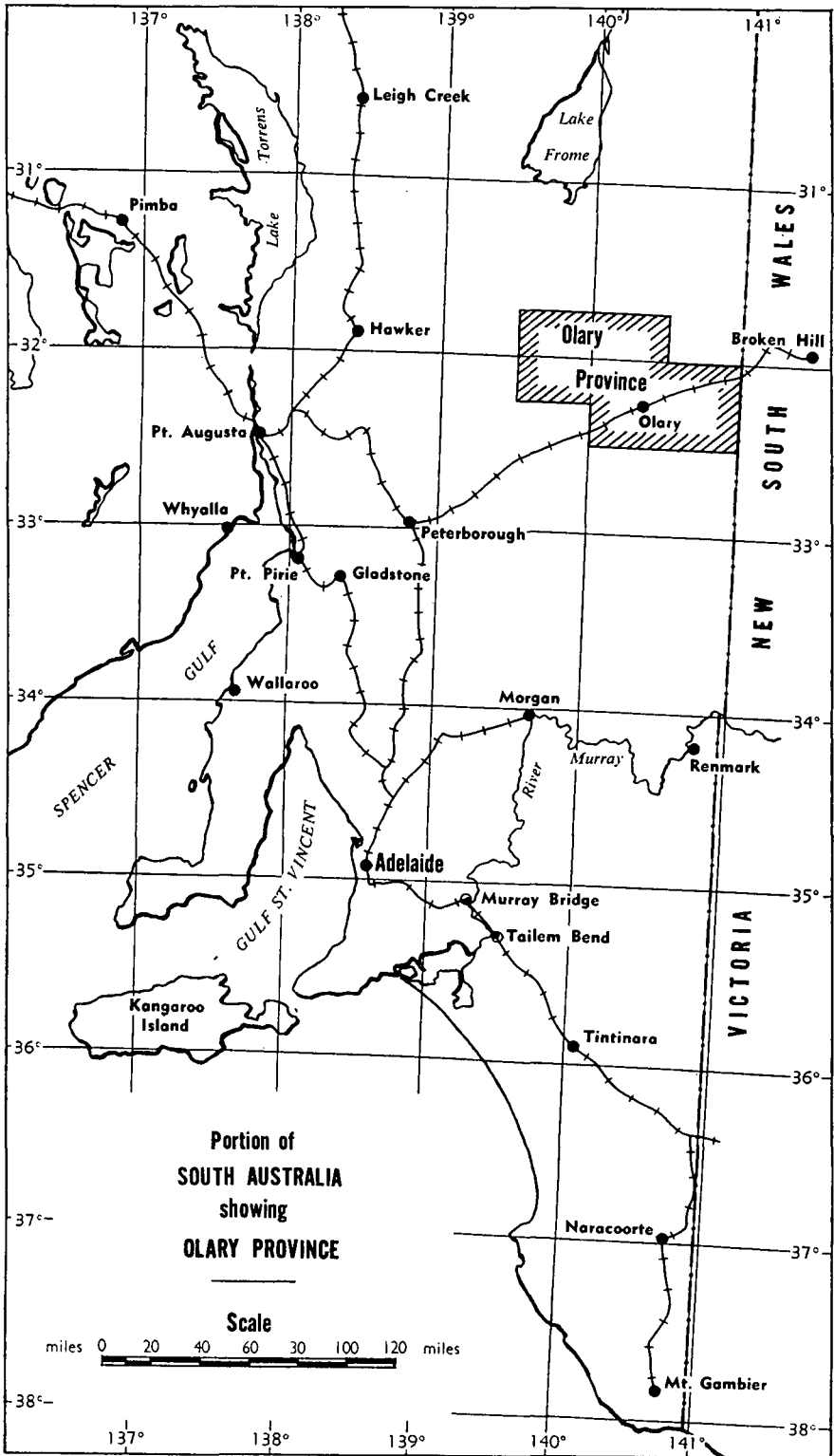
---

Submitted for approval to print as a Bulletin of the Geological Survey of South Australia.

Approved,

A. LYELL McEWIN,

Minister of Mines.



Portion of  
SOUTH AUSTRALIA  
showing  
OLARY PROVINCE

Scale

miles 0 20 40 60 80 100 120 miles

# CONTENTS

## PART I—REGIONAL GEOLOGY

### CHAPTER I

	PAGE
INTRODUCTION .....	11
Previous Geological Investigations and Conduct of This Work .....	11

### CHAPTER II

STATIGRAPHY AND PETROLOGY .....	13
Crystalline Basement .....	13
Archaean metasediments and proterozoic granites .....	13
The terrains—general characters .....	14
Major rock units .....	14
Archaean metasediments .....	15
Weekeroo-Billeroo schists .....	15
Ethiudna calc-silicate group .....	16
Arkosic quartzites, passing to granite-gneisses .....	18
General stratigraph column .....	20
Felspathized Archaean metasediments .....	21
Migmatites and granite-gneisses .....	21
Anatectic granites, granodiorites, and granulites .....	22
Pegmatites .....	24
Aplites, alaskites, and adamellites .....	25
Amphibolite group .....	26
Para-amphibolites .....	26
Ortho-amphibolites .....	27
Age, Metamorphism, and Granitization of the Crystalline Formations .....	28
Age .....	28
Metamorphism and granitization process .....	29
The Sedimentary Mantle—Upper Proterozoic Beds of the Adelaide System .....	31
The Grand Unconformity .....	31
The Torrensian Series .....	31
Basal conglomerate .....	31
Slates, dolomites, and magnesite beds .....	31
Thickness, facies, and sedimentation environment .....	32
The Sturtian Series .....	32
The lower glacial sequence .....	33
Boulder tillites .....	33
Dolomites .....	35
Iron-rich siltstones .....	35
Fluvioglacial quartzites .....	35
Glacio-lacustrine slates and siltstones .....	35
Thickness, facies, and sedimentation environment .....	36
The interglacial sequence .....	36
Thickness and sedimentation environment .....	36
The upper glacial sequence .....	37
Boulder tillite and associated quartzites .....	37
Slates and siltstones .....	37
Thickness and sedimentation environment .....	37

### CHAPTER III

STRUCTURAL GEOLOGY—	38
The Olary Province as an Anticlinorium Reflecting an Axial Culmination .....	38
Structural Evolution of the Area in Time and Space .....	38
Fundamental orogenic traits—the repeated foldings of a geosynclinal area .....	38
Derived tectonic effects—axial flexures, shears, and overthrusts .....	40
Vertical evolution of the structures .....	41
Relations between folding, granitization, and mineralization—age of the orogenic cycle .....	41

## PART II—MINERAL RESOURCES

### CHAPTER I

INTRODUCTION .....	43
History .....	43
Early mineral investigations .....	43
Radium Hill mine exploration .....	44
Aerial surveys and discovery of the uranium prospect at Crocker Well .....	44
Regional Mapping and Mineral Exploration Since 1953—Discovery of Crocker Well East and Mt. Victoria Uranium Deposits .....	44
Mineral Location Reference .....	45

### CHAPTER II

METALLOGENIC EPOCHS—CLASSIFICATION OF THE MINERAL DEPOSITS .....	46
Age of the Mineral Deposits—As Deduced From the Isotopes of Uranium, Thorium, and Lead .....	46
Precambrian Metallogenic Epochs .....	47
Primary uranium and rare-earth mineralization .....	47
Copper-cobalt-tungsten occurrences and their relation to uranium mineralization .....	47
Industrial mineral deposits .....	47
Early Palaeozoic Metallogenic Epoch .....	48

CHAPTER III		PAGE
<b>MINERAL DEPOSITS OF THE PRECAMBRIAN METALLOGENIC EPOCHS</b> . . . . .		49
Uranium and Rare-Earth Mineral Deposits . . . . .		49
Distribution . . . . .		49
Types of deposits . . . . .		49
Pegmatite deposits . . . . .		49
Pneumatolytic deposits . . . . .		50
Hydrothermal deposits . . . . .		50
Residual deposits . . . . .		50
Mineralogy . . . . .		50
Davidite . . . . .		51
Pegmatitic davidite . . . . .		51
Pneumatolytic davidite . . . . .		53
Metasomatic davidite-ilmenite intergrowths . . . . .		53
Summary of the properties of davidite . . . . .		53
Absite . . . . .		54
Complex pegmatitic uranium and rare-earth minerals . . . . .		55
Uraninites . . . . .		56
Secondary uranium minerals . . . . .		56
Thorium and rare-earth minerals . . . . .		56
Zoning . . . . .		57
Radium Hill uranium mine . . . . .		58
Introduction . . . . .		58
Regional geological setting . . . . .		58
Lode structure . . . . .		59
Lode mineralization . . . . .		59
Mine development . . . . .		59
Crocker Well uranium deposits . . . . .		60
Regional geological setting . . . . .		60
The ore mineral . . . . .		60
Rock types in relation to ore localization . . . . .		60
Metasediments . . . . .		62
Grey mafic granodiorite . . . . .		62
Adamellite . . . . .		62
Alaskite and alaskite-pegmatite . . . . .		62
Granodiorite dykes . . . . .		62
Granite-pegmatites . . . . .		62
Structural controls . . . . .		62
Ore genesis . . . . .		63
Grade evaluation—methods and problems . . . . .		64
Assays of diamond-drill cores . . . . .		64
Recovery of diamond-drill sludges . . . . .		64
Radiometric borehole logging . . . . .		65
The original prospect . . . . .		66
Geology . . . . .		66
Development . . . . .		66
Ore reserves . . . . .		67
Grade . . . . .		67
Tonnage estimate . . . . .		67
Crocker Well East prospects . . . . .		67
Geology . . . . .		67
Development . . . . .		68
Ore reserves . . . . .		70
Grade . . . . .		70
Tonnage estimates . . . . .		70
Metallurgical investigations . . . . .		70
General appraisal . . . . .		71
Mt. Victoria uranium deposit . . . . .		71
Introduction . . . . .		71
Surface geology . . . . .		71
Lode minerals . . . . .		72
Diamond drilling . . . . .		73
Interpretation of drilling . . . . .		73
Country-rock structure . . . . .		73
Lode structure . . . . .		73
Lode dimensions . . . . .		74
Controls in ore localization . . . . .		74
Grade analysis . . . . .		75
Outcrop sampling . . . . .		75
Assays of drill core . . . . .		75
Radiometric borehole logging . . . . .		77
Bulk sample . . . . .		77
Ore reserves . . . . .		77
Definitions . . . . .		77
Tabulation of ore reserves . . . . .		77
Other significant uranium deposits . . . . .		79
Spring Hill uranium prospect . . . . .		79
Introduction . . . . .		79
Surface geology . . . . .		79
Ore mineral and association . . . . .		79
Diamond drilling . . . . .		81
Ore reserves and grade . . . . .		81
Mindamereeka Hill uranium prospect . . . . .		82
Introduction . . . . .		82
Surface geology . . . . .		83
Uranium minerals . . . . .		83
Diamond drilling . . . . .		84
Assays . . . . .		84
Windamerta North uranium prospect . . . . .		86
Introduction . . . . .		86
Surface geology . . . . .		86
Radioactivity . . . . .		88
Diamond drilling . . . . .		88

## CONTENTS—continued

## PART II—CHAPTER III—continued

	PAGE
Windamerta South uranium prospect	88
Introduction	88
Geology	88
Diamond drilling	90
Jagged Rocks uranium prospect	90
Introduction	90
Geology	90
Diamond drilling	91
Results	91
Copper-Cobalt-Tungsten Mineral Deposits	91
Introduction	91
Mineralization controls	91
Metaliferous deposits with stratigraphic controls	94
Copper-cobalt-tungsten deposits in calc-silicate rocks of the Ethjudna group	94
The Ethjudna mines	94
Stratigraphy	94
Mineralogy	94
Structure	94
Mine workings	96
Ore localization	99
Mt. Howden cobalt mine	101
Distribution of scheelite	101
Copper deposits in epidote-actinolite quartzite	102
Dome Rock mine	102
Woman in White mine	103
Putt Well deposit	103
Meningie Well deposit	103
Raven Hill copper show	103
Other deposits	103
Copper deposits in the banded iron formation	103
Green and Gold mine	103
Perryhumuck mine	103
Mt. Bull mine	103
Other deposits	104
Copper deposits associated with amphibolite	104
Mutooroo mine	104
Mutooroo West mine	104
Mt. Victoria mine	104
Pimponda mine	106
Other deposits	106
Pegmatitic copper deposits	106
Mary mine	106
Trinity mine	106
Mulga Hill mine	106
* Industrial Mineral Deposits	106
Commercially important pegmatite minerals	107
Felspar and beryl	109
Old Booloomata area	109
White Rock deposit	109
Raven Hill deposit	109
White Lady deposit	109
Gum Creek (Cold Tea) deposit	109
Hamper Hat deposit	110
Little Rat deposit	110
Viney Claim	110
Bimbowrie area	110
Maggie mine	110
Boundary deposit	110
Ameroo deposit	110
Other deposits	110
Morialpa area	110
White Hope deposit	110
Mica	110
Phosphates	113
Old Booloomata apatite workings	113
Spring Well apatite deposit	113
Other occurrences	113
Tantalum-columbium minerals	113
Tantalite-columbite	114
Mixed oxides of titanium and tantalum-columbium	114
Fluorite	114
Plumbago fluorite workings	114
Newly discovered fluorite vein	115
Aluminium silicate refractories	116
Andalusite	116
Tommy Watty deposit	116
Maggie deposit	116
Andalusite (var. chiastolite)	117
Mt. Howden chiastolite occurrence	117
Poothlaringa chiastolite occurrence	117
Alconie Hill chiastolite-graphite occurrence	117
Andalusite-sillimanite	117
Ameroo West deposit	117
Sillimanite	118
Morialpa occurrence	118
Centralia occurrence	118
Kyanite	118
Radium Hill prospect	118
Dey Hill prospect	119
Bonython Hill prospect	119
Mutooroo prospect	119

CONTENTS—*continued*

PART II—CHAPTER III—*continued*

PAGE

Barite .....	119
Weckeroo (Walparuta) deposit .....	120
Mt. Mulga deposits .....	120
Dome Rock deposit .....	122
Waukaloo deposit .....	122
Miscellaneous non-metallic minerals .....	122
Carphosiderite .....	122
Graphite .....	122
Corundum .....	122
Tremolite .....	122

CHAPTER IV

POST-PROTEROZOIC VEIN DEPOSITS OF THE CRYSTALLINE BASEMENT .....	123
Luxemburg and Queen Bee Mining Area .....	123
Queen Bee mine .....	123
Luxemburg mine .....	123
John Brown workings .....	125
General Appraisal .....	125
Other Mines .....	125
Bimba mine .....	125
Cutana mine .....	125
Centralia mine .....	125
Other deposits .....	125

CHAPTER V

POST-PROTEROZOIC EPITHERMAL VEINS IN THE ADELAIDE SYSTEM .....	126
Auriferous Quartz Reefs .....	126
Silver-Lead .....	126
Copper .....	127

CHAPTER VI

IRON ORE OCCURRENCES .....	128
Proterozoic (Braemar, Bimbowrie) Iron Ore Deposits .....	128
Maldorky area .....	128
Cutana area .....	128
Olary area .....	129
Bimbowrie area .....	129
Archean (Koolka-Billeroo) Iron Ore Deposits .....	129
Koolka area .....	129
Billeroo area .....	129
Other deposits .....	129

ACKNOWLEDGMENTS .....	130
-----------------------	-----

REFERENCES .....	131
------------------	-----

TABLES

TABLE I.—Radioactive minerals of the Olary Province .....	51
TABLE II.—Chemical analyses of davidite .....	53
TABLE III.—Chemical analyses of absite samples .....	54
TABLE IV.—Chemical assays of bulk shaft-samples—Original prospect .....	66
TABLE V.—Assays of core from vertical boreholes within the breccia zone—Original prospect .....	67
TABLE VI.—Summary of diamond-drilling results—Crocker Well East prospects .....	68
TABLE VII.—Summary of diamond-drilling results—Spring Hill prospect .....	82
TABLE VIII.—Production and uses of industrial minerals—Olary Province .....	107
TABLE IX.—Chemical analyses of industrial minerals—Olary Province .....	112

# PLANS AND ILLUSTRATIONS

## PART I

### PLATES

PLATE I.—Geological map of the Olary Province . . . . .	} In pocket (at back of Bulletin)
PLATE II.—Tectonic map of the Olary Province . . . . .	
PLATE III.—Geological sections across the Olary Province . . . . .	

### TEXT FIGURES

FIG. 1.—The Archaean succession—Weekeroo Hill area . . . . .	Page 16
FIG. 2.—Weekeroo-Billeroo mica schists, with pegmatite sill . . . . .	} Facing p. 16
FIG. 3.—Weekeroo-Billeroo mica schist sequence . . . . .	
FIG. 4.—Upper portion of the Weekeroo-Billeroo mica schists . . . . .	} Facing p. 17
FIG. 5.—Epidote-garnet quartzite as a remnant in granitized terrains . . . . .	
FIG. 6.—Brecciation of the epidote-quartzite horizon . . . . .	
FIG. 7.—Bedded limestone, converted into a tremolite-diopside formation . . . . .	} Page 19
FIG. 8.—The Archaean succession—Ameroo Hill area . . . . .	
FIG. 9.—The Archaean succession—Old Boolcoomata area . . . . .	Page 20
FIG. 10.—Unaltered laminated arkosic quartzite . . . . .	} Facing p. 24
FIG. 11.—Development of quartz-felspar strings along bedding plane of the arkosic quartzite formation . . . . .	
FIG. 12.—Migmatite stage in the arkosic quartzite formation . . . . .	} Facing p. 25
FIG. 13.—Granitization in bedded quartzite, with development of arctic migmatite and gradation to massive granite . . . . .	
FIG. 14.—Granitization in foliated schist, with development of arctic migmatite showing ptygmatic folding . . . . .	} Facing p. 26
FIG. 15.—Granitization process in obdurated laminated hornfels, by infilling of fissure networks with uraniferous quartz-felspar material . . . . .	
FIG. 16.—Advanced stage of granitization in obdurated hornfels, showing preservation of blocky remnants in predominantly structureless uraniferous leucogranite . . . . .	} Facing p. 27
FIG. 17.—Coarse-grained felspar-rich anatectic granite with sedimentary remnants . . . . .	
FIG. 18.—Anatectic granite—typical tor structure . . . . .	} Facing p. 30
FIG. 19.—Massive anatectic granite forming prominent bosses in the central portion of the granitic terrains . . . . .	
FIG. 20.—The Archaean-Proterozoic Grand Unconformity—Oualpa-Weekeroo area . . . . .	} Facing p. 31
FIG. 21.—Basal conglomerate of the Adelaide System, unconformably resting on migmatites of the crystalline basement . . . . .	
FIG. 22.—Basal tillite of the Adelaide System unconformably resting on granite-gneisses of the crystalline basement . . . . .	Page 32
FIG. 23.—The Grand Unconformity as exposed in the Weekeroo area . . . . .	} Facing p. 32
FIG. 24.—Granitic tillite—Old Boolcoomata area . . . . .	
FIG. 25.—Granite erratic, dumped by floating ice in fluvio-glacial sandy beds—Old Boolcoomata area . . . . .	} Page 34
FIG. 26.—Stratigraphic sections of the transgressive basal tillite—Plumbago-Mt. Victor area . . . . .	
FIG. 27.—Basal tillite—passing upward to sandy dolomite . . . . .	} Facing p. 36
FIG. 28.—Glacio-lacustrine slates and siltstones . . . . .	
FIG. 29.—Glacio-lacustrine laminated slates intruded by quartz veins . . . . .	} Page 39
FIG. 30.—Structural-stratigraphic relationship between granitic terrains and metasediments . . . . .	
FIG. 30a.—The anticlinal granite wedge—near Bimbowrie homestead . . . . .	Page 41

# PLANS AND ILLUSTRATIONS

## PART II

### PLATES

PLATE IV.—Mineral Map of the Crocker Well area	} In pocket (at back of Bulletin)
PLATE V.—Mineral Map of the Outalpa-Bimbowrie-Old Boolcoomata area	

### TEXT FIGURES

FIG. 31.—Anomaly location map of the Olary Province	} In pocket (at back of Bulletin)
FIG. 32.—Davidite occurrence at margin of pegmatite—Crocker Well West	
FIG. 33.—Pseudocrystalline davidite aggregates in pegmatite—Billeroo	} Facing p. 54
FIG. 34.—Globular aggregates of davidite along border zone of pegmatite	
FIG. 35.—Davidite from pegmatite—near Bimbowrie	} Facing p. 55
FIG. 36.—Residual davidite from weathered pegmatite—Billeroo	
FIG. 37.—Pseudocrystalline absite in adamellite—Crocker Well East	} Facing p. 58
FIG. 38.—Zoned gummite in pegmatite—Old Boolcoomata	
FIG. 39.—Xenotime crystal in pegmatite—near Mt. Victoria	} Facing p. 59
FIG. 40.—Residual xenotime crystals weathered out of pegmatite—near Bimbowrie Station	
FIG. 41.—Geological locality plan—Crocker Well uranium deposits	} Facing p. 61
FIG. 42.—Residual pseudocrystalline absite slugs from soil—Main Eastern prospect	
FIG. 43.—General view of the Main Eastern prospect with diamond-drilling plant in operation	} Facing p. 62
FIG. 44.—Surface geological plan—Original prospect, Crocker Well	
FIG. 45.—Typical shear zone in adamellite—Crocker Well East	} Facing p. 66
FIG. 46.—Biotite-absite intergrowths in fractured adamellite—Crocker Well East	
FIG. 47.—Detailed Geological Plan—Crocker Well	} In pocket (at back of Bulletin)
FIG. 48.—Cross-section of the Main Eastern prospect, Crocker Well	
FIG. 49.—Surface geological plan—Crocker Well Main Eastern and Central prospects	} In pocket (at back of Bulletin)
FIG. 50.—Radium Hill mine—showing headframe, crusher station, etc.	
FIG. 51.—Diamond-drilling plants operating at the Mt. Victoria mine site	} Facing p. 70
FIG. 52.—Surface geological plan—Mt. Victoria uranium deposit	
FIG. 53.—Samples of lode rock—No. 1 shaft, Mt. Victoria mine	} Facing p. 72
FIG. 54.—Core samples from boreholes—Mt. Victoria mine	
FIG. 55.—Geological cross-section along boreholes—Mt. Victoria mine	} Facing p. 74
FIG. 56.—Longitudinal projection along the main lode—Mt. Victoria mine	
FIG. 57.—Surface geological plan—Spring Hill uranium prospect	} Page 76
FIG. 58.—Cross-sections along boreholes—Spring Hill uranium prospect	
FIG. 59.—Spring Hill Uranium prospect—general view of the mineralized area, etc.	} Page 80
FIG. 60.—Mindamereeka Hill uranium prospect—Boring plant at site	
FIG. 61.—Mindamereeka Hill uranium prospect—Photomicrograph	} Facing p. 82
FIG. 62.—Geological plan and section—Mindamereeka Hill uranium prospect	
FIG. 63.—Geological Plan—Windamerta North uranium prospect	} Page 85
FIG. 64.—Geological Plan—Windamerta South uranium prospect	
FIG. 65.—Locality plan—Metalliferous ore deposits, Olary Province	} Page 87
FIG. 66.—Regional geological plan—Ethiudna mining area	
FIG. 67.—Detailed geological plan and section—main workings, Ethiudna mine	} Page 89
FIG. 68.—Plan and cross-section—main shaft, Ethiudna mine	
FIG. 69.—Ethiudna mine main shaft	} Page 92
FIG. 70.—Piper shaft—Ethiudna mining area	
FIG. 71.—Detailed geological plan and section—Ethiudna East cobalt prospect	} Facing p. 93
FIG. 72.—Surface geological plan and section—Mt. Howden cobalt mine	
FIG. 73.—Surface geological plan—Old Boolcoomata scheelite prospect	} Page 100
FIG. 74.—Surface Plan—Mutooroo copper mine	
FIG. 75.—General view of the Mutooroo mining area	} Page 102
FIG. 76.—A pinnacle of the Archaean banded hematite-quartz formation—Billeroo	
FIG. 77.—Locality plan—industrial mineral deposits, Olary province	} Facing p. 106
FIG. 78.—Plan of feldspar-beryl deposits—Bimbowrie-Old Boolcoomata area	
FIG. 79.—Geological plan—newly discovered fluorite vein near Plumbago station	} Page 108
FIG. 80.—Radiating beryl prisms from pegmatite	
FIG. 81.—Chiastolites from the Mt. Howden locality	} Facing p. 116
FIG. 82.—Geological plan—kyanite deposit near Radium Hill	
FIG. 83.—Geological plan—Weekeroo barite deposit	} Page 119
FIG. 84.—Surface geological plan—Luxemburg and Queen Bee mining area	

# REGIONAL GEOLOGY AND MINERAL RESOURCES OF THE OLARY PROVINCE

---

## Part I—Regional Geology

---

### Chapter 1

#### INTRODUCTION

##### **Previous Geological Investigations and Conduct of this Work**

The Olary Province of South Australia is defined in this Bulletin as the area bounded by longitudes 139° 30′-141° 00′ and latitudes 31° 45′-32° 30′. The term "province" is introduced with a geological connotation, for the area corresponds with a well-defined geological unit, as illustrated by plate I of this work.

The area belongs to a semi-arid, very sparsely populated zone which extends, with similar geological and physiographic characteristics, beyond the east border of South Australia into the New South Wales territory, where the great lead-ore body of Broken Hill supports the only large town of this zone.

The Olary Province is a relatively high land, which forms the water divide between the Murray Basin to the south and the Lake Frome Basin to the north. It will be seen below that this physiographic rise reflects a fundamental structural trait of the area, *i.e.*, an axial swelling of the Mount Lofty-Olary mountain arc, which brings the oldest rocks of the State to the surface. The relief elevation varies between 600 and 1,800ft. above sea-level, the highest part being the Binberrie Hill-Triangle Hill area and the lowest one the Mingary-Cockburn depression. The advanced stage of degradation is reflected by a subdued fully mature relief, dominated by round hills and ridges with intervening wide stretches of flat country.

The erosional agents are typically those of the arid regions, with short but violent precipitation, rather sharp changes and wide ranges of daily and seasonal temperatures, and equinoxial strong winds. Thus, in spite of low relief, bedrock is admirably exposed over large tracts of country, either bare or covered only at intervals by a thin veneer of residual soil. This feature, combined with the mineral potentialities of the area, is responsible for the early start of mineral prospecting, which took place almost at the beginning of the State settlement (See Introductory Notes, Part II, p. 43).

Geological investigations on portions of the Olary Province have been carried out by D. Mawson (1912) and at a later date by geologists of the South Australian Department of Mines (Whittle, 1948; Campana, 1953; Dickinson and Sprigg, 1953; Sprigg, 1952-1954). The latter is also the author of unpublished geological mapping which has been incorporated in this work (plate I). Numerous unpublished reports related to the mineral deposits of the area have also been compiled in the past 10 years, to which reference is made in Part II.

No geological work dealing with the area as a whole has been compiled previously. Detailed geological mapping was initiated in the late forties by the State Government in relation to a wide search for radioactive minerals in the area and the contemplated development of the Radium Hill uraniumiferous lodes. R. C. Sprigg extended the mapping of the Radium Hill mine area to the whole Ballara military sheet in 1951, and to part of the Outalpa sheet. B. Campana mapped in 1950 the area of the Kalabity sheet and extended afterwards the field work to the adjoining Plumbago, Glenorehy, Olary, and Cockburn military sheets, assisted in part by K. W. A. Summers and R. B. Wilson.

In the course of the geological mapping of the Kalabity, Plumbago and Glenorchy sheets, it was noted that some Archaean beds relatively rich in lime provided a control for a part of the regional mineralization (Campana, 1953a, 1953b), an observation which permitted an intensification of the mineral search, the results of which are described in Part II of this *Bulletin*. One of the present writers (Campana) was particularly concerned with the regional mapping, stratigraphic and tectonic research, and studies of general mineralization problems. The other co-author (King) carried out detailed studies of the mineral occurrences, and particular economic appraisals, testing programmes and mineralization type and distribution.

---

## Chapter 2

### STRATIGRAPHY AND PETROLOGY

Two fundamental groups of terrains outcrop in the Olary Province; the crystalline formations of the basement and the unmetamorphosed sediments of the Adelaide System. Of the latter, only the lower series (Torrensian) and the middle series (Sturtian) are represented. The upper series (Marinoan), which in other parts of the State forms the top of the Adelaide System and is overlain by fossiliferous Cambrian beds, has not here been recognized.

A thin veneer of residual or alluvial clayey sand, of recent deposition, associated in places with a travertine crust, masks the bedrock over large tracts of the area. But the aridity of the climate gives rise elsewhere to fresh and bare rock exposures, which permit petrological and stratigraphic observations of particular clarity. From the oldest to the youngest formations, the stratigraphic succession is as follows:

#### Crystalline Basement

##### ARCHAEAN METASEDIMENTS AND PROTEROZOIC GRANITES

The crystalline formations of the Olary Province were first studied by D. Mawson (1912) who described their general character and named them the Willyama Complex.

Although Mawson's early investigations were mainly related to the Broken Hill area, this author has dealt with the formations of the Olary district in articles on the Radium Hill uranium minerals (1906, 1916, 1944) on the minerals of the Booloomata area (1926) and on the Bimbowrie chistolite schists (1911). Together with petrological and mineralogical data, Mawson has clearly shown the age relationship of the crystalline rocks, postulating an Archaean age for the metamorphic series and a later Precambrian age for their granitic elements. On the whole these views have been confirmed by subsequent studies, although significant divergences have arisen in relation to the genesis and mode of emplacement of the granitic rocks.

While Mawson holds that these rocks are of igneous origin and intrusive character, A. W. G. Whittle (1948) stressed the importance of the granitization process in the Booloomata area, suggesting that portions of the Adelaide System have also been granitized.

In numerous other reports and publications compiled by geologists of the South Australian Department of Mines between 1940 and 1955 rocks of the crystalline basement are described, in relation to mineral deposits (see bibliographic references). No general attempt has however been made in these or previous works to group the crystalline formations in rock units of regional validity. It was thus one of the writers' main objectives to recognize mapping units and to investigate their relationship in space and time.

The geological map of a portion of the Olary Province (Kalabity sheet) carried out by one of the writers in 1950, had shown that the subdivision of the crystalline basement rocks in mapping units was possible, although difficult (B. Campana). The extension of the mapping work to the adjoining Plumbago and Glenorchy areas, and also the studies carried out by Sprigg in the Outalpa region, confirmed the regional validity of the rock units of the Kalabity zone, though disproving the hypothesis (suggested in the legend of the Kalabity sheet) that beds of the Adelaide System have been involved in regional metamorphism. Moreover, discussions, map comparisons, and field excursions with geologists of the Broken Hill mining companies have demonstrated the possibility of correlating the formations of the Broken Hill district with those of the Olary area. Additional field work has now led to the identification of mineralized beds and of stratigraphic horizons whose regional correlation may be regarded as certain.

### The Terrains—General Characters

The dominating stratigraphic feature of the crystalline terrains is the presence of metasediments of great antiquity—phyllites, schists, quartzites, calc-silicate beds, paragneisses, amphibolites—which have been affected in varying degree by later wide-spread granitization.

The process of granitization will be considered and critically discussed in a later paragraph. For descriptive and mapping purposes in granitized terrains the writer has adopted Sederholm's and Wegmann's definitions and terminology, (Sederholm, 1926, Wegmann, 1935) which have been widely accepted in the geological literature even though the related genetic questions are still controversial. In the field, vertical and lateral gradations from uncontaminated metasedimentary strata to feldspathized beds are most common. Feldspathized schists and gneisses merge into migmatites, which in the more central portions of the granitized series pass gradually to massive granite, with scanty xenoliths and rare structure relicts.

Whatever the causes and mechanism of the granitization may be, the field relations suggest that the granitic terrains derive in the main from a pre-existing metasedimentary succession, with formation of anatectic granites surrounded by large zones of migmatites and granite-gneisses.

Migmatites, granite-gneisses and granite form the largest portion of the crystalline rocks exposed in the Olary Province. The highly granitized cores are particularly conspicuous in the Boolcoomata-Bimbowrie and in the Plumbago-Mount Victoria areas, where they give rise to bold, round, reddish-coloured hills which dominate the landscape (fig. 19). Around these cores, a more subdued relief is occupied by migmatites, gneisses and schists feldspathized in varying degrees, while in the marginal parts of the granitized zone uncontaminated metasedimentary successions give rise to a fringe of long, dark-coloured ridges, such as the Koolka, Billeroo, and Weekeroo Hills.

In addition to the more accentuated relief, a distinctive character of the crystalline rock exposures is the timber and bushy vegetation growing on them. Whereas exposures of impervious slates and siltstones of the Adelaide System are usually bare and desolated, the crystalline rocks—and particularly the more granitized ones—support a forest of mulga (*Acacia aneura*) and other species of the semi-arid zone. This forest marks with accuracy even small outcrops of the crystalline basement and is therefore of particular value for the tracing of geological boundaries.

### Major Rock Units (Plate I)

Metamorphism and granitization have obliterated or obscured a great deal of the sedimentary character of the rocks of the Olary Province, which have also been much disturbed by repeated orogenic cycles. The recognition of regional rock units and their inter-relationships is therefore a complex problem.

Initially, only two major groups of rocks, distinct by their petrology and age relationship, were recognized: the relatively unaltered metasedimentary succession of the peripheral region and the granitic bodies of the central areas. Age determinations based on uranium/lead ratio have demonstrated an Archaean age for the metasedimentary beds and a Proterozoic age for the granite (Campana, 1954).

Granitization phenomena have, however, produced between these two extreme rock types, a series of intermediary stages, with gradations from almost structureless migmatite to highly feldspathized schists, intruded by pegmatites. Although the boundaries of these intermediate rock types are only vaguely defined, two further major rock units have been recognized and mapped (plate I): the feldspathized metasediments and the migmatite-granite-gneiss group.

*Archaean Metasediments (A<sub>g</sub>)\**

Archaean beds having entirely escaped later feldspathization and granitization do not, as a rule, give rise to large outcrops. The present cycle of erosion, already well advanced, has selectively planed down these rather soft and schistose beds, which are now masked by the alluvial and residual deposits of the pediment surfaces and lowlands. However, discontinuous belts of metasediments circumscribe the granite and migmatite massifs, giving rise to the prominent hills of Weekeroo, Billeroo, Koolka, Alconie, Nancatee, Waukaloo and Dome Rock. Archaean metasediments are also well exposed in a narrow synclinal zone which flanks the granite and migmatite of Bimba Hill-Triangle Hill, and they crop out again in another tight syncline south and north of Bimba mine. Most characteristic beds of the Archaean succession are also exposed northeast and southeast of Old Booloomata homestead, where they form long and depressed slivers penetrating or circumscribing vast zones of granite and migmatites. Between Bimbowrie homestead and Ameroo Hill, a thick succession of Archaean rocks shows, in planimetric view, an almost circular synclinal pattern crowned with granitized country-rock.

As a rule, the Archaean metasediments still retain a great deal of their original sedimentary features, particularly in areas where pegmatite development and feldspathization are mild. Gradational passages from phyllites to silky sericitic schists and to muscovite schists are not uncommon, while laminated sandy beds merge into banded paragneisses. Schists include quartz-muscovite-biotite schists, sericite-quartz-garnet-chiastolite schists, garnet-biotite-quartz schists, chloritoid mica schists, sillimanite schists and kyanite schists.

Feldspathic sandstones grade in many places to gneissic, granitic or aplitic-looking rocks while siliceous quartzites give rise to massive, flinty bands which may be followed over long distances.

The presence of calcareous formations in the original Archaean sediments is evidenced by widespread and fairly continuous beds with abundant calc-silicate minerals as principal or accessory constituents. Epidote quartzites and hornstones are the most common, and form excellent marker beds for stratigraphic and structural interpretations within the crystalline complex. Tremolite-diopside rocks, garnet rocks, skarns and amphibolites of sedimentary origin are not uncommonly associated with epidote-quartzite bands. The calc-silicate formations are also of great significance for mineralization control, and have therefore been carefully mapped and petrologically investigated.

In order to establish general time-rock units in the Archaean metasedimentary succession, some of the most characteristic stratigraphic sections will be briefly described.

*Weekeroo-Billeroo Schists*

Schists and quartzites form the bulk of the metasedimentary series of the area. A large and characteristic development occurs in the area of Weekeroo Hill, where the section illustrated by fig. 1 has been studied in some detail.

The base of the Weekeroo sequence consists mainly of a regular alternation of silky, well-laminated and very fissile sericite-muscovite schists, sandy in part, with interstratified thin-bedded sandstones. These formations retain practically all their sedimentary characters, such as bedding, lamination, and occasional ripple-mark and cross-bedding (figs. 2-4).

A suite of more basic rocks, which carry abundant calc-silicate minerals, occupies a well-defined stratigraphic horizon within the schistose succession (figs. 1, 8, 9). These rocks are considered to be genetically related and have been named the "Ethiudna calc-silicate group", for it is in the Ethiudna mine area that they show their most typical development and assemblage.

\* A<sub>s</sub>, A<sub>f</sub>, A<sub>m</sub>, A<sub>g</sub>, are the symbols by which the major rock units of the crystalline basement are distinguished on the geological map and sections.

*Ethiudna Calc-Silicate Group* (Fig. 7)

During the mapping work and related mineral investigations in the Kalaby and Plumbago areas, it was recognized that a bedded rock type characterized by abundant calc-silicate minerals, was one of the most persistent of the crystalline basement of the Olary Province. The writers also observed that these bedded formations play an important and fairly general role in mineralization control, for numerous mineral deposits of the Olary Province are confined to distinctive tremolite-diopside-epidote-garnet rocks alternating with more ordinary rock types, such as sandstones, schists and quartzites. In a few places an amphibole carrying brown dolomite is associated with the calc-silicate rocks. Elsewhere, originally limy beds appear to have been completely basified, thus giving rise to amphibolites which could be mistaken, but for their field relationship and mode of occurrence, for igneous intrusive bodies. However, amphibolitic intrusives also occur in the area, and because of the difficulty of distinguishing them from para-amphibolites, this category of rocks will be dealt with in a special paragraph.

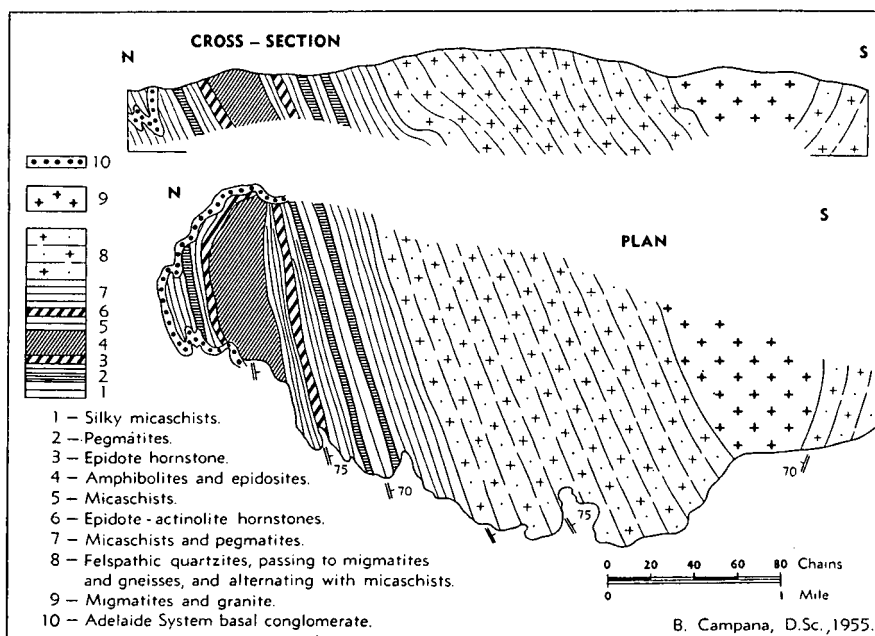


FIG. 1—THE ARCHAEOAN SUCCESSION IN THE WEEKEROO HILL AREA  
Plan and cross-section

In the type section of Ethiudna, the calc-silicate rocks are interstratified with a considerable thickness of well-bedded and highly folded sandstone-quartzites, which in places grade to albitites and microclinites due to feldspathization. From the base to the top, the measured Ethiudna section is some 800ft. in thickness and consists of the following members:

1. Grey flaggy feldspathized sandstone-quartzites, grading to gneissic granite and invaded in places by granite and pegmatite dykes either along or across the strike.

2. Pale-grey, massive to coarse banded zoisite-quartzite, 10ft. thick, the main constituents of which are clinozoisite, tremolite and quartz. Accessory minerals are zircon, sphene and apatite and scattered scheelite grains.

3. Flaggy feldspathized sandstone-quartzite 300ft. in thickness, consisting mainly of microcline, albite, quartz and subordinate biotite. Small amounts of calc-silicate minerals—tremolite, actinolite and scapolite—are present. Accessories are sphene, tourmaline and apatite. Weak disseminations of chalcopyrite and pyrrhotite have been found in borehole samples.



Fig. 2

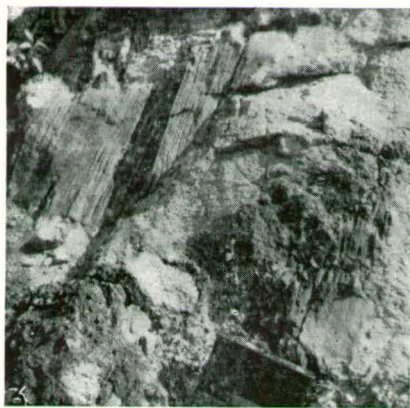


Fig. 3



Fig. 4

FIG. 2—WEEKEROO-BILLEROO MICA SCHISTS—WITH PEGMATITE SILL  
Weekeroo area, core of the central anticline—  
8 miles south of Plumbago homestead

FIG. 3—WEEKEROO-BILLEROO MICA-SCHIST SEQUENCE—LAMINATED HORNFELS INTERSECTED BY URANIFEROUS PEGMATITE DYKES

Jagged Rocks—2½ miles north of Glenorchy homestead

FIG. 4—UPPER PORTION OF THE WEEKEROO-BILLEROO MICA SCHISTS—LAMINATED SANDY LAYERS

Old Boolcoomata area—Near Cathedral Rock

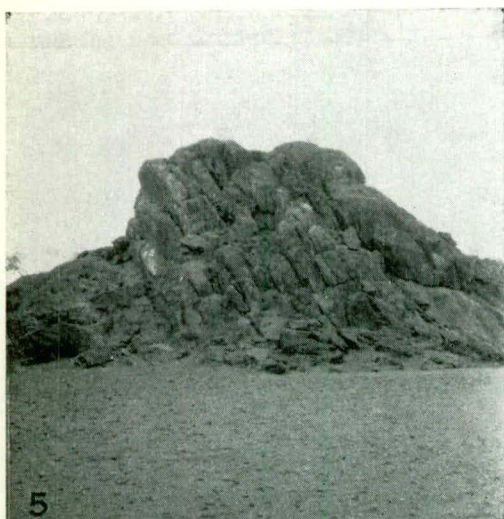


Fig. 5



Fig. 6



Fig. 7

FIG. 5—EPIDOTE-GARNET QUARTZITE AS A REMNANT IN GRANITIZED TERRAINS

Northern end of Mindamereeka Hill—3 miles north of Plumbago homestead

FIG. 6—BRECCIATION OF THE EPIDOTE-QUARTZITE HORIZON AT THE NOSE OF TIGHT FOLDS—WITH SUBSEQUENT INFILLING OF THE FISSURES BY EPIDOTE OR QUARTZ-FELSPAR MATERIAL

Outalpa area—7½ miles north-northwest of Outalpa homestead

FIG. 7—BEDDED LIMESTONE CONVERTED INTO A TREMOLITE-DIOPSIDE FORMATION

Ethiudna mine

4. Epidote-diopside quartzite, 20ft. thick, associated with coarse-grained calc-silicate beds of the skarn type consisting almost entirely of pale-pink grossularite, pale-green diopside and massive vesuvianite.

5. Well-bedded tremolite-diopside horizon, grading to a diopside-scapolite marble and having a maximum thickness of 30ft. Prominent bedding, a characteristic limonitic staining and a remarkable persistence make this formation quite distinctive on the field. It contains, in addition to coarsely crystalline tremolite, diopside and minor amounts of garnet, vesuvianite and sphene. Associated impure marble of fine to medium grain size is composed of calcite, scapolite, diopside and actinolite. Partial chemical assays of two borehole samples of this marble show the following compositions:

	Per cent	Per cent
CaCO <sub>3</sub> . . . . .	92.98	88.74
MgCO <sub>3</sub> . . . . .	0.45	4.64
Insoluble . . . . .	6.72	3.94

The tremolite marble formation (fig. 7) is considered a major stratigraphic marker in the Archaean succession, and also an important element of mineralization control, as suggested by the widespread sulphide mineral grains disseminated in the rock matrix. Its stratigraphic and metallogenetic significance is discussed in later paragraphs.

6. Massive cherty quartzite, up to 15ft. in thickness.

7. Flaggy feldspathized sandstone-quartzite, 300ft. thick, similar to No. 3 member.

8. Massive epidote-quartzite, 50ft. thick, with local development of very coarse vesuvianite and andradite.

9. Thin magnesian marble, grading to an actinolite-marble. Samples from two occurrences in the Ethudna mine area were chemically analysed with the following results:

	Per cent	Per cent
CaCO <sub>3</sub> . . . . .	9.8	25.3
MgCO <sub>3</sub> . . . . .	59.5	45.5
Insoluble . . . . .	21.5	20.9

10. Sillimanite-mica schists, quartz-mica schists with three thin bands of epidote-quartzite interbedded at about 200ft. intervals. North of the mine area one of these bands is conformably overlain by a massive dark-green amphibolite.

Calc-silicate rocks of the Ethudna type have a wide distribution throughout the Archaean terrains of the Olary Province. The most common rock of this suite is a tough, flinty, epidote-actinolite hornstone which rarely exceeds 100ft. in thickness, but which forms pinnacles rising above the low relief of the metasedimentary belt. Cathedral Rock, Dome Rock and the prominent hills east of Bimba mine are outstanding examples.

Specimens from the Bimba mine area have been studied in thin section and reveal the following mineralogical features:

A common type of epidote-quartzite is a green, fine-grained and dense rock with epidote, quartz, almandine and actinolite as main constituents. The rock is finely banded, with layers of a granoblastic quartzose aggregate, several millimetres thick, alternating with layers composed of quartz, epidote, pink almandine and actinolite. Apatite and sphene are also present in minor amounts.

This formation locally grades to an epidote-quartz-actinolite rock, almost approaching an epidosite in composition. It consists of an abundance of euhedral epidote, up to 1-2mm. in size, with interstitial quartz which is partly recrystallized. Bundles of fibrous actinolite develop throughout the rock. Sphene, apatite and opaque iron minerals occur as accessory minerals.

Another not uncommon rock type of this category is a green, dense, fine- to medium-grained schist, the main constituents of which are sericite, quartz and epidote. The latter occurs as fine granular aggregates and as larger subhedral crystals. Magnetite becomes in places a prominent mineral of this and of other calc-silicate beds, which are believed to derive from aluminous, ferruginous, calcareous sandy sediments.

Epidote-actinolite quartzite and garnet formations are quite persistent in the belt of metasediments which skirts around the granitic massifs, and they also occur within the granitized areas, where they form isolated relicts or xenoliths (fig. 5). The preservation of these relicts is undoubtedly due to the more calcareous composition of the original beds, which behave as "resisters" during the feldspathization process, while the bulk of the associated pelitic sediments have been converted into migmatites and granite. Massive, bold, calcareous relicts entirely surrounded

by granitic terrains are admirably exposed in the vicinity of Plumbago homestead (fig. 5), where the thick dark band of epidote-amphibole quartzite which forms the summit of Mindamereeka Hill may be traced for many miles to the north, before it disappears beneath a thick mantle of alluvial deposits built up around Tombstone Hill.

In the Weekeroo section described above, the members of the calc-silicate group occur in such an intimate and heterogeneous association that it becomes virtually impossible to map them separately (fig. 1). The more basic formations are dark-green hornblendites and amphibolites which vary from a coarse-grained to a micro-crystalline rock type. These basic elements form lenses and nests distributed at random in the more acid calc-silicate host-rock into which they gradually merge. No clear-cut contacts are observable between the various rock types. The sequence is often invaded by pegmatites, with development of feldspathized zones which indiscriminately affect each member of the suite, as if feldspathization had post-dated the basification of the original beds.

The Weekeroo basic suite has a maximum thickness of 2,500ft., and may be followed along the strike over many miles, before being covered at both ends by the transgressive Adelaide System beds.

#### *Arkosic Quartzites, Passing to Granite-Gneisses*

A thick sequence of arkosic quartzites and arkoses, has been observed in many places, stratigraphically above the calc-silicate group. Among the numerous sections observed, the following ones are the most characteristic:

*Weekeroo Section* (Fig. 1)—In the well-exposed and typical section of Weekeroo, the calc-silicate group is overlain by a thick succession of thick-bedded and fairly coarse arkosic beds, large portions of which merge into migmatites and granitic bodies. The clay-free facies of this group have given rise by metamorphism to prominent bands of brittle aplitic-looking rocks which sometimes extend on strike for many miles. One of the most characteristic exposures occurs along the slope of the narrow valley which dissects the Weekeroo anticline (plate I), east of the road from Plumbago to Weekeroo. These white flinty quartzitic rocks, which could be mistaken at first sight for an intrusive body, show however a clear bedding, in spite of the heavy brecciation and silicification which obscures much of the original sedimentary features. Along the strike, the beds often become more aplitic in appearance, or are entirely replaced by pegmatite bodies whose contact with the country-rocks is as clear-cut and smooth as that of the original sedimentary beds.

At a higher level the Weekeroo sequence consists of an alternation of quartzites and mica schists. Quartzites dominate, and show well-preserved bedding or very regular lamination, along which pegmatite-granite bands and strings have developed lit-par-lit laminae of hematite and magnetite, up to a few millimetres thick. This becomes in places quite a distinctive feature and emphasizes the very regular lamination. These magnetite-hematite laminae may be thick enough and close enough to form locally bedded iron formations, such as those interbedded in quartzites in the Ameroo Hill area.

*Ameroo Hill Section*—In this area the succession observed in the Weekeroo region is repeated in the same general order (fig. 8). A large syncline of the Archaean sequence shows, from the base to the top, the following succession:

1. *Schistose basal beds*: These consist mainly of mica schists and andalusite schists, minutely puckered and containing abundant imperfect porphyroblasts of andalusite and kyanite. These are overlain by—

2. *Calc-silicate rocks*, comprising bands of epidote-quartzites, garnet formations and amphibolites, interstratified with dark mica schists and surmounted by magnetite-barite quartzites, which pass along the strike to high-grade iron formations.

3. *Fine-grained gneissic granite*, which carries magnetite, orthite and fluorite. Pegmatitic phases of this rock contain magnetite with possible monazite intergrowths. Abundant field evidence suggests that the fine-grained gneissic granite is the result of granitization of feldspathic quartzites and arkoses. In many places the granitized formations still retain the original bedding, emphasized by thin layers of iron minerals observed both in little-altered arkosic quartzites and in their granitic derivatives.

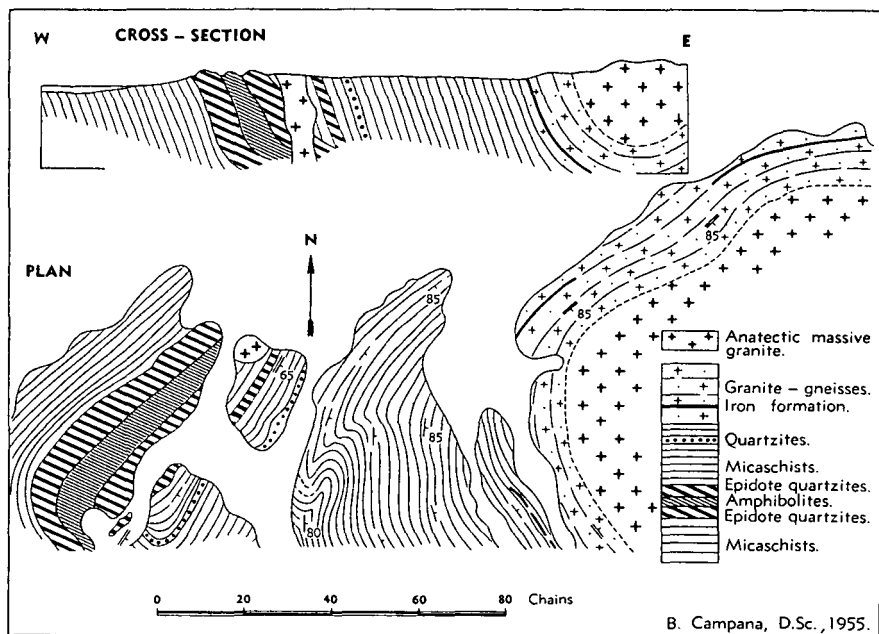


FIG. 8—THE ARCHAEOAN SUCCESSION IN THE AMEROO HILL AREA  
Plan and cross-section

*Old Boolcoomata Section* (Fig. 9)—Another characteristic section clearly showing the stratigraphic succession of the Archaean terrains is observable in the Old Boolcoomata and Cathedral Rock areas. The lower beds consist of rocks of the calc-silicate group, overlain by quartzites which pass rapidly to aplitic gneissic granite or to massive granite. At Meningie Well, easterly of Old Boolcoomata homestead, the succession is as follows:

1. *Mica schists*, invaded by pegmatites.
2. *Calc-silicate group*, consisting of (a) Epidote quartzite, much dragged and brecciated, describing a complex anticlinal loop; (b) Mica schists and pegmatites; (c) Bedded iron formation, baritic or calcic in places and graded to a coarse-banded magnetite-tremolite-garnet rock near the granitic bodies; (d) Mica schists and kyanite schists.
3. *Quartzites, grading to an aplitic-looking gneissic granite*. A noticeable bed of this horizon is a red quartzite, somewhat granitized, well-banded, with gritty layers and occasionally current-bedded. Quartz is the main rock constituent, with abundant minute magnetite granules. Green actinolitic hornblende is also an important accessory mineral.

As shown in the sections described above, the bedded iron formations associated with the calc-silicate group of rocks do not attain a great development. Their thickness does not exceed a few inches and their presence has been noted at intervals only.

At a higher level however, the Archaean succession contains more conspicuous bands of bedded quartz-hematite-magnetite rocks, which reach in places over 30ft. in thickness. These bands often give rise to dark pinnacles standing out in an otherwise depressed and rolling topography. A suite of discontinuous outcrops is found at intervals in the Billeroo and Koolka areas. These belong to the same

stratigraphic horizon, the continuity of which has been proved by geophysical investigations. In the Koolka area for instance a magnetometric survey carried out by the Geophysical Section of the Geological Survey of South Australia has traced the magnetite-bearing formation over 10 miles. At Billeroo the same formation has been recognized over a distance of 1½ miles (plate I).

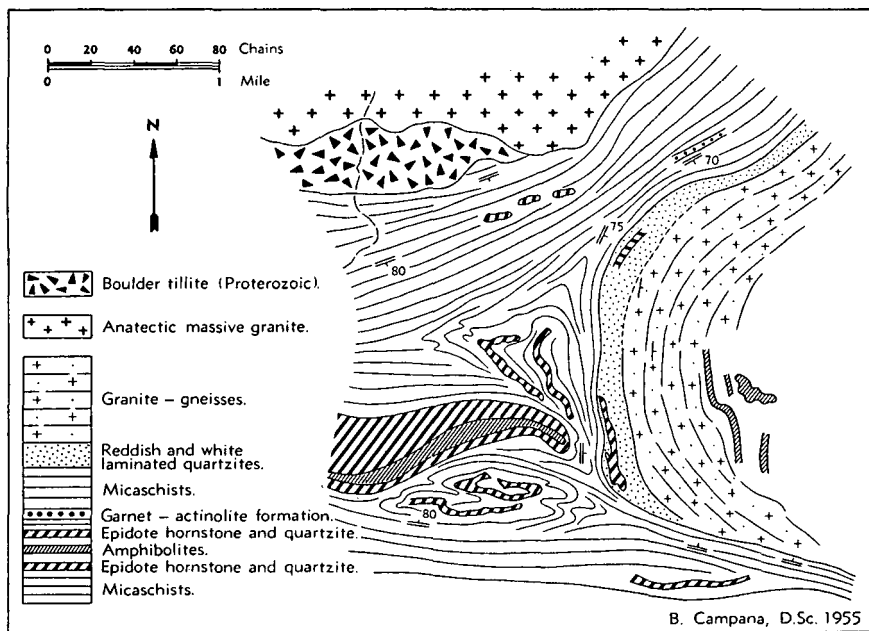


FIG. 9—PLAN OF THE ARCHAEN SUCCESSION IN THE OLD BOOLCOOMATA AREA

The Koolka-Billeroo magnetite formation is a well-laminated to massive bed, whose thickness rarely exceeds 30ft. Its most massive and iron-rich parts consist of quartz, magnetite and hematite, with which actinolitic hornblende is not uncommonly associated. By gradual decrease of iron content and increase in actinolite, the rock passes sometimes to an actinolite-quartzite. Elsewhere the formation merges into magnetite-bearing schists, phyllites, or sandstones, which have been more easily worn away and covered by drift. This last type of rock is well developed in the Dome Rock area, where ferruginous sandstones, 150ft. thick, have been described by Dickinson (1942).

Petrological evidence and general geological considerations suggest a possible correlation between the Dome Rock iron formations and those of the Koolka-Billeroo areas. From the relative constancy of their characters along the strike, from the similarity of the stratigraphic assemblage in the different localities, and from comparisons with the Precambrian iron formations found elsewhere in the world, it may be inferred that they represent the metamorphic equivalent of sedimentary iron-rich beds, deposited in small basins or marshes.

#### *General Stratigraphic Column*

The foregoing sections, studied in various part of the area and correlated by detailed regional mapping, show that it is possible to recognize stratigraphic markers and to establish a chronological order of deposition within the Archaean sequence, as long as advanced granitization does not completely obliterate the primary sedimentary features. Although more work remains to be done to clarify many stratigraphic and petrological details, the general stratigraphic column of the Archaean metasediments may be thus tabulated:

Stratigraphic level	Main rock types	Localities of typical occurrences
UPPER GROUP— Arkosic quartzites passing to granite gneisses	Bedded quartz-magnetite formations. Felspathic quartzites and arkoses, frequently well bedded or laminated, containing bedded iron formations, and grading to granite-gneisses and migmatites in area of pronounced granitization	Weekeroo Hill area, Ameroo Hill area, Old Boolcoomata-Menin- gie Well area
MIDDLE GROUP— Calc-silicate rocks	Relicts of actinolitic dolomite and marble, tremolite-diopside rocks, skarn rocks, garnet rocks and epidote-actinolite bands, separated by flaggy sandstones and schists. Amphibolites, associated in places to epidote-actinolite quartzites and skarn rocks. Thin-bedded iron formations present in places	Ethiudna area, Weekeroo Hill area Mindamereeka Hill, Ameroo Hill, Old Boolcoomata, Meningie Well, Cathedral Rock, Dome Rock
LOWER GROUP—	Mica schists and paragneisses with laminated quartzitic sandstones, silky phyllitic schists or high-grade schists	Weekeroo Hill, Billeroo, Black Hill, Koolka Hill, Ameroo Hill

#### *Felspathized Archaean Metasediments (A<sub>f</sub>)*

This rock unit is essentially formed by the rock types described above—schists, paragneisses, calc-silicate formations and quartzites, which however have undergone a certain amount of felspathization. In places a great number of pegmatites and granite lenses are present in the succession, either as sills developed along arkosic beds which they possibly replace (fig. 2), or also as long narrow dykes which may intersect the series at a high angle and which in some cases can be traced for more than 1 mile in length.

This unit represents an intermediary stage of granitization. The next stage is the migmatite group (A<sub>m</sub>) described in the following paragraph.

#### *Migmatites and Granite-Gneisses (A<sub>m</sub>)*

Approaching the central portion of the area, felspathized metasediments of the Archaean sequences merge into migmatites and granite-gneisses which constitute the third unit of the crystalline basement. This unit gives rise to bold, wooded ridges which occupy large portions of the regions of Boolcoomata, Outalpa, Bimbowrie, Plumbago, Crocker Well, Glenorchy and Mount Victoria.

The rock assemblage is most characteristic of granitized areas. Pelitic metasediments grade rapidly to migmatites and granite-gneisses, which in turn pass to fairly massive granite in the more central portions of the complex. The process of granitization may be clearly observed through all its development stages (figs. 10-12). Felspathic quartzites may grade to an aplitic-looking granite by blastic recrystallization, as is the case for many arkosic rocks described above. But it is often manifest that the original metasediments have been mobilized to a varying degree, and that feldspar-rich material has been injected or permeated into the rocks in a liquid or very plastic state. For, independently of their original composition, these rocks are intersected at any angle by numerous quartz-feldspar dykes, veinlets or strings, which may be so close as to obliterate the original characters of the rock. Lit-par-lit alternations of unaltered country-rock and quartz-feldspar bands are plentiful, thus giving to the rocks the characteristic ribbon pattern of injection gneisses. Ptygmatic folding of the alternating bands is also common. By an increase of introduced quartz-feldspar materials the rocks grade to migmatites, which in turn merge into granitic rocks from which all sedimentary features have been obliterated (fig. 13). Noticeable examples of such a process of granitization are observable along numerous creeks in the areas of Glenorchy, Mount Victoria, Weekeroo, Boolcoomata, etc., where arid climatic conditions and infrequent

torrential erosion produce and maintain exposures comparable for their clarity and variety with those described by Sederholm and Wegmann in the glacially polished migmatite of Finland.

It may be seen from the preceding examples, that granitization *in situ* of pre-existing metasediments is a wide-spread feature of the basement rocks of the Olary Province. However, it must be added that magmatic mobilization and displacement undoubtedly occurred, for in many instances large granitic dykes or pegmatite clearly show intrusive relationships with the country-rock. The fact that part of the granite was, at some stage of its formation in a liquid or semi-liquid state, is also evidenced by the mode of occurrence of xenoliths (fig. 16). These consist often of calc-silicate beds, which in places have been forcibly dis-jointed and float, as it were, in a granitic groundmass. However, by following these beds along their general strike, they are seen becoming again continuous and undisturbed where granitic intrusions have been less conspicuous or less violent.

In the zones of intense granitization, and particularly near the anatectic masses, the calc-silicate beds are intersected, at a high angle to the strike, by granite dykes and by very numerous pegmatites. In these zones arkosic layers and quartzites have as a rule completely lost their sedimentary character, but mica schist and sillimanite schist relicts and especially epidote-actinolite quartzite and hornfels are found up to the very edge of the anatectic granite, thus providing evidence of the regional tectonic trends even in the areas of advanced migmatization.

In the zones of migmatite and granite gneiss, dykes and sills of pegmatite and granite are abundant. Leuco-granitic rocks, such as the uranium-bearing adamellite and alaskite to be found in the Crocker Well area, are found at intervals, as shown in a later paragraph. Among the granitic rocks of these units, there is a coarse-grained, reddish, biotite-muscovite granite, common occurrences of which are also to be found near Crocker Well and Mount Victoria. Rocks of a granodioritic composition are also an associate of migmatite and granite. Quartz veins and plugs, associated or not with pegmatites are also present, and characterize in many instances important shear zones. Long metadolerite dykes are also to be found at intervals intersecting at various angles the regional trends.

#### *Anatectic Granites, Granodiorites, and Granulites (A<sub>g</sub>)*

The most central portions of the granitized areas are often occupied by undifferentiated and almost structureless granite masses (figs. 17-19). These give rise to conspicuous ridges and bosses, whose summits are often a few hundred feet above the level of the surrounding zones of migmatites (fig. 19). Thus their characteristically rounded and smooth profiles form distinctive topographic features, among which those of the Booleoomata area, Triangle Hill, Bimba Hill, Tombstone Hill, Ethiudna Hill and Mount Victoria are the most important. Other numerous smaller occurrences are irregularly distributed within the migmatite complex. These have not always been mapped either because their boundaries are indefinite or because they are too small to be graphically represented at the map scale. It has, therefore, to be kept in mind that the picture of the granitized terrains on the map printed herein involved some degree of simplification. This is unavoidable even in large-scale mapping, for the complexity of the relations between migmatite-granite-gneiss complex and anatectic granite is such that it defies complete definition. In almost every instance the massive granite is the last stage of a process of felspathization, all previous stages of which are also represented.

Exposures of this rock type are particularly extensive and fresh, for they are continuously rejuvenated by the peculiar exfoliation form of weathering induced by the arid climate prevailing in the area.

Even on short distances, the granite shows much lateral variation in texture and composition. From a coarse-grained or porphyritic type, it grades rapidly to a pegmatitic variety or inversely to a fine-grained dense rock. Because of the

irregular distribution and frequent lithological gradations, the detailed mapping of these granite varieties is most difficult. It has been noticed, however, that certain granite types are predominant in a given area and poorly represented elsewhere, so that a broad picture of their regional distribution can be attempted.

In the Boolcoomata area, Whittle (1948) described a massive medium- to coarse-grained, feldspar-rich granite as the dominant rock of the granite suite. In the area of the Kalabity sheet the anatectic masses consist of massive adamellites, associated granites and minor granodioritic bodies. Some occurrences of these rock types have been systematically sampled, and their microscopical study, carried out by Whittle (Chief Mineralogist) will suffice to illustrate their main characteristics.

Some 3 miles south of Kalabity homestead, a light-coloured, medium-grained potassic granite consists essentially of microcline and perthite, with subordinate oligoclase and quartz. The rock has a subidiomorphic texture, with a grain size of 0.25 cm. Muscovite and biotite are also abundant rock constituents and possess a random orientation. A particularly interesting feature of this granite is the development of bundles of sillimanite needles in the muscovite-sericite aggregate. Much opaque mineral and a little zircon are present as accessory constituents. The feldspars have a poikilitic texture towards quartz, feldspar and quartz showing interpenetrant faces. The rock appears unstrained.

About 4 miles south-southwest of Kalabity homestead occurs a light-coloured, coarse-grained and distinctly porphyritic granodiorite. Oligoclase is the dominant mineral. Quartz and microcline, although in subordinate amount, are also important constituents. The phenocrysts, up to 2 cm. in size, are largely oligoclase idiomorphs, sometimes intergrown with microcline. Large flakes of muscovite and greenish-brown biotite are abundant, with a black opaque mineral usually intergrown with biotite. Euhedral apatite and zircon are present in minor amount. The effects of strain are few, and poikilitic texture is again seen in feldspar.

Another granodioritic rock of this area is medium to coarse-grained oligoclase ( $Ab_{83} An_{17}$ ) being its main rock constituent. Some 20-30 per cent of quartz is present in association with oligoclase. Chloritized biotite-pennine is abundant in the interstices of other minerals or isolated in small clots. Inclusions of radioactive zircon are numerous in the chlorite.

Metasomatism appears also as an important process of granitization. A series of specimens collected in the Tonga Hill area, at the edge of the anatectic masses of Bimba Hill-Triangle Hill, are described by Whittle as highly distinctive granitoid rocks of metasomatic origin.

The more important of them is a granitoid, fine-grained, quartz-feldspathic rock forming the prominent Tonga Hill ridge and outcropping again 1 mile northwest of Poodla Dam. It consists mainly of sodalase, microcline and quartz. The sodalase has a peculiar twin structure due to combined albite and periclinal lamellae. The rock has a cataclastic texture, shown in optical strain. Poikilitic texture of quartz in feldspar is very prominent. Actinolite, sphene, epidote and a black opaque mineral have been developed in the rock, apparently as a result of metasomatism. Quartz is partly recrystallized and occurs mainly as granular aggregates of strained grains.

Along the northeast slopes of Tonga Hill this formation is flanked by a dark-green, mottled rock, essentially consisting of diopside, hornblende and plagioclase. Diopside is predominant as large subhedral crystals, altered in part to fresh bluish-green hornblende. Large crystals of sphene, apatite and magnetite have been developed by metasomatism. Finer-grained, granoblastic sodalase forms the groundmass. Quartz is present in very little amount, together with epidote, biotite and granular magnetite. A particular feature of this formation is the abundance of coarse apatite grains.

Granitoid rocks of this type are fairly common throughout the crystalline basement of the area. Their classification is difficult. For mapping purposes they have been ranged either in the migmatite complex or in the calc-silicate group according to their composition. All have, macroscopically, a pseudo-igneous appearance, but would represent in fact feldspathized rock rich in mafic minerals. Typically, these rocks are massive, medium-grained, very rich in sodalase and poor in quartz. They may be defined as albite-ferromagnesian granulites.

### *Pegmatites*

In no other part of the State are pegmatitic rocks so widely and variously represented as in the area under review. Throughout the whole tracts of country occupied by the crystalline rocks, swarms of pegmatite and/or pegmatitic granite give rise to outstanding, elongated outcrops which may be traced sometimes for many miles.

The most conspicuous occurrences of pegmatite are found in the areas of Booloomata, Bimba Hill, Calico Well, Wiperaminga Hill, Koolka Hill and also in the Mount Victoria area, invading every facies and zone of the crystalline basement. They become particularly abundant in the intermediate areas occupied by the feldspathized metasediments and migmatite complex, but they are also to be found in the inner granitic cores and in the outer skirt of schists and quartzites. Pegmatite varies in size from thin sheets and strings, developing in fissures or in a lit-par-lit manner along the bedding planes of the country-rocks, to huge lenticular stocks, dykes or sills which are often over 100ft. in thickness and over 1 mile in length.

In the outer belts of metasediments and feldspathized metasediments, pegmatite bodies are found mainly as sills. As the schistose country-rock is more easily worn away, these sills stand out as regular walls, which show conformable, very smooth and undisturbed contact surfaces with the host-rock and retain an absolute constancy of thickness over long distances. This mode of occurrence would suggest that part at least of the pegmatite suite has been formed by metasomatism. It has also been noted in this respect that pegmatite swarms of the metasedimentary belt often follow a more quartzitic or arkosic horizon, suggesting a genetic relationship between pegmatite and host-rock. This however is not the general rule, and in places long pegmatite dykes crosscut at a high angle the whole sedimentary succession, irrespective of the petrological composition of single beds or groups of beds (figs. 3, 15).

Within the migmatite zone, pegmatites are also plentiful, but their relationships with the host-rocks are not as clear as in the preceding cases. Large pegmatites are found to intersect metasedimentary bands and granitic bodies alike, but more often pegmatitic veins and segregations are so abundant that they leave no uncontaminated masses in the host formations and become in fact in many places the dominant rock type.

Likewise the anatectic granite is not uncommonly crosscut by large pegmatitic bodies of very irregular shape and size. Well-defined dykes or sills of such as those of the metasedimentary or migmatite zones are uncommon. Instead develop pegmatitic masses having no clear-cut contact with the granite, into which in fact they gradually merge.

Most of the pegmatites of the area are acid, felspar-rich, coarse-grained rocks, with a quartzose core and little mica. As accessory minerals, magnetite, tourmaline and to a lesser extent beryl, have often been noticed. In addition, a very large suite of more rare minerals has been recently discovered which are described in detail in Part II of this *Bulletin*.

Coarse-grained microcline pegmatites, containing minor albite, quartz and muscovite amounts, are particularly abundant in the area covered by the Kalabity

ARCHAEAN METASEDIMENTS—ARKOSIC QUARTZITE PASSING TO MIGMATITE AND GRANITE-GNEISS



Fig. 10



Fig. 11

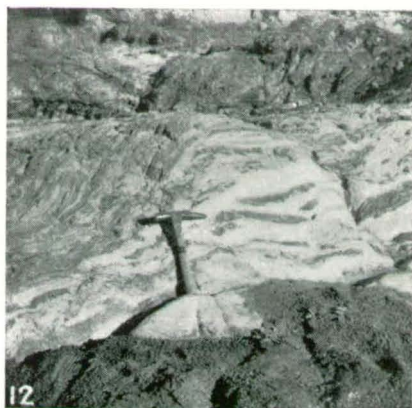


Fig. 12

FIG. 10—UNALTERED LAMINATED ARKOSIC QUARTZITE (OUTALPA QUARTZITE)  
Old Boolcoomata area—Near Cathedral Rock

FIG. 11—DEVELOPMENT OF QUARTZ-FELSPAR STRINGS ALONG THE BEDDING  
PLANE OF THE ARKOSIC QUARTZITE FORMATION  
About 60 feet above the outcrop shown in fig. 7

FIG. 12—MIGMATITE STAGE IN THE ARKOSIC QUARTZITE FORMATION  
About 100 feet above the outcrop shown in fig. 7



FIG. 13—GRANITIZATION IN BEDDED QUARTZITE—  
WITH DEVELOPMENT OF ARTERIC MIGMATITE  
AND GRADATION TO MASSIVE GRANITE

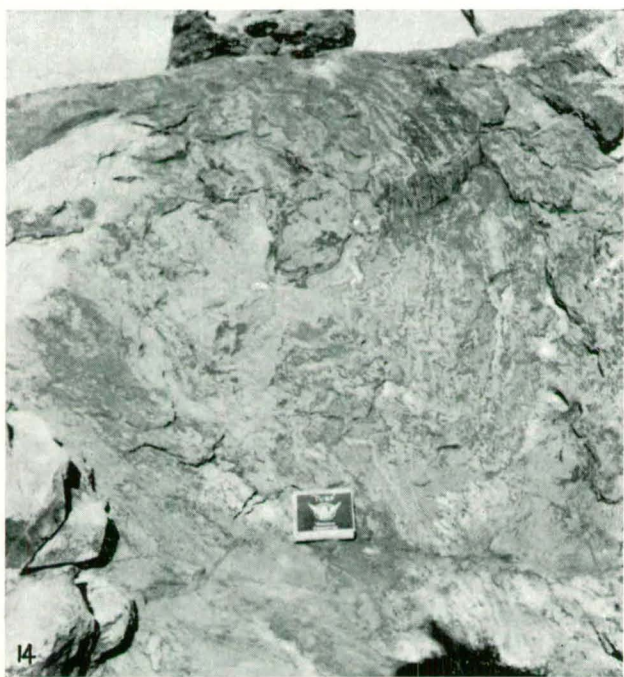


FIG. 14—GRANITIZATION IN FOLIATED SCHIST—  
WITH DEVELOPMENT OF ARTERIC MIGMATITE SHOWING  
PTYGMATIC FOLDING

Glenorchy area

sheet. Quartz is often found as a graphic intergrowth with microcline-microperthite. Albite has been found as anhedral crystals with a composition of  $Ab_{94}An_6$ . Small euhedral crystals of apatite have also been observed.

Other pegmatites of this area are light-coloured adamellite pegmatites, containing comparable amounts of orthoclase and oligoclase. Quartz is also abundant and occurs as coarse granular crystals which show severe optical strain. Muscovite is present as crystals up to 1-2 cm. in size. Brown biotite and opaque black minerals occur as sparse accessory minerals. In places, felspar crystals have been subject to such alteration that only a crystal skeleton remains. Secondary silica may interfinger the felspar in long streaks, and numerous flakes of muscovite occur, in random orientation, over the altered felspar.

Pegmatite bodies of the Bimbowrie-Booleoomata area, some of which are of economic importance, have been described by previous workers, particularly by Mawson (1912), Whittle (1948) and Sprigg (1954).

#### *Aplites, Alaskites, and Adamellites*

Aplitic lenses are commonly associated with pegmatites, although they form much less-conspicuous and less-numerous bodies. They represent a facies of the pegmatites, to which they often gradually pass. Because of their intimate association and identical mode of occurrence these rock types have not always been separately represented on the regional maps of the area; but they have been differentiated and carefully investigated in zones of mineralization, as it will be shown in Part II of this work. It will suffice here to make reference to the Crocker Well adamellites, alaskites and pegmatites, of special economic importance, and to the extensive adamellite masses of the Triangle Hill-Bimba Hill-Kalabity area which have also been microscopically investigated.

The Crocker Well adamellites have been described by one of the writers (King, 1954) as an originally massive rock-type which has been modified in places by jointing and by tectonic stresses. The main rock constituents are potash felspar, sodic plagioclase and quartz, with an unusually small content of biotite. The main occurrence, north of the Crocker Well exploration camp, is over 2 miles in length and almost 1 mile wide and it includes a narrow band of metasediments which runs east-west. The adamellites are intersected by coarse felspar-quartz-rutile pegmatites, the most prominent of which in-filled joint fissures while others are quite irregular in shape and disposition.

Alaskites and albite pegmatites found in close association with adamellites consist of medium-grained felspar-quartz rocks. Pegmatite bodies intersect the adamellite and appear thus to be a later product of the same granitization process. The alaskites consist of potash felspar and albite in equal proportion, with blue quartz, which also occurs in the associated pegmatite veins.

Absite (brannerite) occurrences have been located in many places within the adamellite-alaskite complex, and there is no doubt that the mineralization has a close genetic relationship with these rock types. Determinations of the absolute age of some of the uranium minerals have been carried out on the basis of uranium/lead ratio technique as discussed below. The Triangle Hill-Bimba Hill adamellites are light-coloured, medium- to coarse-grained rocks, the essential minerals of which are microcline, oligoclase and quartz. Orthoclase and perthite have also been observed in some of the specimens collected. Large flakes of muscovite are abundant, as also are greenish-brown flakes of biotite. Magnetite, tourmaline, zircon, apatite and rutile are commonly present as accessory minerals.

Specimens of the Triangle Hill adamellite exhibit a subidiomorphic granular texture, which becomes in places slightly porphyritic. Quartz, although strained optically, shows only incipient recrystallization at intergranular borders. Both micas have a random orientation, and are partly altered to chlorite. Oligoclase

has been altered in places to kaolin and sericite. Felspars have a poikilitic texture towards quartz and mica, suggesting that the felspar was formed in place.

The Bimba Hill adamellite appears, from microscope evidence, to have been considerably stressed, without brecciation but with recrystallization of quartz, optical strain, and destruction of the idiomorphic form of the felspars. As for the Triangle Hill adamellite, the poikilitic texture displayed by the felspars, towards quartz and mica, suggests growth of felspars *in situ*, due to granitization rather than to magmatic crystallization.

A similar rock type has been found 4 miles southeast of Kalabity homestead, with oligoclase ( $Ab_{88} An_{12}$ ), microcline, perthite, orthoclase, quartz, and muscovite as essential constituents. The grain is very irregular, ranging from an original size of 0.25 cm. to a fine aggregate of grains having less than 0.1 mm. in diameter. Brecciation is incipient within the rock, its texture being in part cataclastic.

Another adamellite occurrence in the same area is slightly richer in sodic felspar. Oligoclase of composition  $Ab_{87} An_{13}$ , microcline-micropertthite and quartz are essential minerals, together with muscovite and biotite. Radioactive zircon is present in accessory amounts, some crystals being included in biotite and other larger ones free.

#### *Amphibolite Group*

This group consists of a suite of basic rock types which are exclusively associated with the crystalline basement, but show wide variations in composition, mode of occurrence and origin.

These rocks have been generally described in previous work as igneous dykes or sills intruding the Archaean metasedimentary succession as well as the younger granitic terrains of the area. But recent investigations in the adjoining Broken Hill region have clearly proved that many rock types of the basic suite are derived from calcareous sediments. This origin has been confirmed by the current investigation in the Mutooroo, Ethidna and Weekeroo area, and more recently by prospecting work in the region covered by the Outalpa military sheet (plate I). It is thus well established that most of the amphibolites of the Olary crystalline terrains are altered calcareous beds of the calc-silicate group already described. However, amphibolitic rock of intrusive character also occurs in the area. As no general field criteria for distinguishing between the two rock types have been recognized and also because of the uncertainty as to their age and their petrological characteristics, no detailed subdivision of the basic rock group has been attempted. To illustrate the field relationship of these rocks, it will suffice to describe some of the most conspicuous occurrences of para- and ortho-amphibolites.

#### *Para-Amphibolites*

These occur as a facies of the calc-silicate beds, and reference to them has already been made. They consist of dark-green to black rock types, sometimes well bedded, massive in other instances, but always conformable with the associated country-rock. Their thickness, which rarely exceeds a few feet, is remarkably constant, and parallel bands may sometimes be traced for several miles, without significant changes in composition or disposition. The most conspicuous of these bands is between the Mutooroo mines and Ballara station, where they form the prolongation of one group of the para-amphibolites recognized in the Broken Hill stratigraphic succession.

The Mutooroo mines para-amphibolites consist of a series of at least six bands interstratified with well-laminated granite-gneisses. Petrologically, this formation can hardly be distinguished from intrusive bodies. A. W. G. Whittle (Chief Mineralogist), who examined these rocks microscopically, has described them as follows:

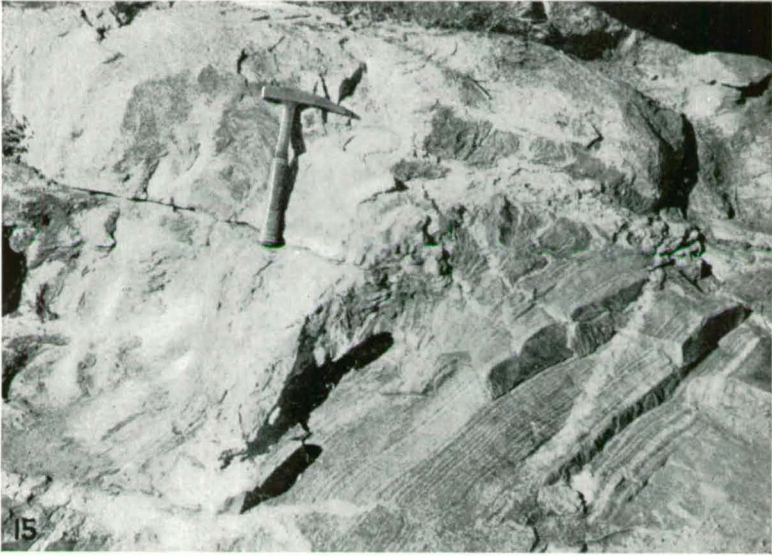


FIG. 15—GRANITIZATION PROCESS IN OBDURATED LAMINATED HORNFELS BY INFILLING OF FISSURE NETWORKS WITH URANIFEROUS QUARTZ-FELSPAR MATERIAL  
Talbot Creek—3 miles east of Glenorchy station



FIG. 16—ADVANCED STAGE OF GRANITIZATION IN OBDURATED HORNFELS—SHOWING PRESERVATION OF BLOCKY REMNANTS IN PREDOMINANTLY STRUCTURELESS URANIFEROUS LEUCOGRANITE  
Talbot Creek—3 miles east of Glenorchy station

PROTEROZOIC GRANITIC ROCKS

Fig. 17—COARSE-GRAINED FELSPAR-RICH ANATECTIC GRANITE—WITH SEDIMENTARY REMNANTS  
About 500 yards north of Mount Victoria trig station.

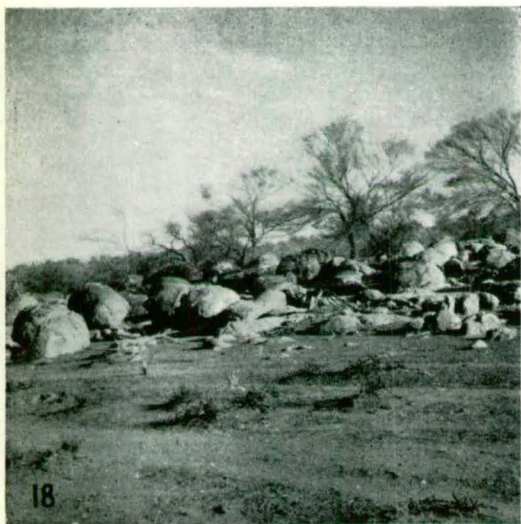
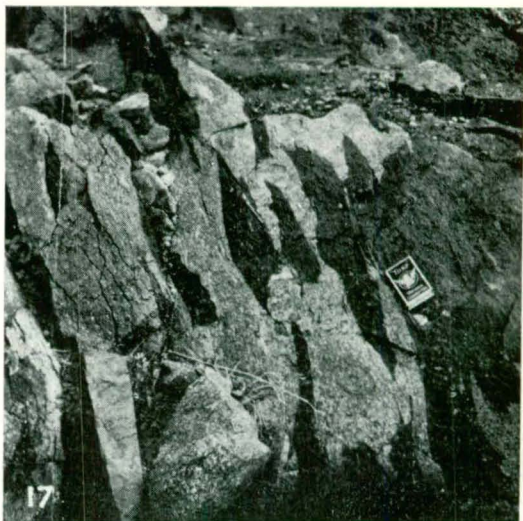
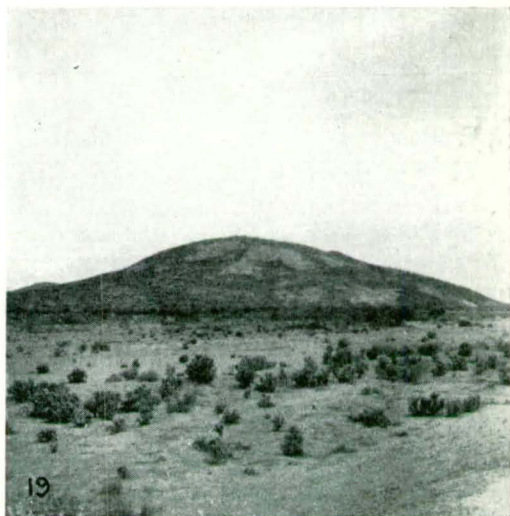


FIG. 18—ANATECTIC GRANITE—TYPICAL TOR STRUCTURE  
About 5 miles southeast of Plumbago homestead

FIG. 19—MASSIVE ANATECTIC GRANITE FORMING PROMINENT BOSSES IN THE CENTRAL PORTIONS OF THE GRANITIC TERRAINS

Tombstone Hill—4 miles north of Plumbago homestead



"There is no great compositional or textural variations among the basic rocks at Mutooroo mines, except that in the central portion of the field the rocks are slightly more acid, viz. quartz 'micro-gabbro' to quartz 'micro-diorite', whereas they are normal calc-alkaline gabbros to the north and south of the central region.

"The micro-gabbro is a fine-grained, dark-coloured massive rock with an hypidiorphic granular texture. Its grain size is within the limits 0.5-1.0mm. Strongly pleochroic blue-green to light-brown hornblende make up about 60 per cent of the rock, mainly as subhedra or euhedra which carry numerous inclusions of quartz.

"There is an abundance of unaltered labradorite ( $Ab_4-An_6$ ), and about 5 per cent of interstitial quartz. Minor constituents include a little scapolite occurring as alteration rims round feldspars, epidote in aggregates of small granules along feldspar interfaces, associated with granular quartz and scattered fine-textured epidote-leucoxene aggregates."

Thus petrologically the Mutooroo amphibolites vary from a gabbroic to a micro-dioritic type. According to Whittle the gabbroic types are frequently affected by uraltization and scapolitization phenomena, scapolite being in places extremely abundant, particularly in the proximity of feldspar. Other constituents include sphene, clinozoisite and sometimes granules of apatite.

The writers' opinion that these formations are not igneous but para-amphibolites is based on field relationships observed throughout the Olary Province and in the adjacent Broken Hill district. In the Mutooroo-Ballara area, for instance, the amphibolites show conformable contacts with the banded gneisses forming the country-rock, and follow sympathetically the local structures. North of the Mutooroo mines the trace of an amphibolitic band forms a closed ring which evidently corresponds to an overturned fold (plate I). Likewise at Pine Hill, 2 miles to the east, the continuity and parallelism of a few bands of amphibolites emphasize the structural pattern of the area and may be considered the most valuable marker beds. The most decisive argument in favour of a sedimentary origin of these amphibolites is however the unquestionable gradual passage from calcareous sediments (or metasediments) to amphibolites, which has been observed in many places and by different workers in the Broken Hill area and in the adjoining South Australian region. In the Broken Hill area the amphibolites are derived from a group of calcareous beds, among which the Ettlewood Limestone is the best known. In the South Australian area, the association of amphibolite with the calc-silicate metasediments is a common feature (figs. 1, 8, 9). Basification of limy beds has been directly observed in the Ethiudna area where a dolomitic limestone, by progressive enrichment in hornblende, is seen grading to a massive para-amphibolite.

#### *Ortho-Amphibolites*

This category includes the basic rocks which have cross-cutting relations with the bedding planes or with the regional structural trends of the country-rock, and which therefore are considered to be intrusive. The better known are found in the Radium Hill uranium mines, already described in a previous *Bulletin* by Sprigg and Whittle (1954). In this mine, two generations of amphibolites have been noted, both of which have an intrusive relationship with the enclosing formations and with the Radium Hill lode. The older amphibolites are altered hornblendite; the newer ones range from an ultra-basic to a dioritic composition. Among these, tonalites, microtonalites, microdiorites and diorite-porphry dykes are the most common rock types.

Other conspicuous occurrences of rock, of this category are found north and south of Outalpa Hill, south of Plumbago head station, east of Weekeroo Hill, south of Old Boolcoomata homestead and easterly of Triangle Hill. Minor amphibolitic lenses are found scattered at random in practically all formations of the crystalline basement. Many of them, of a doleritic to metadoleritic type, occur in sheared zones of the migmatites and granites and may be traced over long distances, notwithstanding a lenticular disposition and a thickness which rarely exceeds 50ft. In other instances swarms of ortho-amphibolites occur adjacent to or within the

calc-silicate sequence, and may be distinguished from the para-amphibolites of this group only by their crosscutting attitude. The detailed petrological investigation and separate mapping of these two rock types was beyond the scope of this writer's survey and has been therefore omitted. Ortho- and para-amphibolites are shown on the accompanying maps as a single rock unit.

## Age, Metamorphism, and Granitization of the Crystalline Formations:

### AGE

No organic remains whatever have been discovered in the Pre-Cambrian formations of the Olary Province. The metasediments of the basement are not only highly recrystallized, but their deposition is of great antiquity and very probably pre-dates the earliest known organisms. The sedimentary mantle, to which an Upper Proterozoic to Lower Cambrian is assigned, is in this respect also most unfavourable, for its deposition often took place either in a brackish to continental environment or under glacial and subglacial climate.

In spite of the total lack of fossils, age relationship between the different rock units have been established, owing to the presence of radioactive minerals in the crystalline complex. Age determinations based on the uranium/lead ratio have been carried out for the Radium Hill and Crocker Well uranium fields, and the result may be thus tabulated:

Locality	Mineral and Mode of Occurrence	Best age of mineral (million years)	Inferred age and type of country-rock
Crocker Well . . . . .	Absite (brannerite) as fissure veins in adamellite. Also as grains disseminated in the adamellite groundmass.	580 $\pm$ 30*	Proterozoic: anatectic granite
Radium Hill . . . . .	Davidite, epigenetic	1,510 $\pm$ 100†	Archaean: Gneisses, invaded by pegmatites and intersected by amphibolites

\* Age determination by Dr. J. L. Kulp, Columbia University, New York.

† Age determination by Prof. J. T. Wilson, University of Toronto, Toronto.

It may thus be seen that age-determination data justify and emphasize the two main divisions established in the crystalline formations, i.e., an older metasedimentary suite and a much younger granitic complex. This has been confirmed by data obtained with similar methods in other parts of South Australia, and it may be conclusively stated that the metasediments of the Olary Province are of Archaean age. They pre-date the Radium Hill lode, and may compose more than one cycle of sedimentation, although no unconformity has been noted within the Archaean sequence.

As for the younger granitic rocks, it is now recognized that they are responsible for the last phase of uranium mineralization in the Crocker Well area (see Part II). In particular the absite (brannerite) mineralization would have taken place in the final stage of the granite consolidation, and it is reasonable to assume that the age determination of the mineral dates also with a good degree of approximation

the granitic host-rocks. These have thus been formed at the end of the Middle Proterozoic or at the very beginning of the Upper Proterozoic times.\*

### METAMORPHISM AND GRANITIZATION PROCESS

D. Mawson (1912) was the first author to give a comprehensive account of the metamorphism phenomena and emplacement of large granitic masses of the Olary Province. This author recognized the sedimentary origin of most of the metamorphic rock suite, although he held that the granite gneisses surrounding the massive granite masses would represent igneous granitic rocks which have been subsequently metamorphosed. Mawson considered the granite as intrusive bodies, responsible for many contact, assimilation and feldspathization phenomena of original sediments. He classified the granite as a protogine type, occurring both in Olary and Broken Hill areas.†

In the last few years, the genesis of the granitic suite and its relationship with the country-rock have been investigated by geologists of the South Australian Department of Mines, and particularly by Whittle, Sprigg and the writers.

Whittle (1948), after a detailed study of the Boolcoomata area, concludes that "much evidence suggests that the granite masses of Boolcoomata are the result of a process of granitization rather than of intrusion".

The writers found this view partially correct, for vast portions of the Archaean terrains have been converted into granitic-looking rocks, although mobilization was so great that masses of anatectic granite bear in places distinct intrusive relationship with the Archaean metasedimentary sequence. On the other hand, Whittle's view that glacial beds of the Adelaide System have also been partly granitized has to be discarded, for in the area concerned the granitization phenomena definitely pre-dates the deposition of these beds and are strictly confined to the crystalline basement.

Sprigg (1954), described the metamorphism and granitization process of the area in the following terms:

"The metamorphic rocks of the province are variously intruded by acid to basic igneous rocks and are varyingly granitized. The whole has been involved in one or more major orogenies, and without exception the metasediments have the appearance of endless 'soaking' by processes of feldspathization. Lit-par-lit gneisses and 'injection' type phenomena are ubiquitous, and all stages through feldspathic gneisses, augen gneisses and migmatites to granite-like rocks are evidenced. Centres of extreme alteration to granite-like rocks show evidence of mobilization and upward migration in typical pluton form. Granitizational 'migma' has been variously mobilized from local or deeper crustal levels so that the upwellings produce various approaches to true batholith form."

\* M. F. Glaessner proposed recently the following time units of the late Precambrian: 520 million years = Lower Cambrian; 520-600 million years = Late Proterozoic; 600-800 million years = Middle Proterozoic; 800-1,000 million years = Early Proterozoic.

The writers have found these divisions quite adequate and have adopted them.

† Protogine is a rock of the granitic type, defined and largely represented in the Mont Blanc area of the Alps. Felspars, quartz, biotite and also muscovite are the main constituents, with apatite, zircon, orthite, epidote and magnesite as accessories. Felspars are mainly orthoclase and microcline and also oligoclase. Corbin and Oulianoff (1932) have distinguished five different facies of protogine:

1. A coarse-grained granite, tending to a porphyritic structure.
2. A medium-grained granite with uniform structure.
3. A medium-grained porphyritic structure.
4. A microgranite, porphyritic in places.
5. An aplitic facies.

The similarities of the geological conditions in the Mont Blanc and Olary crystalline terrains are striking in many other respects; in particular the relations between granitic elements and metasediments, the composition of the metasedimentary succession, the metamorphic and metasomatic phenomena are in both areas almost identical (Corbin and Oulianoff, 1932, 1935; Oulianoff, Parejas *et al.* 1951.).

Sprigg's very apt description of the actual field conditions conveys also in the writers' opinion the correct picture of the general process by which the granitic rocks were formed. The mode of occurrence of these rocks definitely suggests their derivation by a scale granitization process involving mobilization; for, if there is in the area concerned abundant evidence that former sediments have been converted into rocks of granitic texture and composition without changing their physical state, it is also manifest that part of these rocks behaved at some stage or other of their history as liquid or very plastic material.

In the outer skirt of the granitic area, it would appear that granitization took place in many cases by simple blastic recrystallization of pre-existing feldspathic rocks, with or without material addition. This applies for instance to the Weekeroo crystalline inliers, where arkosic beds have given rise by recrystallization to conspicuous aplitic or granitic rocks, which often retain their original sedimentary structures. Likewise, laminated pelitic beds have produced in this zone well-banded gneissic rocks or quartzitic schists without apparent mobilization or addition of material. These beds, however, grade rapidly to rocks which clearly show partial mobilization, with separation of the leucoeratic portions and production of residual melanocratic bands. The mobilized leucoeratic elements (quartz, feldspars) are often disposed in lit-par-lit fashion along the lamination planes, while the remaining basic material often appears to have been concentrated in compact masses at the edges of the partially mobilized formations.

Well within the migmatite zone, mobilization was more intense. As a consequence the former sediments have lost most of their original characters, and displacements and intrusions become a common feature. Feldspathized beds, migmatites, granitic dykes and pegmatitic granites often show clear crosscutting relationships and the great predominance of leucoeratic constituents suggests an important addition of feldspar to the original sedimentary material.

The granitic masses of Boolcoomata, Crocker Well and Mount Victoria represent the extreme form of the mobilization process. Being derived from pre-existing rocks, they appear to have passed through a liquid or semi-liquid stage for in places their intrusive relationships are beyond question (figs. 15, 16). They are in every respect comparable with the anatectic (paligenetic) granite defined and described by Sederholm (1926) in southwestern Finland.

This view is also substantiated by the relationship between the central anatectic granites and the related swarms of pegmatites, aplites, or granitic apophyses which invade the country-rock. From the central bosses of massive granite where often they have their roots, these swarms cut through the country-rock for many miles, contaminating or digesting portions of the host, and evidencing a high degree of mobility.

Not uncommonly, these dykes also intersect the massive anatectic granites themselves, the contact being sometimes straight and sharp, sometimes irregular and hazy. It can hardly be doubted that anatectic granite and pegmatite swarms are co-migmatic. The pegmatitic and aplitic suite would represent a more mobile residual product of migmatic differentiation, emplaced in the late stages of the migma consolidation.

Thus, after careful consideration of the field data and after having given much thought to the modern views on granitization, the authors have reached the conclusion that the genesis of the granitic suite of the Olary area was in fact a complex one. Blastic recrystallization in the outer belt, partial mobilization and permeation in the migmatite-gneiss zone, deep-seated anatectic and intrusive processes of the central granites, have all been responsible to a varying degree for converting large portions of the Archaean metamorphics into granitic rocks.

THE GRAND UNCONFORMITY



FIG. 20—THE ARCHAEOAN-PROTEROZOIC GRAND UNCONFORMITY IN THE OUTALPA-WEEKEROO AREA

Note the gradual flattening of the sediments from the base upwards

- A—Archaean migmatites, schists, and gneisses
- U—Unconformity plan
- Pt<sub>1</sub>—Basal conglomerate of the Upper Proterozoic formations (Adelaide System—Torrensian Series)
- Pt<sub>2</sub>—Slates, dolomites, and thin sedimentary magnesite layers (Torrensian Series)
- Ps<sub>1</sub>—Tillites, boulder quartzites, and slates (Sturtian Series—Lower glacial sequence)
- Ps<sub>2</sub>—Slates and dolomites (Sturtian Series—Interglacial sequence)

THE GRAND UNCONFORMITY

FIG. 21—BASAL CONGLOMERATE (C) OF THE ADELAIDE SYSTEM (TORRENSIAN SERIES) UNCONFORMABLY RESTING ON MIGMATITES (M) OF THE CRYSTALLINE BASEMENT

About 4 miles north-northeast of Weekeroo homestead



Fig. 21—Elevation



Fig. 21—Plan

FIG. 22—BASAL TILLITE (T) OF THE ADELAIDE SYSTEM (STURTIAN SERIES) UNCONFORMABLY RESTING ON GRANITE-GNEISSES (G) OF THE CRYSTALLINE BASEMENT

About 2½ miles southwest of Plumbago homestead

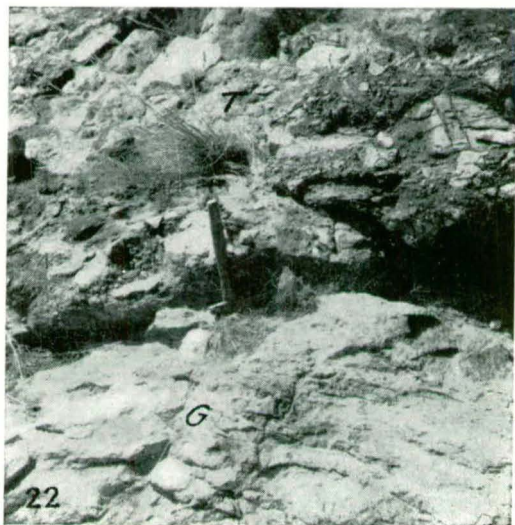


Fig. 22

## The Sedimentary Mantle—Upper Proterozoic Beds of the Adelaide System

### THE GRAND UNCONFORMITY

The crystalline basement rocks are unconformably overlain by the well-bedded, thick and little-altered beds of the Adelaide System, which essentially consists of slates and phyllitic slates, quartzites, tillites, siltstones, conglomerates and minor dolomitic layers. The basal unconformity which separates these formations from the crystalline complex is usually well marked by coarse conglomeratic beds at the very base of the sedimentary succession (figs. 20-22). The strike and dip of this conglomerate often form a high angle with those of the underlying metamorphic formations, a feature which persists throughout the whole area and may be clearly observed over tens of miles. It has been named by Mawson the "Grand Unconformity" for it represents one of the most significant geological features of the Olary area and indeed of the whole State.

Slates and siltstones of these units are responsible for the subdued monotonous relief of large stretches of country. The landscape is commonly bleak and bare, except along drainage channels, where clumps of trees grow at intervals. The monotony is however broken where massive quartzite beds occur. These give rise to long and sharp ridges or cuestas and steps, which often form the distant skyline. Quartzites and tillite hills are frequently timbered, for their crevices allow a foothold to the trees and provide some water supply. Thus the relief, combined with the distribution of the timber vegetation, closely reflects the geological features of the area, emphasizing over long distances the structural and stratigraphic outlines.

### THE TORRENSIAN SERIES

All around the elliptical crystalline inliers of the Weekeroo area, the sedimentary succession begins with a rather coarse conglomerate, overlain by alternating argillaceous and dolomitic beds, with which minor lenses of sedimentary magnesite are associated (fig. 20). These beds may be correlated with the Torrensian Series for their facies, lithology and stratigraphical relationship are almost identical with the Torrensian beds of the type section near Adelaide.

#### Basal Conglomerate

This is a coarse, cross-bedded sediment consisting of well-worn pebbles up to a few inches across, closely cemented in a sandy micaceous matrix. Most of the pebbles are derived from quartz or tough quartzitic rocks, suggesting a long, selective wearing and weathering process at work during their deposition, for softer rocks of the crystalline basement are scarcely represented. Cross-bedding is commonly brought into prominence by dark laminae of heavy minerals, closely recalling the basal conglomerate and sandstone overlying the crystalline inliers at Humbug Scrub, Aldgate, Myponga, Grey Spur and Second Valley, 250 miles to the south. This formation is interpreted as a shore deposit, marking the transgression of the Proterozoic sea on the Archaean continent. In the Olary area the thickness of the basal conglomerate does not exceed 30ft., and is frequently attenuated by tectonic stresses, as evidenced by conspicuous distortions and mechanical elongation of the pebbles.

#### Slates, Dolomites, and Magnesite Beds

A lenticular succession of slates, dolomites and thin magnesite layers overlies conformably the basal conglomerate.

The slates, of a blue to green colour, acquire in places a silky lustre, particularly in zones of stress or shearing. At certain levels, they are shaly and finely laminated, at others they become rather limy and contain numerous bands of a brown to buff dolomite, often showing fine examples of slump structures. These bands are ordinarily massive and quite continuous even though their thickness

does not exceed 100ft. Like the Torrensian beds of the type section, these formations contain poorly outcropping lenses of white magnesite, observed in places along the depression followed by the tracks which lead from Weekeroo homestead to the Walparuta mine.

The Torrensian beds of the Weekeroo area appear to mark the extreme northeast extension of the Torrensian Series developed in the Adelaide region. Farther to the north, northwest and northeast, in the areas of Plumbago, Outalpa, Boolcoomata and Maldorky, these beds thin out rapidly, the Grand Unconformity being then marked in many places by a boulder conglomerate of glacial origin, which forms the base of the Sturtian Series. (Figs. 22-25.)

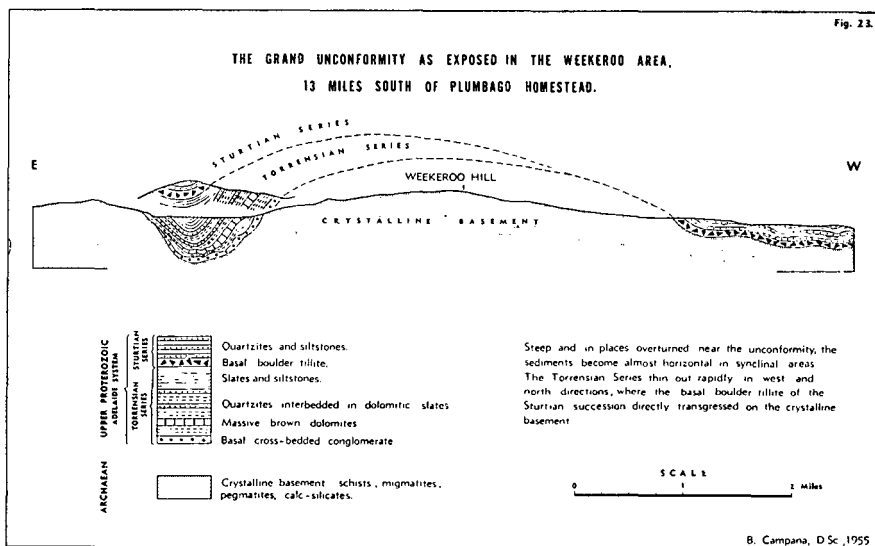


FIG. 23—THE GRAND UNCONFORMITY AS EXPOSED IN THE WEEKEROO AREA—13 MILES SOUTH OF PLUMBAGO HOMESTEAD

### Thickness, Facies, and Sedimentation Environment

The thickness of the Torrensian Series of the Olary Province varies considerably. North of Weekeroo homestead it may reach in places 2,000ft., as for instance in the vicinity of Walparuta mine. However, following the formation both north and south along the strike one observes that the thickness decreases to nil over distances of a few miles only. Similar observations may also be made along the contact between the Torrensian beds and the crystalline rocks forming Weekeroo Hill, where in places the Torrensian Series consists only of a few feet of basal conglomerate. It may thus be inferred that these beds have been deposited in shallow-water sheets, lakes or lagoons locally covering the Precambrian land mass and in which a brackish to lacustrine sedimentation took place.

It is noteworthy that these conditions are repeated in other areas of the State, as for instance in the Adelaide hills region and in the northern Flinders Range, where great variations in thickness and lithology are a general feature of the Torrensian beds.

### THE STURTIAN SERIES

Discovered by Howchin at the River Sturt near Adelaide, defined in the same area by Mawson and Sprigg as an essentially glacial and fluvio-glacial succession of 12,600 ft. thickness, the Sturtian Series has in the Olary area an even greater development. In the Ulupa syncline it reaches 20,000ft. (Campana and Wilson, 1955) and consists of three sequences which may be mapped as distinct units as follows:



FIG. 24—GRANITIC TILLITE  
Old Boolcoomata area

[Photo: S. B. Dickinson]



FIG. 25—GRANITE ERRATIC DUMPED BY FLOATING ICE IN  
FLUVIOGLACIAL SANDY BEDS  
Old Boolcoomata area

[Photo: S. B. Dickinson]

Lower glacial sequence.  
 Interglacial sequence.  
 Upper glacial sequence.

### The Lower Glacial Sequence

This sequence has a maximum thickness of 3,000ft. and has the widest distribution. It is essentially composed of an irregular alternation of boulder tillite, tillitic siltstones, quartzites, slates and dolomites, the order of succession of which may vary considerably from place to place.

#### *Boulder Tillites*

Not uncommonly the lower glacial sequence begins with a coarse basal tillite, which is structureless and unstratified and undoubtedly represents a lithified boulder clay. Its facies, position and mode of occurrence are typical of a land moraine. It contains boulders of all size and degree of angularity embedded in an unwashed and unsorted matrix, and rests directly on the crystalline basement which formed the old glacial floor. This mode of occurrence is well exposed near the Old Boolcoomata homestead where glacial granite boulders, cemented by gravelly quartz and felspar debris, have been scooped from the massive granite forming the local bedrock (figs. 9, 24, 25). At its recession the glacier dumped the granite boulder pebbles and small-quartz-felspar fragments on the old glaciated surface, infilling cracks and depressions but sometimes leaving uncovered the floor rises. Re-cemented and partly crystallized by subsequent diagenesis, the tillitic material at first sight gives the impression of having been metasomatically granitized. The detailed mapping of the Boolcoomata area, together with observations made elsewhere in the Olary and Broken Hill regions, have however proved beyond dispute the detrital origin of these beds which are identical in every respect with the granite tillite, recently described by Leslie and White north of Broken Hill (1952), and also with the boulder basal tillite noted in the northern Flinders Range (Campana, 1955).

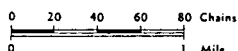
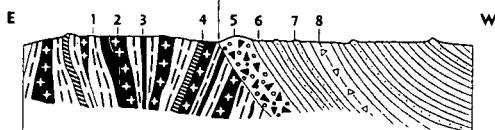
Likewise, north of Bimbowrie, south of Plumbago homestead and in the Weekeroo Hill area the base of the Sturtian Series is formed by a coarse tillite, rich in boulders and fragments of the crystalline rocks on which it rests (figs. 22, 23, 26a). Elsewhere, however, as for instance at Mount Victor and east of Plumbago homestead, the Sturtian Series begins with a few hundred feet of slates, siltstones, and interbedded quartzite (figs. 26b, 26c). These are overlain by fine-grained sediments embedding erratics which, compared with the erratics of the basal granite tillite, are rather smaller, rounder and less representative of the underlying crystalline rock types. It is thus assumed that this horizon, although contemporaneous with the basal granite-tillite, would not represent a land moraine, but a subaqueous tillite deposited by floating ice.

Other less-conspicuous boulder beds may be observed, in many places, at higher levels of the lower glacial sequences. In the southeast corner of the Olary sheet for instance, near Dene Hill, eight boulder beds have been recognized. These occur in alternation with massive quartzites, siltstones and slates, each band being up to 100ft. thick. The same beds are exposed along the prominent ridge east of Weekeroo homestead, where the unusual sedimentation setting of these formations is admirably recorded.

The tillites, many times repeated at different stratigraphic levels, exhibit a most heterogeneous composition. Some beds grade from massive, structureless boulder material to fine-grained quartzites containing very sparse pebbles and occasional boulders. Other tillite lenses merge laterally and vertically into pebbly siltstones, while in other instances there is a gradual but rapid passage from dolomitic boulder beds to sandy brown dolomites (fig. 27). These boulder beds are often lenticular, and unstratified, but they must represent subaqueous deposits for they alternate with well-bedded sediments and no glacier floor, suggestive of land moraines, is observable at their base.

STRATIGRAPHIC SECTIONS OF THE TRANSGRESSIVE BASAL TILLITE  
IN THE PLUMBAGO - MT. VICTOR AREA.

**a** 1 mile south of  
Plumbago H.S.



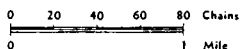
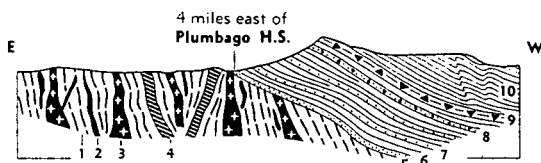
CRYSTALLINE BASEMENT:

- 1 - Micaschists.
- 2 - Granite tongues.
- 3 - Pegmatites.
- 4 - Epidote quartzites.

TRANSGRESSIVE GLACIAL  
AND FLUVIO-GLACIAL BEDS:

- 5 - Boulder tillite, with boulders of 1, 2, 3, 4 up to 5' across, embedded in unsorted and unstratified arkosic matrix. Thickness up to 600'.
- 6 - Fluvio-glacial laminated slates
- 7 - Quartzites with abundant slump structures
- 8 - Slates and siltstones with sparse erratics

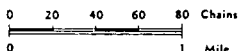
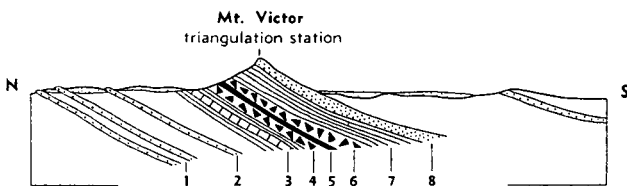
**b**



- 1 - Micaschists.
- 2 - Pegmatites.
- 3 - Granite tongues.
- 4 - Epidote quartzites.

- 5 - Dense, white cross-bedded quartzite
- 6 - Blue fissile slates.
- 7 - Fine grained, cross-laminated quartzite
- 8 - Dark coloured boulder quartzite.
- 9 - Slaty tillite, grading to boulder slates, with interbedded sandy layers.
- 10 - Dark slates and siltstones with sparse pebbles and boulders.

**c**



- 1, 2 - Fine grained, well washed, light coloured, bedded quartzites, in repeated layers.
- 3 - Yellow dolomite bands, up to 6' thick, interbedded in dolomitic slates.
- 4 - Boulder tillite, with erratic embedded in a ferruginous matrix, up to 150' thick.

- 5 - Dark, well bedded hematite siltstones, with abundant pyrite crystals, 25'
- 6 - Boulder tillite with ferruginous matrix, 15'.
- 7 - Slightly calcareous slates with interbedded soft sandy layers, 150'
- 8 - Massive, medium grained quartzite, laminated at top and intersected by numerous tabular veins of quartz along joints, 150'.

B. Campana, D.Sc. 1955.

FIG. 26—STRATIGRAPHIC SECTIONS OF THE TRANSGRESSIVE BASAL TILLITE  
—PLUMBAGO-MOUNT VICTOR AREA

- a. One mile south of Plumbago homestead
- b. Four miles east of Plumbago homestead
- c. Mount Victor

### *Dolomites*

The presence of dolomitic beds in the lower glacial sequence is another general characteristic of the Olary Province stratigraphy. Their mode of occurrence, thickness and stratigraphic position vary considerably from place to place, but as a rule they are more common and better developed in the lower levels of the succession. Quite frequently they are closely associated with the tillites—of which they form in places the groundmass—merging laterally into continuous dolomite bands with or without erratics. The dolomite bands may often be placed over many miles although their thickness does not exceed 30-40ft. They are yellow to brown in colour, poorly bedded or massive and intersected by a dense net of jointings and fractures which allow a foothold to trees and thus give rise to timbered outcrops.

The intimate association and the gradation of these beds to boulder tillites, suggests that they have been precipitated as a result of lowering of the water temperature due to invasions of floating ice. They may also derive, in part at least, from the reworking of dolomitic beds of the underlying Torrensian Series, as evidenced by the presence of numerous dolomite erratics among the tillite boulders.

### *Iron-Rich Siltstones*

Another conspicuous stratigraphic horizon of the lower glacial sequence is an iron formation, observed in the lower beds of the succession. This iron formation consists of hematitic siltstones, the thickness of which varies from 2-12ft. As a rule the iron content is low, of the order of 10-15 per cent or less, so that the formation can hardly come into consideration as a source of iron. But its stratigraphic significance is considerable for it occurs over wide areas at what appears to be a constant stratigraphic level. It forms long dark outcrops, east of Maldorky Range, and also in the Bimbowrie and Mount Victor areas (fig. 26c); and a magnetic survey, carried out by the Geophysical Section of the Geological Survey proved its general presence in the intervening tracts of country between MacDonald Hill and Bimbowrie, as well as south of Radium Hill (plate I).

The iron-rich beds are invariably associated with the major subaqueous tillite horizon, near the base of the Sturtian succession, as illustrated in fig. 26c, and never with the transgressive terrestrial moraine shown in fig. 26a. This mode of occurrence suggests that the iron formation has been deposited in shallow-water bodies just before the glaciation or during a brief interglacial period. It has to be correlated with the iron formation described by Mawson in the Braemar area.

### *Fluvioglacial Quartzites*

The lower glacial sequence also contains the most prominent quartzite beds of the Olary Province. These are particularly well developed at lower levels, in association with massive layers of boulder tillites. Lateral gradation from sandy boulder beds to massive quartzite has been observed in many places, as already stated. More frequently however they occur as distinct and regular beds interstratified in laminated slates or siltstones.

One important quartzite group persists over the whole area, at about the same level as the lower glacial sequence. It consists of three or four sandy beds, the major one of which may reach 100ft. in thickness. Resistant to erosion these beds give rise to characteristically long and steep ridges, among the most conspicuous of which are those of Maldorky, King Bluff and Mount Victor. As illustrated by fig. 26 these major quartzite beds suggest a fluviglacial environment. This is also evidenced by their lithological characters, for they are always well washed, well sorted and frequently cross-bedded.

### *Glacio-Lacustrine Slates and Siltstones (Figs. 28, 29)*

Laminated slates and siltstones form the bulk of the lower glacial sequence and show from the bottom to the top, little lithological variation. In the lower horizons

of the sequence these beds alternate with the tillites, quartzite and dolomite described above; but in the upper part their monotonous succession is broken only at intervals by sparse erratics, dumped at random in the slaty country-rock.

The slates are grey-green to bluish in colour, and the laminae are of the order of 1-5 mm. in thickness (fig. 29). They have in this respect a varve character, but typical alternation of clayish and sandy laminae has not been observed. The siltstones are dark when fresh, dark brown on the weathered surface. More resistant to erosion than the slates, they give rise to low ridges and characteristic ribboned outcrops (fig. 29), on which slump structures and current-bedding are often observable.

#### *Thickness, Facies, and Sedimentation Environment*

A thickness of 3,000ft. at least is observable in many sections of the lower glacial sequence of the Olary Province. Lateral variations in thickness and facies are, however, common features which reflect the special mode of transport and accumulation.

As already indicated, a boulder conglomerate similar in every respect to land moraines has been observed, at the base of the succession, along the edge of the sedimentary area. But the boulder beds which are repeatedly interstratified at high levels in well-bedded deposits have to be regarded as subaqueous tillites. This view is substantiated by the extraordinary thickness of the glacial sequence; by the presence of scattered but voluminous erratics in slaty formations; and, except for the lowest tillite, by the absence of a recognizable rocky floor at the base of the boulder beds. One cannot escape the conclusion that the material of these beds has been dumped in a subsiding periglacial basin at the melting of floating ice, in a manner much similar to that observed by Mawson in the Antarctic sea. No other mode of transport and deposition has been described or can be imagined in the present state of geological knowledge, to account for such a heterogeneous assemblage and for such a thickness of unsorted material.

#### **The Interglacial Sequence**

This succession essentially consists of well-laminated slates, often calcareous and dolomitic and containing at intervals thin dolomite bands. Slates and dolomite are very similar to those associated with the underlying boulder beds, and vertical gradations from glacial to interglacial sediments are common features.

The largest development of interglacial slates and dolomites occurs in the Olary-Ulupa synclinal zone, where they occupy the tract of country between the Olary-Broken Hill railway and Devonborough Downs station. Rather soft and easily eroded, these formations give rise to treeless depressions, often covered by a thin loamy soil supporting in places wide expanses of salt bush and blue bush vegetation. Thus the bedrock may be masked over large areas; but aerial photographs may show structural trends even where no field observations can be made. In this manner the huge synclinal trough south of Olary has been recognized and mapped with a high degree of accuracy, although rock outcrops are almost lacking over tens of square miles.

Breaks of sedimentation between the interglacial sequence and glacial beds have not been recognized. The lower and upper limits of the sequence are therefore often indefinite; for mapping purposes the vertical limits have been established on the basis of facies and lithological criteria.

#### *Thickness and Sedimentation Environment*

In the synclinal zone south of the Olary-Broken Hill railway the interglacial slates reach a thickness of 10,000ft. Their fine lamination, the monotony of the succession and the general absence of coarse deposits indicate a terrigenous deposition taking place in a subsiding basin-lagoon or interior sea surrounded by low, but well-drained land. It is manifest that the general palaeotopographic setting remained

UPPER PROTEROZOIC (ADELAIDE SYSTEM) GLACIAL AND INTERGLACIAL BEDS

FIG. 27—BASAL TILLITE PASSING UPWARD TO SANDY DOLOMITE  
About 16 miles south of Plumbago homestead, where the tillite is the lowest bed of the central anticline limbs.

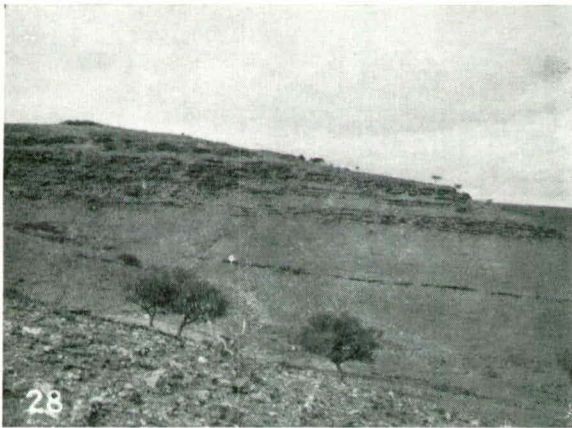


FIG. 28—GLACIO-LACUSTRINE SLATES AND SILTSTONES FORMING A BROAD SYNCLINAL KEEL  
South of Plumbago homestead

FIG. 29—GLACIO-LACUSTRINE LAMINATED SLATES INTRUDED BY QUARTZ VEINS—WITH A BOUDINAGE STRUCTURE  
Showing detail of fig. 28



stable during the whole glacial and interglacial period, and that the variations in sediment facies and petrography are in the main the results of climatic changes.

The mapping of the interglacial beds as a distinct unit is however justified, not only on the basis of the local characteristics of the sediments but also because this unit may be correlated with similar successions which occur in many other parts of the State (Campana and Wilson, 1955). It marked, no doubt, one of the most prominent interglacial phases recognized in the Precambrian glaciations.

### **The Upper Glacial Sequence**

This succession overlies conformably and without sedimentary break the interglacial laminated slates, and consists of a discontinuous boulder tillite layer overlain by alternating quartzites and siltstones.

It has been recognized as the highest level in the stratigraphic column of the area, and it is well exposed in the Ulupa Hill ridges, where it forms the core of the regional Ulupa syncline.

#### *Boulder Tillite and Associated Quartzites*

The boulder tillite is essentially similar to the boulder beds of the lower glacial sequence, with erratics up to 4ft. across embedded in a dense quartzitic matrix. It is well exposed along the southern slopes of Ulupa Hill, where it forms bold smooth outcrops. The boulder tillite is lenticular and grades laterally and vertically to a quartzitic rock with pebbles sparsely distributed in it. The erratics are well worn, less representative of the basement rock type than those of the lower glacial beds, and consist mostly of fine-grained quartzites associated at intervals with granite erratics.

#### *Slates and Siltstones*

Slates and siltstones with interbedded sandstone layers, terminate the upper glacial sequence in this area. They overlie conformably the boulder beds and associated quartzites, and contain in the lower part occasional erratics which suggest a glacial or sub-glacial origin rather than a post-glacial deposit.

#### *Thickness and Sedimentation Environment*

The observed thickness of the upper glacial sequence does not exceed 2,000ft. It should be noted, however, that the top of the sequence is an erosion surface; originally this formation could therefore have been thicker, as suggested by glacial beds found at higher levels in other parts of the State.

The facies and sedimentation environment of this sequence must have been quite similar to those of the lower glacial deposits. It is apparent that the boulder tillite observed at its base is also a subaqueous sediment as evidenced by its conformable relation with the underlying laminated slates. Like those of the lower glacial sequence, the erratics of the upper tillite would have been transported by floating ice during a recurrence of a cold period.

---

## Chapter 3

### STRUCTURAL GEOLOGY

#### The Olary Province as an Anticlinorium Reflecting an Axial Culmination

The Olary Province forms the northern end of a sinuous chain arc, which stretches from Kangaroo Island to the Broken Hill area and has been named the Mount Lofty-Olary Arc (Campana, 1955).

This tectonic unit is the result of a folding process which commenced in the Precambrian times and continued afterwards, with alternating phases of paroxysm and quiescence. It comprises three clearly recorded orogenic cycles of a Precambrian, Early Palaeozoic, and Tertiary age respectively. The Tertiary movements are marked by the present relief, which reaches in places some 2,000ft. above sea-level and therefore can hardly be ascribed to movements of a greater antiquity.\*

It has been generally accepted that the Tertiary movements were purely epirogenic in character, and gave rise by block-faulting to a system of horst and graben to which the Mount Lofty-Olary Ranges would belong. In fact the present relief of these ranges is believed by the writers to be related to a revival of the folding process in post-Palaeozoic and particularly in Tertiary times, as outlined by one of us in a recent work (Campana, 1955). The Olary Province in the north and the Mount Lofty Range in the south would represent two axial culminations which bring to the surface the oldest crystalline formations at both ends of the arc. This view is evidenced by the contacts between the crystalline formations and their sedimentary mantle at the edge of the Archaean basement. Wherever observable these contacts are of a stratigraphic nature, the basement forming the core of outstanding structures from which the Proterozoic beds fall away and disappear with a flat dip beneath the surrounding plains. As these structures are still well connected and block-faulting (as distinct from shearing effects) does not occur, the Olary Province forms a well-defined anticlinorium with outstanding examples of basement folding and overthrusts.

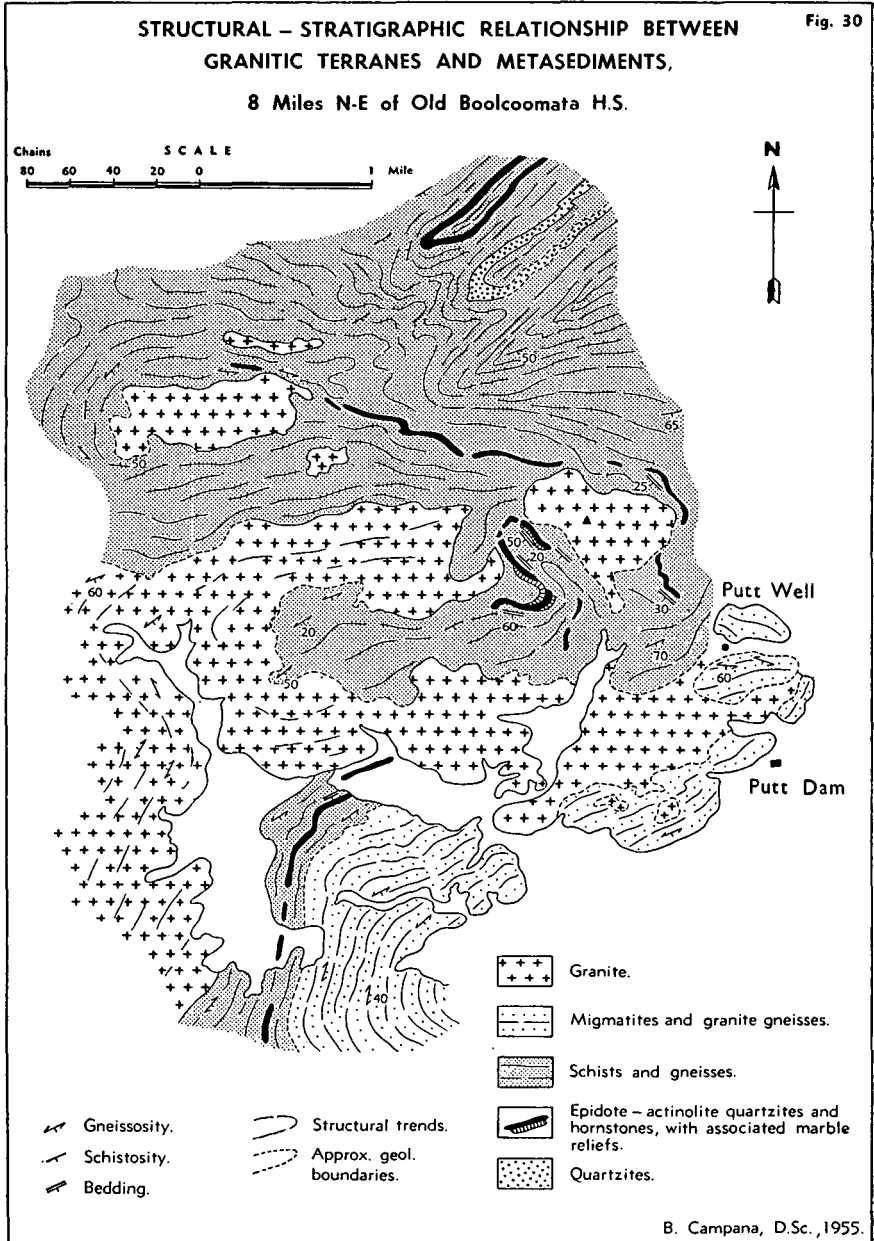
#### Structural Evolution of the Area in Time and Space

The tectonic study of the Olary Province has shown that the folding of the area is due to a deep-seated orogenic process, each phase of which affected the whole stratigraphic column beyond any observable depth. Thus the Archaean metasediments, after having been deformed with their suite of granitic rocks during the Precambrian orogeny, have also been compressed and forced to rise during the Early Palaeozoic cycle, for they emerge at present as large elliptical cores regularly circumscribed by the basal sediments of the Adelaide System. Deeply dissected and well exposed over large tracts of country, these folds afford illuminating records of the structural evolution of the area in time and space.

#### FUNDAMENTAL OROGENIC TRAITS—THE REPEATED FOLDINGS OF A GEOSYNCLINAL AREA

It has been shown in the preceding stratigraphic description that the Olary Province was a part of a geosynclinal setting which persisted through the Precambrian epochs, from the Archaean times onwards. This is evidenced by the facies of the Proterozoic sediments, whose original thickness was over 20,000ft., as well as by the earlier metasedimentary successions, whose lithology and thickness testify a geosynclinal environment (Thomson, 1952; Sprigg 1954). These views

\* It has to be remembered in this respect that outside the Olary Province a strong angular unconformity separates the steeply folded Adelaide System beds from younger flat-lying sediments of Tertiary, Mesozoic, Permian and possibly Ordovician age (Glaessner, 1953; Parkin, 1953; Campana and Wilson, 1955).



**FIG. 30—STRUCTURAL-STRATIGRAPHIC RELATIONSHIP BETWEEN GRANITIC TERRAINS AND METASEDIMENTS—EIGHT MILES NORTHEAST OF OLD BOOLCOOMATA HOMESTEAD**

are substantiated by the tectonic history of the area, whose structural outlines reflect a mobile belt deformed by repeated orogenic cycles.

The Precambrian cycle is recorded by the folding of the crystalline rocks previous to the Adelaide System deposition, as recorded by the grand basal unconformity described above. The Early Palaeozoic cycle deformed these successions as well as the underlying basement, thus giving rise to composite structures in which crystalline material and sedimentary cover are involved.

Later tectonic deformations are not recorded by the stratigraphic sequences, but they certainly occurred, for the transgressive seas which covered the Lake Frome and the Murray Basins during the Mesozoic and Tertiary times did not submerge the Olary Province. This area would have persisted as a ridge, periodically rejuvenated by the revived lateral stresses acting upon the old geosynclinal material. The most apparent of these later movements are those of Tertiary age, responsible for the present relief; but folding phases of Mesozoic age were possibly not less important as outlined by Parkin (1953), in another portion of the old geosyncline.

The dominant structural trends of the Olary Province have an east-northeast orientation, and are almost identical for both the Precambrian and the Early Palaeozoic structural elements. This is observable for instance, along the major structures of the Weekeroo and Olary-Ulupa Hill areas, where the axis direction of the Early Palaeozoic folds coincides with the structural trends of the basement forming their cores (plates I, II, III). Likewise the basement folds near Plumbago, Kalabity, Boolcoomata, Mutooroo, etc., have a northeast orientation. This is also the orientation of the northern end of the structural arc as a whole, and it undoubtedly reflects the persistence, both in sense and intensity, of the deep-seated lateral compression which brought the geosyncline base to the surface.

#### **DERIVED TECTONIC EFFECTS—AXIAL FLEXURES, SHEARS, AND OVERTHRUSTS**

The cyclic deformations of rocks of such a tremendous thickness, heterogeneous composition and different degree of plasticity are responsible for many structural anomalies which seem, at first sight, to obscure the regional tectonic picture. The most striking of these are a set of axial flexures observable in the Weekeroo Hill-Outalpa-Old Boolcoomata anticlinal areas (plates I, II). The largest one runs from MacDonald Hill to Bimbowrie station, and it is marked by a narrow strip of Proterozoic sediments pinched between two swells of the crystalline basement. The sediments strike northwest, almost at a right angle with the general structure trend of the arch. Sprigg (1954) interpreted this structural disposition as the result of a set of faults in the basement, the major one of which has been named by him the "MacDonald Fault." This interpretation is now revised in the light of new tectonic data available, among the most significant of which is the sedimentary sleeve infolded in the crystalline basement which has been observed and mapped in the Weekeroo Hill and Walter-Outalpa mine areas. The true nature of these infolded sleeves is clearly shown by the deep and symmetric re-entrants of the Torrensian beds into the Archaean cores, outlining two unmistakable axial flexures of the regional anticline. Both flexures have a north-northwest orientation, and are almost parallel to another deeper axial depression which develops in the contiguous area between Walter-Outalpa mine and Outalpa H.S. Farther to the east, the same tectonic feature is repeated in the MacDonald Hill-Bimbowrie area, where a still larger axial flexure is responsible for the long sedimentary sleeve which runs northeast over a distance of 20 miles.

In summary, it can be stated that the structural outlines of the Olary Province consist of a set of regional folds having an east-northeast orientation, and crossed at a high angle by a set of parallel axial flexures oriented northwest. These are clearly an effect of the unequal behaviour of complex tectonic bodies during compressional phases and reflect the different degree of competency, rigidity and volume of the rocks involved. Axial flexures are inherent in three-dimensional

tectonic deformations and do not imply an angular change of the compression direction. They are also believed to be unrelated to block-faulting which is not recognized in this area, although they certainly give rise to zones of shearing and overthrust, particularly along their eastern limbs which are often strongly attenuated or missing. This is particularly striking along the eastern limbs of the Outalpa and Bimbowrie axial flexures. There these limbs are overturned to the west and are sheared off, the crystalline basement being sliced in large overthrust wedges. (Fig. 30a; plates I, II, III.)

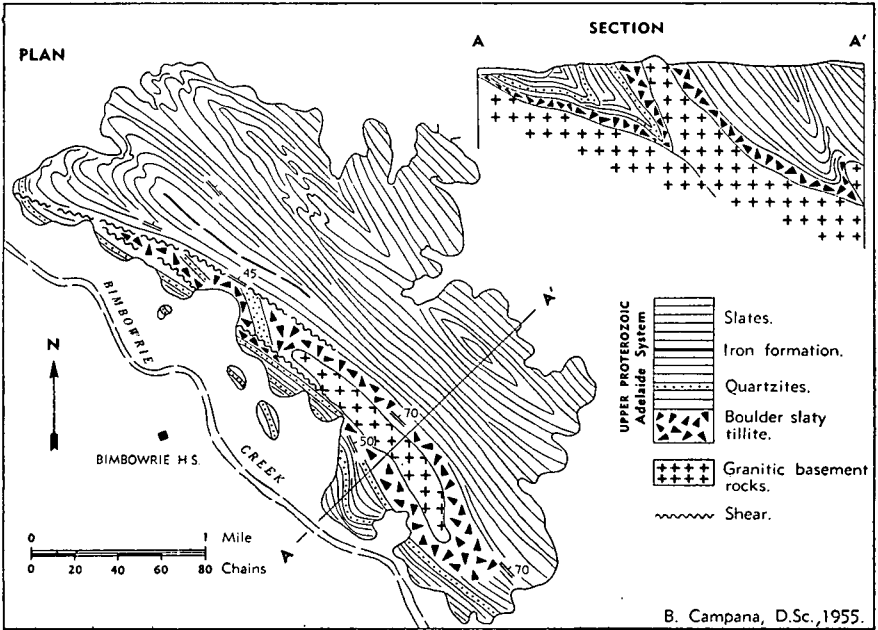


FIG. 30a—THE ANTICLINAL GRANITE WEDGE NEAR BIMBOWRIE HOMESTEAD  
Plan and section

### VERTICAL EVOLUTION OF THE STRUCTURES

Another major tectonic feature of the area is the increasing fold curvature in depth (Figs 23, 30a; plates II, III). In the anticlinal cores, crystalline and sedimentary formations alike are steep and often overturned; but the sediments gradually flatten out at higher stratigraphic levels and they eventually become subhorizontal in the synclinal keels. The most striking expression of this vertical evolution is observable in the Plumbago-Weekeroo zone, where sharp anticlinal core and flat-lying synclinal keels alternate over a length of 20 miles (plate III). These structures afford admirable examples of the plastic folding of the crystalline basement during younger orogenies. It is manifest that this basement, far from being rigid and stable, played an active role in the folding process. At a higher stratigraphic level the sedimentary mantle adjusted itself passively in filling the reduced spaces by drag fold and broad undulations of a simple type. Among the most important drag folds may be mentioned those of the Maldorky Hill quartzites at the nose of the Olary-Ulupa Hill syncline.

### RELATIONS BETWEEN FOLDING, GRANITIZATION, AND MINERALIZATION— AGE OF THE OROGENIC CYCLE

Orogenic phenomena, granitization and metallogenic processes show throughout the area an intimate relationship from which it is possible to recognize a broad chronological sequence.

The folding of the geosynclinal trough is no doubt the primary cause of the mobilization of the oldest rocks and of the mineralization of the area. It was this process which gave rise to the large metalliferous deposits of the Olary and Broken Hill Provinces, and indeed to most of the igneous or metasomatic mineral deposits of South Australia. Although much more work is required to fully elucidate the succession and the relations of these phenomena in certain areas, such as those of the Crocker Well and Old Boolcoomata, detailed investigations suggest the following preliminary conclusions:

1. Most of the copper and uranium mineral deposits in the crystalline basement are related to the granitization and granite emplacements which took place during or towards the ends of the Proterozoic orogenic cycle ("best age": 580 million  $\pm$  30 million years). In places the minerals are distributed in concentric belts around granitic masses with decreasing temperature gradients in the outer belts.

2. No older granite generations have been recognized; but the existence of older mineral deposits has been demonstrated by age determinations on the Radium Hill uranium lode (1,200-1,500 million years) and orogenic movements may therefore be inferred which would date back to the Archaean times.

3. Hydrothermal veins post-dating the Adelaide System beds have been recognized throughout the area. They are undoubtedly pre-Permian in age, and would be related to the Early Palaeozoic orogenic cycle, which involved the Adelaide System and, in other parts of the State, also the Cambrian beds. In the Olary Province no granitic rocks related to this cycle have been found, but they occur in the southern end of the Mount Lofty-Olary arc, where they are intrusive into Cambro-Ordovician formations.

4. Although absolute age determinations are still too scanty to afford an accurate chronology of the tectonic-metallogenic events, it appears established that certain mineral species, such as davidite, have been formed at different epochs of the geological history of the area. Considering the very rare occurrences of davidite throughout the world, it seems improbable that this mineral has been repeatedly formed in the Olary area by independent and unrelated metallogenic processes. The same observation is valid for the abundance, in South Australia, of copper occurrences distributed throughout the whole Cambrian, Proterozoic and Archaean formations. To account for these repetitions of identical mineral types at various geological epochs, it is reasonable to assume redistribution and reconstruction of the mineral deposits during the revivals of the geosynclinal folding and related rock mobilization.

---

## Part II—Mineral Resources

### Chapter I

#### INTRODUCTION

##### History

##### EARLY MINERAL INVESTIGATIONS

The history of mineral search and mining in the northeast of South Australia dates back to the late 1860's when intensive gold prospecting commenced in this and adjoining areas in New South Wales. The first discovery of any consequence was the Waukaringa goldfield, made by a shepherd in 1872.

In 1876, rich silver-lead ores were found near the South Australian border at Thackaringa. This discovery led to the great 1882-1886 silver-lead rush of the Barrier Range, which culminated in the chance discovery in 1884 of the main Broken Hill lode. In this active prospecting period some small cupriferous deposits such as the Billeroo, Mount Victoria, and Benowie mines were located in the Olary Province of South Australia.

The discovery of the Mannahill goldfield in 1885 revived gold prospecting in the area and the tempo of the search increased to boom proportions in subsequent years when gold was reported from the Teetulpa (1886), Olary (1887), and Wadnaminga (1888) districts. During this period several thousand prospectors and miners were operating in the area at the one time. The principal copper and gold occurrences of the Olary Province, including the Luxemburg-Queen Bee, Mutooroo, Bimba, and Ethiudna mines were developed during the same period, while iron ore was quarried at Cutana for use as a flux in smelters at Broken Hill.

The gold discoveries led to the establishment of a Government battery at Peterborough and to a numbers of small plants at various mines. Small amounts of copper ore were mined during the same period. By 1900, almost all of the gold and copper mines were worked beyond their economic limits and only small parties of tribute miners and fossickers remained in the region.

Radioactive minerals were first reported from the region in 1906, when a new uranium mineral described as davidite (Mawson, 1906) was found in samples from the Radium Hill mine area, and small grains of monazite (now known to be detrital) were obtained from shallow gold workings in Adelaide System rocks at King Bluff (Mawson, 1912).

The Radium Hill deposits were worked periodically until 1931 by various small companies, primarily as a source of radium. These early enterprises were unsuccessful financially because the extraction of radium from the highly complex ore proved to be extremely difficult and expensive and the market value of radium deteriorated rapidly with the discovery of higher-grade deposits overseas.

There are indications that prospectors observed but passed over numerous other occurrences of unweathered uranium minerals, and it was not until 1944 that further discoveries of uraninite-type specimens were reported from felspar quarries at Old Boolcoomata and Ameroo Hill (Mawson, 1944; Sprigg, 1945). In 1949, traces of weakly radioactive florencite were taken from near Wiperaminga Hill (King, 1954<sup>(b)</sup>), and xenotime was detected in pegmatite at Old Boolcoomata (Whittle, 1954<sup>(c)</sup>) and in creek alluvium near Radium Hill.

### RADIUM HILL MINE EXPLORATION (1944-1952)

In 1944, when uranium became of outstanding importance for military and industrial purposes, the South Australian Government commenced an extensive programme of exploration and mining of the Olary Province uranium resources. The old Radium Hill mine was first examined. Following appraisal of the surface and mine workings, extensive diamond-drilling led to the establishment of large ore-reserves. Suitable methods for treatment of the refractory ore were developed and exploratory mining was commenced by the Government in May, 1952. Subsequently a pipeline water supply was constructed to link the field with the Umberumberka Reservoir of the Broken Hill district, electric power was provided from Adelaide via Morgan, and a spur railway line, 11 miles in length, laid from Cutana siding. The Radium Hill mine was officially opened and commenced full-scale production in November, 1954, and is at present one of the major mines of the State.

### AERIAL SURVEYS AND DISCOVERY OF THE URANIUM PROSPECT AT CROCKER WELL

In June, 1951, an air radiation survey indicated other areas of abnormal radioactivity in the Olary Province. An off-scale radiation anomaly recognized in this survey led to the discovery of a significant radioactive deposit near Crocker Well, which has been described in previous publications (King, 1954<sup>(a)</sup>; Whittle, 1954<sup>(b)</sup>).

Investigation of this discovery proceeded immediately; a departmental camp was established in the area for diamond drilling, exploratory mining, and geological personnel.

In December, 1952, an aeromagnetic and air radiation survey of the Olary Province was undertaken by the Bureau of Mineral Resources, Geology and Geophysics, to aid in a regional geological and mineral-resources survey. The region was flown at a height of 500ft. above ground-level along meridional lines  $\frac{1}{2}$  mile apart; changes in radioactivity were recorded continuously on a scintillometer, and total magnetic intensity was simultaneously registered on an AN/ASQ-1 airborne magnetometer. The radiometric results of the survey are summarized on the anomaly location map (fig.31).

No important discoveries resulted directly from this data, although it was recognized early in the ground survey which followed that clusters of anomalies correspond in a general way with areas featured by the presence of uranium and rare-earth minerals.

Aeromagnetic anomalies up to a maximum of 10,600 gammas were located which can mostly be related to bedded ironstone formations of the region. (See Part II, Chapter 6.)

### Regional Mapping and Mineral Exploration Since 1953—Discovery of Crocker Well East and Mount Victoria Uranium Deposits

The necessity for an understanding of the regional setting became apparent as exploration of the Crocker Well deposit proceeded. Accordingly, in July, 1953, one of the authors (B. Campana) was assigned the geological mapping of the Plumbago and Glenorchy military sheets. Radiometric prospecting with the assistance of H. E. Campana (Departmental Prospector) was also carried out. In the course of this work, new uranium occurrences were recognized at Mindamereeka Hill and east of Crocker Well, in the area which became known as Crocker Well East. Soon afterwards other uraniumiferous bodies were found in the Windamerta-Billeroo areas, some 10-15 miles north of Crocker Well.

As a result of these findings the exploration work was intensified and a team of prospectors were added to the technical staff. The mineral survey was extended to cover a great part of the crystalline basement rocks, and a large number and a wide variety of mineral occurrences were thus located. Among these was the

Mount Victoria uranium deposit, found by two departmental prospectors (J. Johnson and H. E. Campana) operating with R. K. Pitman (a geologist seconded from the U.S. Atomic Energy Commission).

The majority of newly discovered uraniferous mineral occurrences lie in the Crocker Well and Mount Victoria areas, and the more promising of these have been tested by drilling and shaft sinking.

Further airborne radiometric surveys were also undertaken as a means of thoroughly testing particularly promising outcrops in areas indicated by the earlier regional study. The equipment used comprised a Brownell scintillometer (MkVI) with a thallium-activated sodium iodide crystal (3¼ in. diameter, 1½ in. high) mounted in a small single-engine aircraft. Flight lines at 100- to 150-yd. intervals were flown using photographs as control, at heights of 60-80ft. and an air speed of 70-80 miles per hour.

The exploration work carried out since 1953 has been principally concerned with the detection and economic appraisal of uranium minerals in the crystalline basement rocks. Detailed prospecting has been concentrated to a large degree in the areas of Plumbago-Glenorehy and Outalpa-Bimbowrie-Old Boolcoomata, where some several hundred mineral occurrences have been found and investigated.

### Mineral Location Reference

The two mineral maps which accompany this *Bulletin* record the location of all known mineral occurrences in the areas investigated in detail.

Plate IV covers the Plumbago-Glenorehy district surrounding the Department of Mines camp at Crocker Well, where uranium deposits predominate. Areas of sufficient mineral concentration or promise which have warranted further detailed investigations, are distinguished from numerous other small mineral showings.

Plate V shows the distribution of all observed mineral deposits in the Outalpa-Bimbowrie-Old Boolcoomata district. The location of many old copper workings and industrial-mineral deposits are shown in addition to the known uranium occurrences.

The more important occurrences shown on these maps are named as prospects or workings and are described separately. Minor occurrences are allocated serial numbers and brief details of each are recorded as explanatory notes on the mineral maps. Text references to them are preceded by letter symbols defining on which particular map they are shown, namely:

C.W. for the Plumbago-Glenorehy Series—plate IV.

Out. for the Outalpa-Bimbowrie-Old Boolcoomata Series—plate V.

The position of mineral occurrences outside these areas are shown on the regional geological map (plate I), and in text figures 65 (metalliferous), 77 (industrial), and 78 (felspar-beryl).

---

## Chapter 2

### METALLOGENIC EPOCHS—CLASSIFICATION OF THE MINERAL DEPOSITS

#### Age of the Mineral Deposits—As Deduced From the Isotopes of Uranium, Thorium, and Lead

As indicated in the preceding text, all the mineral deposits of the Olary Province, with the exception of the iron formations, are believed to be genetically related to the structural evolution of the area—it being understood that this evolution comprises also the magmatic, migmatic, and metasomatic process which accompanied the actual tectonic deformations. It has been seen that the tectonic history of the area is characteristic of a geosynclinal belt which was periodically active over a very considerable time span, with alternating orogenic activity and periods of quiescence. Two at least of these orogenic epochs, i.e., the Precambrian and the Early Palaeozoic, gave rise to mineral deposits which are distinctive in type and in their mode of occurrence and distribution. They are accordingly discussed below in separate categories. Within these categories, the mineral deposits have been classified according to their genetic types and controls, and dealt with in various degrees of detail according to their economic significance.

A third category embraces the bedded iron formations which are believed to be of sedimentary origin. As indicated in Part I of this work, these occur within the Archaean metasediments as well as in association with the Adelaide System glacial beds.

Specific data on the absolute age of the mineralization phenomena have been obtained by isotope determinations of uranium, thorium and lead in selected mineral specimens.

A specimen of the Radium Hill uranium lode, which was investigated in 1953 by Prof. J. T. Wilson of the University of Toronto, showed an absolute age of  $1,510 \pm 100$  million years.

In 1954, samples containing absite (thorian brannerite) from the uranium prospect at Crocker Well were examined by Dr. J. L. Kulp, of the University of Columbia, on behalf of the South Australian Department of Mines, and by arrangement with the United States Atomic Energy Commission. They gave the following results:

Pb 206/U238 . . . . .	520 $\pm$ 10 million years
Pb 207/U235 . . . . .	600 $\pm$ 40 million years
Pb 208/Th232 . . . . .	585 $\pm$ 40 million years

According to Kulp these results point to a "best age" of  $580 \pm 30$  million years, which can be accommodated within the general stratigraphic data of the area (Campana, 1954). It will also be noticed that the isotope ratios involved in Kulp's determination appear to afford, in comparison with other age determination procedures, the highest degree of reliability (Holmes and Cahen, 1955)—with the qualification, however, that the mineral used is one not previously considered for this purpose.

In 1955, J. T. Wilson carried out age determinations on galena from various localities in the adjoining Broken Hill district.\* The determinations have been made by the ordinary lead methods, employing the ratio 206/204, 207/204 and 208/204. On the basis of these investigations, Wilson concludes that the age of the main Broken Hill orebody is  $1,200 \pm 250$  million years. This agrees with the determination by A. Holmes (1947)† who obtained an age of 1,200 million years from cerussite and galena of the same lode. Similar determinations on samples of other lead deposits from the Broken Hill area show, according to Wilson, an influence of later (and even Tertiary) metallogenic phases.

\* Communication from H. F. King to the South Australian Department of Mines.

† But differs considerably from the figure of 1,680 million years indicated by Sprigg (1954).

Although more investigations are required to establish an accurate chronology of the metallogenic events of the Olary-Broken Hill area, it is reasonable to infer the existence of more than one mineralization epoch during Precambrian time. At this stage, however, their effects cannot be distinguished, for they are superimposed in the same rock sequences and absolute age determinations are still too scanty to afford general differentiation criteria. The distinction adopted between the Precambrian metallogenic epoch and an Early Palaeozoic mineralization phase adequately reflects the present state of knowledge on this subject.

### **Precambrian Metallogenic Epochs**

The older mineralization of the basement is featured by high-temperature deposits of pegmatitic and pyrometasomatic type. The former include most, if not all, of the uranium rare-earth occurrences; the latter include the copper-cobalt and tungsten deposits occurring chiefly in certain favourable lime-bearing sediments of Archaean age.

#### **PRIMARY URANIUM AND RARE-EARTH MINERALIZATION**

This is found only within the crystalline formations and is believed to be related to the granitization of large portions of the Archaean metasedimentary series. Most of the radioactive deposits are concentrated within the migmatite complex at the border zones of the principal granite masses, and show a marked affinity for particular phases of the granite.

The uranium minerals do not as a rule occur as true accessory constituents of the granites. They are usually found in pegmatitic apophyses or as disseminated fissure fillings of various types within the granite or migmatite.

#### **COPPER-COBALT-TUNGSTEN OCCURRENCES AND THEIR RELATION TO URANIUM MINERALIZATION**

Sulphides of copper and cobalt, and scheelite, are mainly found as disseminated grains and aggregates in the matrix and in minor fissures of the metasedimentary host rocks. These occurrences are similar to the copper and scheelite showings in the Barrier Range of the adjacent Broken Hill district and show, as a rule, a definite stratigraphic control. In a few localities, however, there are small mine-workings in pegmatites carrying random segregations and isolated grains of copper sulphides. It is, therefore, reasonable to infer that this latter copper mineralization is of granitic parentage and of similar origin to the typically pegmatitic uranium ores of the area.

There are a few places in which copper and uranium are found together, but in general, they are not directly associated. This apparent incompatibility may be accounted for by the contrasting temperature-conditions which characterize deposition of the respective metals. In the Crocker Well area (plate IV), the typically hydrothermal copper deposits are located in a peripheral zone surrounding the pegmatitic uranium deposits of the highly granitized areas. In the hypothermal lode deposits of Mount Victoria and Radium Hill, however, intermediate temperature-conditions favourable for the precipitation of both copper and uranium apparently prevailed, for in both these places traces of chalcopyrite are intimately associated with davidite.

#### **INDUSTRIAL MINERAL DEPOSITS**

Minerals such as feldspar, beryl, mica, phosphates, tantalum-columbium minerals, andalusite, sillimanite, graphite, corundum, etc., form a third group strictly confined to rocks of the Precambrian crystalline basement, mostly contained in pegmatites. Barite and fluorite are featured in both the Precambrian and Early Palaeozoic mineral groups.

### **Early Palaeozoic Metallogenic Epoch**

As previously mentioned, the granitized complex is overlain by an Upper Proterozoic glacial sequence of the Adelaide System which post dates the granitization process and related mineralization.

Numerous low-temperature siliceous reefs carrying gold, silver-lead, and traces of copper and cobalt, invade the Adelaide System sediments without any visible wall-rock alteration. As a general rule these epithermal vein deposits are introduced along bedding or cleavage in structural openings which are related to the Palaeozoic orogeny. The veins proper have a common east-west trend sympathetic with the axial lines of the folding, although minor stringers, which in some cases are auriferous, commonly crosscut the principal reefs.

Siliceous veins with a similar mineral assemblage and structural orientation (fig. 65) have also been recognized in the basement rocks and are tentatively correlated with the post-Proterozoic mineralization.

---

## Chapter 3

# MINERAL DEPOSITS OF THE PRECAMBRIAN METALLOGENIC EPOCHS

## Uranium and Rare-Earth Mineral Deposits

### DISTRIBUTION

Complete coverage by aerial scintillometer surveys and ground work on at least a reconnaissance scale has indicated a marked clustering of radioactive mineral occurrences at the periphery of the most highly granitized areas in the central and western portions of the Province. Other finds have been made in the eastern portion in the vicinity of the established mine at Radium Hill, where, however, they have no apparent zonal distribution.

The location of all known radioactive mineral occurrences is shown on the two Mount Victoria granite massifs, where some two hundred separate occurrences, including several important deposits, have been discovered within an area of 200 sq. miles of actual outcrop on Plumbago and Glenorehy stations. The same applies but to a lesser degree in the adjacent area lying within the environs of the Old Booloomata and Ameroo Hill (Outalpa) granite masses. A few radioactive deposits have also been reported from the Broken Hill district, the most noteworthy of which are davidite-monazite occurrences in the Thackaringa Hills, a few miles inside the New South Wales border.

The location of all known radioactive mineral occurrences is shown on the two mineral maps (plates IV and V).

### TYPES OF DEPOSITS

The radioactive minerals are found almost exclusively as primary hypogene deposits in association with granitic rock types of the crystalline basement. The most abundant form of mineralization is pegmatitic or aplitic, but there are also a wide variety of stockwork-type deposits and replacements which are attributed to related pneumatolytic and hydrothermal activity.

The uranium minerals present are dominantly stable forms which are highly resistant to chemical weathering, and there is no appreciable redistribution of deposits by supergene agencies. There are, however, numerous places where the radioactive minerals are concentrated as residual material in the surface soil, or in the basement beds of the overlying Proterozoic rocks.

### Pegmatite Deposits

Pegmatites which are so extremely abundant in the granitized portions of the Archaean complex are very variable in form, texture, and mineral assemblage, and may be classified genetically and mineralogically in two main groups, of which only the minority group carries radioactive or rare-earth minerals.

The more abundant form of pegmatite is represented by discontinuous and irregular segregations of moderately coarse-grained equigranular feldspar and quartz, with minor amounts of magnetite and rutile. These exhibit gradational boundaries with the granitic rocks and migmatites, but locally they may be injected along lines of weakness afforded by shear zones or prominent bedding planes.

The rare-metal minerals are characteristically found in discordant pegmatite swarms of apparently younger intrusive origin. These pegmatites are very coarsely crystalline with, in some cases, zoning or segregation of the mineral constituents. Complex uranium and rare-earth minerals occur as interstitial sporadic grains where zoning is absent (*e.g.*, C.W. 164; Billeroo), or as bunches marginal to the central quartz core in the massive zoned pegmatites (*e.g.*, C.W. 122; Out. 15). The distribution of the rarer minerals is too sparse and irregular in these pegmatites to be of any economic importance.

### Pneumatolytic Deposits

Several occurrences of radioactive minerals are notable for their association with only small amounts of salic gangue minerals as irregular fracture fillings in the granitoid rocks, and this applies particularly to the absite and absite-davidite deposits of Crocker Well. Their deposition in small fractures and fissures evidently represents the pneumatolytic stage of the granite intrusive. There is some evidence that mineralization of this type was accompanied by sodic metasomatism—particularly albitization—of the country-rock (Whittle, 1954<sup>(b)</sup>).

### Hydrothermal Deposits

The Radium Hill and Mount Victoria ore occurrences are of hydrothermal origin. The uranium minerals and chalcopyrite occur as typical replacements and infillings of shear zones.

### Residual Deposits

Surface concentrations of coarse pegmatitic and pneumatolytic uranium minerals are locally found in the Crocker Well area (*e.g.*, Crocker Well East and Billeroo) and small quantities required for metallurgical test purposes have been gathered manually from several places. Trace amounts of all the radioactive and rare-earth minerals are found in creek detritus throughout the region.

## MINERALOGY

The radioactive and rare-earth minerals are dominantly oxides, silicates, and phosphates of typically high-temperature formation, and in a general way, belong to three distinctive paragenetic associations as described below.

(1) The complex multiple oxides in which uranium and rare earths occur in various combinations with dominant titanium; these include the important ores davidite and absite, and less common pegmatitic minerals samarskite, euxenite, betafite, polycrase, fergusonite, brannerite, and ytrocraosite. The associated minerals are similarly characterized by richness in titanium, being represented particularly by rutile and ilmenite.

(2) Minerals of the uraninite group are found in a few places with tantalite and beryl in pegmatites.

(3) A wide range of thorium-rare-earth silicates and phosphates, relatively free of uranium and titanium; these include monazite, xenotime, orthite, thorite, and florencite, which are typically found in pegmatitic granite or pegmatite, accompanied by magnetite.

The composition and relative abundance of uranium, thorium, and rare-earth minerals from the Province that have been identified\* are listed in table I. Davidite and absite are described in detail whilst the other complex uraniferous oxides and secondary uranium and thorium-rare-earth minerals are treated as a group. A few typical occurrences are referred to in the text; others are shown on the mineral maps (plates IV and V).

---

\* Mineral determinations are largely based on reports by A. W. G. Whittle (Chief Mineralogist).

TABLE I  
 RADIOACTIVE MINERALS OF THE OLARY PROVINCE

Mineral	Chemical formula	Uranium content (approx.), U <sub>3</sub> O <sub>8</sub>	Relative abundance
		per cent	
Pitchblende	2UO <sub>2</sub> , UO <sub>3</sub>	80	Very rare
Broeggerite	2(U,Th)O <sub>2</sub> , UO <sub>3</sub>	65	Very rare
Gummite	UO <sub>3</sub> , n H <sub>2</sub> O	60	Very rare
Absite	ThO <sub>2</sub> , 2UO <sub>3</sub> , 7TiO <sub>2</sub> , 5H <sub>2</sub> O	33(UO <sub>3</sub> )	Locally abundant
Davidite	(Y,Fe)O <sub>2</sub> , 3(Fe,Ce,Y) <sub>2</sub> O <sub>3</sub> .6TiO <sub>2</sub>	5	Abundant
Samarskite	(Y,Ce,U,Ca,Fe,Pb,Th).(Cb,Ta,Ti) <sub>2</sub> O <sub>6</sub>	12	Rare
Fergusonite	(Y,U,Ce,Fe).(Cb,Ta,Ti)O <sub>4</sub>	8	Very rare
Euxenite	(Y,Ca,Ce,U,Th).(Cb,Ta,Ti) <sub>2</sub> O <sub>6</sub>	5	Very rare
Betafite	(U,Ca).(Cb,Ta,Ti) <sub>2</sub> O <sub>9</sub> , n H <sub>2</sub> O	20	Very rare
Brannerite	(U,Ca,Fe,Y,Th).Ti <sub>3</sub> O <sub>18</sub>	44	Very rare
Yttrocrasite	(Y,Th,U,Ca) <sub>2</sub> .(Ti,Fe) <sub>4</sub> O <sub>11</sub>	2	Very rare
Polycrase	(Y,Ca,Ce,U,Th).(Ti,Cb,Ta) <sub>2</sub> O <sub>6</sub>	6	Very rare
Yttrocolumbite	(Fe,Y,U,Ca).(Cb,Ta)O <sub>4</sub>	4	Very rare
Uranophane	CaO. 2UO <sub>3</sub> . 2SiO <sub>2</sub> . 6H <sub>2</sub> O	66	Common
Torbernite	Cu(UO <sub>2</sub> ) <sub>2</sub> .(PO <sub>4</sub> ) <sub>2</sub> .10H <sub>2</sub> O	60	Rare
Autunite	Ca(UO <sub>2</sub> ) <sub>2</sub> .(PO <sub>4</sub> ) <sub>2</sub> .10H <sub>2</sub> O	60	Rare
Uranospathite	Not precisely known	Not known	Rare
Uranospinitite	Ca(UO <sub>2</sub> ) <sub>2</sub> .As <sub>2</sub> O <sub>8</sub> .8H <sub>2</sub> O	60	Rare
Carnotite	K <sub>2</sub> (UO <sub>2</sub> ) <sub>2</sub> .(VO <sub>4</sub> ) <sub>2</sub> .3H <sub>2</sub> O	65	Locally common
Ilmenorutile	Fe(Cb,Ta) <sub>2</sub> .Ti <sub>2</sub> O <sub>10</sub>	Trace	Common
Thorite	ThSiO <sub>4</sub>	Trace	Rare
Orangite	ThSiO <sub>4</sub> .n H <sub>2</sub> O	Trace	Very rare
Monazite	(Ce,La,Y,Th).(PO <sub>4</sub> )	Absent	Common
Xenotime	YPO <sub>4</sub>	Trace	Common
Florencite	CeAl <sub>3</sub> .(PO <sub>4</sub> ) <sub>2</sub> .(OH) <sub>6</sub>	None	Very rare
Orthite	H <sub>2</sub> O, 4(Ca,Fe)O. 3(Al,Fe,Ce) <sub>2</sub> O <sub>3</sub> . 6SiO <sub>2</sub>	Trace	Abundant
Cyrtolite	Essentially ZrSiO <sub>4</sub>	Trace	Rare

### Davidite

The prototype mineral first described as davidite from the Radium Hill workings consists of small euboidal crystals of a black iron-uranium titanate with a brilliant lustre and conchoidal fracture which were found to be quite a rare constituent of the Radium Hill orebody (Mawson, 1906; 1916). Mawson also accurately reported how gradations in physical characters and degree of radioactivity can be observed ranging from ilmenite to pure davidite. The name davidite has, however, now become rather loosely applied to an assortment of complex iron-uranium titanates and mixtures of quite variable physical properties and chemical composition found in the Olary Province and in other parts of South Australia.

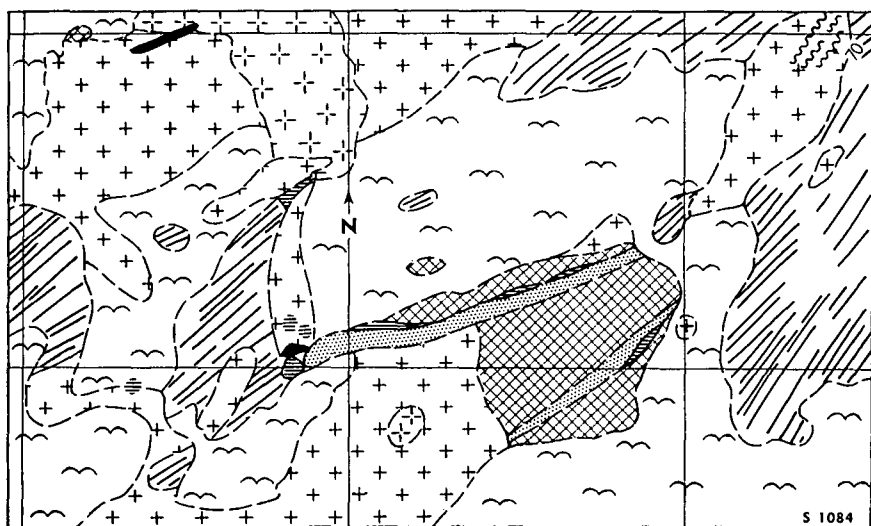
Davidite and complex daviditic mixtures are the most abundant and widely distributed form of uranium mineralization in the Olary region, having been reported from a total of some 50 separate occurrences in addition to being the ore at two established mines and several other prospects.

Three different genetic types of davidite have been recognized, in each of which the ore is featured by contrasting morphology and degree of purity.

### Pegmatitic Davidite

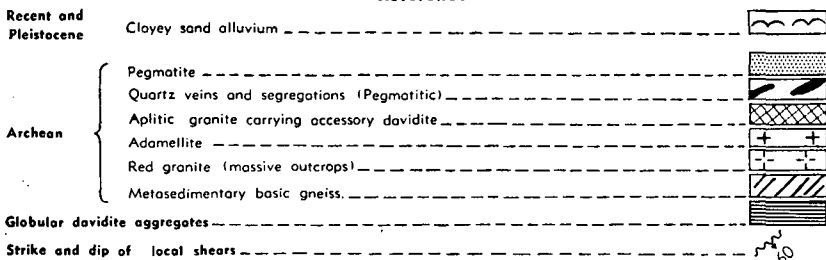
Relatively pure davidite of similar specifications to the prototype material occurs as coarse pseudo-crystalline or massive forms in acid pegmatites and pegmatitic quartz veins, usually associated with minor amounts of fergusonite, xenotime, and rutile, but in some cases is the only rare mineral present. This variety is jet black in colour, with an adamantine lustre and conchoidal fracture, and is notable

for an absence of secondary alteration products. Examples of the pegmatitic davidite are evident over a wide area near Billeroo (C.W. 164, etc.), where they occur as coarse irregularly distributed pseudocrystalline aggregates in pegmatites (fig. 33) and as small grains disseminated throughout bluish quartz veinlets. The coarse masses, weathered from the pegmatite, present a striking concentration of residual davidite at the surface. Many samples show a well-developed crystalline habit resembling cubic or octahedral forms. (fig. 36).



S. A. Department of Mines

### Reference



### SCALE IN FEET

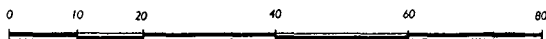


FIG. 32—CROCKER WELL WEST AREA  
Plan showing davidite occurrence at margin of pegmatite

At another locality  $1\frac{1}{2}$  miles northwest of Crocker Well camp (C.W. 163) globular aggregates of untarnished davidite are segregated along the border zone of a 2ft. wide pegmatite (figs. 32, 34) and as accessory grains in an adjacent aplitic granite. In the same area davidite occurs with ilmenite in the quartzose fraction of zoned pegmatites.

Large crystals of detrital davidite presumably derived from pegmatite have been observed at Wiperaminga Hill (Miles, 1951) and an isolated specimen measuring six inches across (fig. 35) was taken from pegmatite near Bimbowrie homestead (Out. 29).

*Pneumatolytic Davidite*

This comprises a coarsely granular and dull-brown variety of davidite or daviditic ilmenite with a conchoidal fracture and sub-metallic lustre, but otherwise is similar to the pegmatitic davidite in order of radioactivity. It also has a strong resistance to decomposition by weathering and, in consequence, has a decided tendency to accumulate in detritus. It is found along joint openings and shatter zones in several of the more important prospects at Crocker Well where it occurs intergrown with absite. At Spring Hill it forms coarse-grained aggregates and veinlets with some quartz in shattered granite.

Davidite with similar characteristics is found with samarksite, rutile, and ilmenite in swarms of quartz veinlets cementing fissures in quartzite near Outalpa Springs (Out. 44, 45).

*Metasomatic Davidite-Ilmenite Intergrowths*

Impure davidite is found in the ore deposits of Radium Hill and Mount Victoria as replacements along biotitic shear zones in which it is intimately associated with and replaces complex intergrowths of ilmenite, hematite, and rutile (Mawson, 1906; Whittle, 1954<sup>(d)</sup>). In these deposits the davidite-rich material assumes the form of iron-grey anhedral grains with a metallic lustre. It weathers appreciably to carnotite and to a lesser extent to autunite and torbernite. A feature of these metasomatic davidite-ilmenite mixtures (or solid solutions—Mawson, 1916) is a relatively high overall uranium content, usually between 6 and 9 per cent  $U_3O_8$ .

Davidite with similar characteristics occurs as granules replacing ilmenite in stressed and metasomatized granodiorites at Jagged Rocks Prospect, near Glenorchy station.

Chemical analyses of pegmatitic davidite from the Crocker Well area are compared with those of typical Radium Hill and Mount Victoria davidites in table II.

TABLE II  
CHEMICAL ANALYSES OF DAVIDITE\*

	1 Radium Hill	2 Billeroo (C.W. 164)	3 Mount Victoria	4 Spring Hill	5 Crocker West (C.W. 163)
	per cent	per cent	per cent	per cent	per cent
$UO_2$ . . . . .	8.9	2.5	3.7	6.9	2.2
$LnO_2 + ThO_2$ . . . . .	7.1	11.9	8.2	9.8	8.8
$TiO_2$ . . . . .	47.4	51.5	55.8	54.4	—
$Fe_2O_3$ } as $Fe_2O_3$ . . . . .	31.6	30.2	18.5	20.9	—
$FeO$ . . . . .					
$Cr_2O_3$ . . . . .	0.6	0.7	1.9	0.8	—
$V_2O_5$ . . . . .	1.5	1.2	7.8	0.5	—
$PbO$ . . . . .	0.9	0.5	1.1	1.2	—
$H_2O$ . . . . .	1.2	0.3	1.1	4.3	—
Not determined . . . . .	0.8	1.0	1.9	1.1	89.0

\* Chemical analyses by the Analytical Section with corrections for elimination of inseparable impurities by micrometric analysis (Whittle, 1955(b)).

*Summary of the Properties of Davidite*

The following notes were provided by Whittle (Chief Mineralogist):

“Davidite is a black lustrous mineral with a hardness of 5.5-6 on Mohs' scale. It is opaque except on the edge of very thin splinters, where it is brown and translucent. The refractive index exceeds 2.2. Its density varies between 4.2 and 4.4 according to the amount and grain size of its minute inseparable inclusions of rutile, hematite, and ilmenite.

“Davidite polishes well and presents a light-grey colour in incident light with a reflectivity which lies between 18-19 per cent compared with pyrite taken as 54.5 per cent (white light in air).

“Most davidite is massive and amorphous, but samples exhibiting crystalline outline have been found in pegmatite. These forms are rough and no measurements have been made on them (fig. 36).

“Davidites from eight localities were subject to X-ray examination. The mineral in its natural form fails to give a diffraction pattern apart from that of its inclusions such as rutile. After heating to 950°C. for 4 hours in an inert atmosphere each of these davidites produces a diffraction pattern comparable with published patterns of Mozambique davidite.

“The true composition of davidite is unattainable because of the presence of inseparable inclusions of rutile, hematite, or ilmenite which it always contains. An approximate composition can be arrived at by correcting an analysis after computation of visible inclusions by mineragraphic examination of a duplicate sample of the material analyzed.

“By this means it has been ascertained that davidite is a complex oxide mineral composed essentially of  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{UO}_2$ ,  $\text{Ln}_2\text{O}_3$ . Chromic and vanadic oxides substitute for ferric oxide in varying degrees in different davidites.

“It has also been observed in different davidities that the total equivalent proportions of the lanthanon oxides and uranium oxide are reasonably constant. Since in various davidites the ratio of these two oxide groups varies, it appears that there is a substitution series of davidites varying from those low in uranium and high in lanthanons (*e.g.*, Billeroo davidite) to those high in uranium and low in lanthanons (*e.g.*, Mozambique davidite).

“Investigations into the composition of davidite carried out at the Research and Development Branch suggest that the amount of titania in chemical combination with iron, uranium, and the lanthanon oxides is unknown, but is certainly less than that indicated by published analyses. Experimental leaching, electron microscope, and X-ray investigations indicate the possibility of a large amount of ultra-microscopic free titania as a mechanical component of davidite. This means that davidite may be a mechanical mixture of titania with a complex iron-titanium uranium-rare-earth oxide mineral of much higher uranium and rare-earth content than davidite is generally thought to have.”

#### Absite

Absite, a mineral species closely related to and possibly a variety of brannerite, is essentially a hydrated titanate of uranium and thorium containing approximately 32 per cent  $\text{UO}_3$ . (*See* table III.) It is an important primary mineral of extensive low-grade orebodies in the Crocker Well area.

TABLE III  
CHEMICAL ANALYSES OF ABSITE SAMPLES\*

	1 Original Prospect, outcrop	2 Main Eastern Prospect, detrital crystals	3 Main Eastern Prospect, bore E.C. 1 at 39ft.
	per cent	per cent	per cent
$\text{TiO}_2$ .. . . .	35.13	38.2	43.5
$\text{ThO}_2$ .. . . .	12.81	10.1	10.1
$\text{UO}_2$ .. . . .	nil	nil	nil
$\text{UO}_3$ .. . . .	31.83	30.4	29.4
$\text{Ta}_2\text{O}_5$ .. . . .	} nil	nil	nil
$\text{Cb}_2\text{O}_5$ .. . . .			
$\text{ZrO}_2$ .. . . .	0.38	—	—
$\text{Fe}_2\text{O}_3$ .. . . .	1.37	—	—
$\text{Sc}_2\text{O}_3$ .. . . .	0.19	—	—
$\text{PbO}$ .. . . .	2.79	—	—
$\text{Ce}_2\text{O}_3$ .. . . .	1.43	—	—
$\text{Y}_2\text{O}_3$ .. . . .	3.71	—	—
$\text{H}_2\text{O}-105^\circ\text{C.}$ .. . . .	2.54	—	—
$\text{H}_2\text{O}+105^\circ\text{C.}$ .. . . .	7.41	—	—
$\text{P}_2\text{O}_5$ .. . . .	0.13	—	—
Total	99.72	78.7	83.0

\* Chemical analyses of microscopically selected samples by the Analytical Section, Research and Development Branch.



FIG. 33—PSEUDOCRYSTALLINE DAVIDITE  
AGGREGATES (d) IN PEGMATITE  
Billeroo (C.W. 164)

[Photo: K. R. Miles]

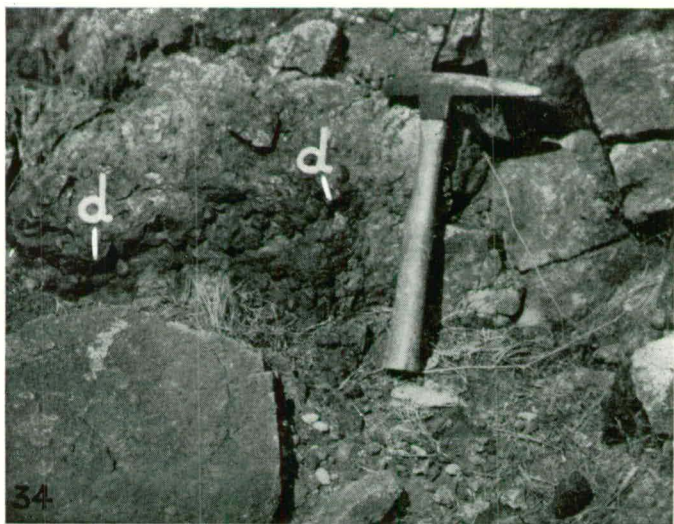


FIG. 34 GLOBULAR AGGREGATES OF DAVIDITE (d)  
ALONG BORDER ZONE OF PEGMATITE  
(Location: C.W. 163)

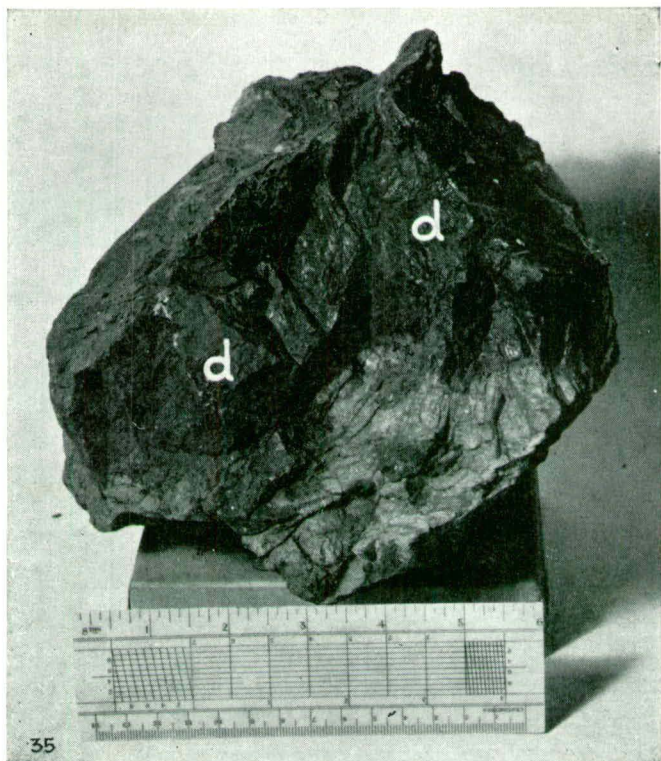


FIG. 35—DAVIDITE (d) FROM PEGMATITE  
Near Bimbowrie (Out. 29)

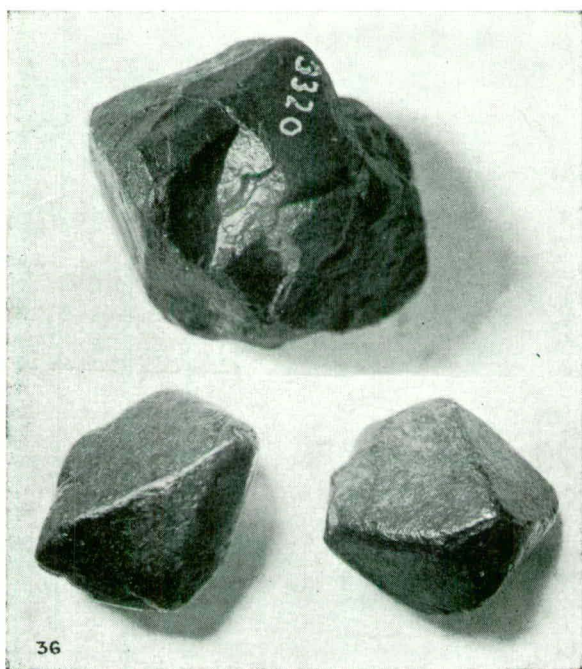


FIG. 36—RESIDUAL DAVIDITE FROM WEATHERED  
PEGMATITE.—SHOWING WELL-DEVELOPED  
CRYSTALLINE HABIT  
Billeroo area

Fresh samples are yellow-brown to olive-green in colour, with a distinct resinous lustre, but the residual material found in the surface soil has a superficial brown staining and is quite inconspicuous (fig. 42—see also page 50). Except for this tarnish, however, absite is unusually resistant to chemical weathering agencies, and no secondary minerals are found associated with it.

The ore is highly brittle, with a sub-conchoidal fracture, a hardness of between 5 and 6, and a specific gravity of 4.1. Optically it is metamict-isotropic, with an R.I. of 1.96.

Absite is distinguished from brannerite chiefly on the basis of a considerably higher thorium content at the expense of uranium, larger amounts of combined water, and a lower refractive index (Whittle, 1954<sup>(a)</sup>).

Absite is chiefly found as a fracture filling in the granitoid rocks, in which case it commonly assumes pseudocrystalline forms with hexagonal, triclinic, or rarely octahedral outlines (fig. 42). Minor amounts of absite found in the matrix of adamellite or quartz veins are usually anhedral and surrounded by externally radiating fissures so typical of uranium ores (fig. 37).

A wide variety of primary minerals is found in close association with absite, particularly granular rutile (with which it is commonly intergrown), coarse bronze biotite, apatite, and pearl-blue quartz. Intergrowths of absite and davidite and pure davidite veinlets have been identified in a few places. Other associations present in subordinate amounts include rare-earth minerals, thorite (and variety orangite), orthite, and samarskite, as well as hematite, ilmenite, pyrite, the zeolite epidesmene, and traces of purple fluorspar.

No other occurrences have been found which bear any resemblance to the Crocker Well ore.

#### Complex Pegmatitic Uranium and Rare-Earth Minerals

An assortment of complex uranium and rare-earth minerals containing abundant titanium and varying amounts of columbium and tantalum is known as comparatively rare constituents of pegmatites in the western portion of the Province. Members of this suite are similar macroscopically, being generally fresh and lustrous in appearance, of conchoidal fracture, dominantly greenish colour, and moderately high radioactivity. All are metamict-isotropic and cannot be critically distinguished by optical or X-ray methods; precise determinations have been made only in a few cases where sizable samples are available.

A mineral determined optically as *fergusonite* (Whittle, unpublished) is present as lustrous brownish-black ovoid inclusions in lamellar hematite near Victoria Hut (C.W. 111). It bears a striking resemblance both in its appearance and associations to samples identified as fergusonite (or possibly samarskite) from Radium Ridge, Mount Painter. Small crystals with an external dull-yellow crust from Crocker Well West (C.W. 79) are also reported to be fergusonite.

*Samarските* has been determined in samples from the Mount Victoria copper mine area (C.W. 80) and Glenorchy (C.W. 25), where it occurs in pegmatite as coarsely crystalline and highly lustrous greenish-black masses with a dull-yellow staining and surrounded by radial cracks. Identical specimens occur in nearby pegmatites with coarse apatite (C.W. 86) and with ilmenite (C.W. 82). Residual samarskite, with chocolate-brown alteration, can be seen weathering from quartz veins near Crocker Well (C.W. 81). Other similar mineral specimens doubtfully referred to as samarskite occur with beryl in a felspar quarry at Old Booleomata (Out. 9), and with davidite in quartz veinlets near Doughboy Well (Out. 46).

Greenish-black coarse prismatic crystals with rectangular cross-sections which occur with ilmenite in pegmatite at Crocker Well West (C.W. 70) are considered to be *polyrase* on the basis of physical properties and the partial chemical assay shown below. An analysis of polyrase from Zirconia, North Carolina, U.S.A., is also quoted for comparison.

	Presumed polycrase, (Location C.W. 70) Crocker Well West	Polycrase, Zirconia, U.S.A.
	per cent	per cent
FeO . . . . .	—	2.87
(Y, Er) <sub>2</sub> O <sub>3</sub> . . . . .	18.8*	27.55
UO <sub>3</sub> . . . . .	—	13.77
U <sub>3</sub> O <sub>8</sub> . . . . .	16.8	—
ThO <sub>2</sub> . . . . .	3.8	—
TiO <sub>2</sub> . . . . .	23.7	29.31
Cb <sub>2</sub> O <sub>5</sub> . . . . .	} 17.6	19.48
Ta <sub>2</sub> O <sub>5</sub> . . . . .		
Water (combined) . . . .	4.62	5.18
Not determined . . . . .	14.7	1.84

\* Total rare earths (lanthanons).

Detrital polycrase has also been reported in heavy sand concentrates at Crocker Well East.

Other minerals of the titaniferous group are very rare. *Yttrocrasite* is reported from pegmatite near Crocker Well camp (C.W. 76). *Betafite* is found as small resin-brown granules in feldspathized quartzite at Billeroo (C.W. 164). Altered *samiresite* is present as microscopic yellow grains in chloritic schist at the Windamerta North Prospect, and altered *euxenite* as dark-brown crystals near Mount Victoria copper mines (C.W. 89) and Spring Hill (C.W. 58). A greenish-black mineral altering to uranophane occurs in two places about Crocker Well East (C.W. 116, AB 7) and is believed to be *brannerite*.

#### Uraninites

A few minerals consisting essentially of uranium and rare-earth oxides are known as minor constituents of pegmatites. Small iron-grey grains of *broeggerite* have been obtained from feldspar diggings near Ameroo Hill (Maggie mine, Out. 15), where it occurs in quartz with beryl, tantalite, and autunite. Another feldspar quarry at Old Booloomata (Out. 54) has produced spectacular nodules of bright-yellow, orange, and black zoned *gummite* in feldspar (fig. 38); and a black *thorian-uraninite* altered externally to uranophane has been identified in pegmatite and an adjacent fissure near Crocker Well (C.W. 79).

#### Secondary Uranium Minerals

Supergene uranium minerals are found only in quite minor amounts. *Uranophane* is perhaps the most common form, having been identified at the Windamerta and Mindamereeka Prospects, and several other localities in the Plumbago-Glenorchy district. *Carnotite* is locally developed in addition to the rare minerals *uranospinite* and *uranospathite* at Radium Hill (Whittle, 1954<sup>(d)</sup>). Traces of *torbernite* are present at the Mount Victoria mine, Mindamereeka Prospect, and in a small open-cut worked for copper near Walparuta Springs (Cooper Claim). *Autunite* is found in pegmatite with *broeggerite* in the Ameroo Hill locality (Out. 15).

#### Thorium and Rare-Earth Minerals

This is a rather arbitrary grouping of a suite of minerals dominantly composed of rare-earth and thorium compounds which contain little or no uranium and are usually found independently of uranium mineralization.

*Monazite* is of widespread occurrence as an accessory mineral in granitoid rocks and in pegmatites. Among the noteworthy pegmatite occurrences, it has been observed west of Mount Victoria as dark-brown twin crystals with ilmenorutile and traces of samarskite and xenotime (C.W. 123), and nearby with apatite (C.W. 5). Similarly it occurs with ilmenorutile and xenotime in pegmatite 2 miles northwest of Outalpa Springs (Out. 41). Minute accessory grains of monazite are abundant over a large area of coarse pegmatitic granite at the Camel Hump hill, north of Crocker Well and coarse brown crystalline monazite is also present in associated pegmatites.

Highly radioactive ash-grey grains occurring with cyrtolite and ilmenorutile(?) in a zoned pegmatite near Mount Victoria (C.W. 112) are believed to be a mixture of monazite and another undetermined rare-earth mineral. A partial chemical analysis of this material gave the following result.

U <sub>3</sub> O <sub>8</sub> . . . . .	1.2
P <sub>2</sub> O <sub>5</sub> . . . . .	10.7
Rare earths . . . . .	54.3
ThO <sub>2</sub> . . . . .	20.5
H <sub>2</sub> O— . . . . .	0.4
H <sub>2</sub> O+ . . . . .	1.5
Undetermined . . . . .	11.4

Monazite and *cyrtolite* have been observed as detrital grains in Archaean metasediments near Bimbowrie station (Out. 81) and Outalpa station (Out. 49), and as pale-yellow sand grains weathering from a kaolinitic layer in Adelaide System sandstones at King Bluff gold mine. Radiating crystalline aggregates of cyrtolite, with protruding pyramidal faces, are especially well-developed in the pegmatite described above from near Mount Victoria (C.W. 112).

The most common of the cerium-bearing minerals is *orthite*, which assumes the form of coal-black oval or irregular masses with a tendency towards a fibrous structure, greasy lustre and irregular fracture, and is superficially dull dark-brown on weathered surfaces. Coarse orthite has been obtained from quartz seams cutting granite at several localities in the Plumbago-Glenorchy district (C.W. 23, 85, 154), with pegmatite at Crocker Well West (C.W. 21), and with magnetite in pegmatite at Old Boolcoomata (Out. 69, 70). Orthite is also an accessory constituent of some granitoid rocks, as for example near Ameroo Hill (Out. 37) where it occurs as minute disseminated grains accompanied by magnetite and fluorite in granitic gneiss.

The yttrium phosphate *xenotime* has been observed in many places in the Olary Province. Good prismatic crystals of a pale-brown xenotime occur in quartz pegmatite at Old Boolcoomata (Out. 68) and near Teitz Dam, Bimbowrie (Out. 32) (fig. 40), and are intergrown with monazite and ilmenorutile in another pegmatite two miles northwest of Outalpa Springs. In the Plumbago-Glenorchy district, xenotime is found in pegmatite in association with davidite west of Crocker Well (C.W. 163), and with fergusonite (C.W. 111) and samarskite (C.W. 80) in the vicinity of Victoria Hut. A typical occurrence in pegmatite (C.W. 97) is shown in fig. 39.

*Thorite* is found locally as small prismatic crystals with orthite in joints at Camel Hump Hill, Crocker Well, and *florencite* occurs with minute grains of gumite southwest of Wiperaminga Hill (Out. 28).

*Ilmenorutile*—a complex oxide of titanium, iron, and columbium—is commonly associated with monazite and other minerals described in this group, and details of its occurrence are referred to on page 114.

## ZONING

In the Plumbago-Glenorchy district—where abundant mineralogical data have been accumulated during systematic exploration—there is a marked zoning of particular mineral types and associations which closely correspond with geological sub-divisions based on degree of granitization and pegmatization. Five zones can be distinguished.

*Zone I*—The areas of massive and mobilized core granite corresponding to the geological subdivision Ag (plate I), which are usually featured by abnormally high background radioactivity due to accessory minerals including monazite and cyrtolite.

*Zone II*—Dominantly *thorium* mineralization localized within highly granitized (and partly mobilized) formations marginal to the core granites. This association is characterized by the presence of monazite disseminations, accompanied to a lesser extent by xenotime, ilmenorutile, and thorite, and is chiefly developed in an arcuate-shaped area centred about two miles south of Mount Victoria.

*Zone III*—A zone of *uranium-thorium* mineralization coinciding in distribution with migmatite formations (Am) and extending over a wide area from near Billeroo to southwest of Crocker Well. Typical are complex titanates of uranium and thorium, including samarskite, euxenite, absite, and fergusonite, found exclusively in pegmatitic or pneumatolytic environment. Xenotime is found also in Zone III, particularly with samarskite.

*Zone IV*—The *uranium* zone—in which thorium is practically absent—corresponds with partly feldspathized and intensely pegmatized metasedimentary formations (Af and Am) which extend from near Billeroo to north of Mount Victoria. Davidite is the dominant uranium mineral, occurring chiefly in pegmatite, and in at least one example (Mount Victoria mine) as hydrothermal fissure replacement. In the latter case, chalcopyrite is an associated mineral.

*Zone V*—The lowest-temperature or least-granitized zone (As) in which radioactive minerals are absent. Significant *copper-cobalt-tungsten* replacement deposits of the Ethiudna mining area and copper in schist at the Billeroo mines lie within metasediments of this category.

There is naturally a considerable overlapping of the zones in respect to each other. Zone III, for example, is also featured to some extent by davidite and monazite occurrences, but it is strictly only one or the other which may be found in association with absite or samarskite at any particular locality. Certain minerals are of a general distribution, the most notable of which are apatite, orthite, magnetite, pyrite, ilmenite, hematite, and rutile.

Zonal boundaries are less clearly defined in the Bimbowrie-Old Boolcoomata district, but the same general zoning arrangement is however applicable to some areas, and differ from the Plumbago-Glenorehy district in the following details:

Zone III carries, in addition, relatively abundant beryl, tantalite, columbite, and the rare phosphates graftonite, triplite, wagnerite, and florencite, all of which have been observed occurring with uranium minerals.

Zone V is featured by numerous barite deposits.

### RADIUM HILL URANIUM MINE

*Location*:—Twenty-five miles southwest from Olary, connected by a spur railway to the Adelaide-Broken Hill line at Cutana. Out of counties, North-Eastern division.

#### Introduction

The exploration mining developments and geology of the Radium Hill uranium mine have been described in a number of previously published works. Recent contributions by Rodgers (1953), Sprigg (1954), Whittle (1954), and Parkin and Glasson (1954) provide a comprehensive account of the mine geology and petrology based upon surface mapping, underground observations up to No. 3 level, and diamond drilling.

Since these publications, development of the mine has proceeded rapidly to No. 6 level, but the related geological observations were not within the scope of the writers' work. The following notes are thus given for completeness and are mainly based upon the most recent work of Parkin and Glasson (1954). Some data have been added with consideration of the stratigraphic observations made in the Weekeroo-Boolcoomata area.

#### Regional Geological Setting

The mineralization at Radium Hill occurs in fracture-plane structures in Archaean feldspathized gneisses, aplitic gneisses, and schists, intruded by basic and acid bodies.

The distribution and stratigraphic succession of these various rock types has not yet been established for this would require detailed large-scale mapping and more underground data. South of the Luxemburg field, however, a synclinal zone of the basement shows a rock succession similar to the Archaean successions of the Weekeroo-Boolcoomata area, with schistose layers at the base, overlain by granite-gneisses. These may be tentatively correlated with the granite-gneisses of the upper group of the Weekeroo-Boolcoomata type section (figs. 1, 8, 9) and possibly with those overlying the Broken Hill lead lode.

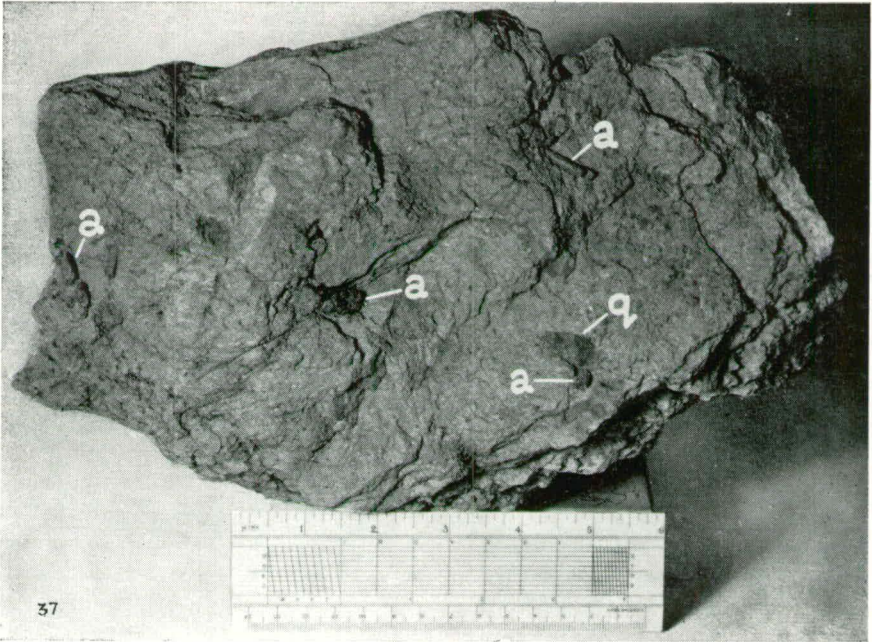


FIG. 37—PSEUDOCRYSTALLINE ABSITE (a) IN ADAMELLITE. (NOTE QUARTZ (q) ASSOCIATED WITH GRAIN IN FOREGROUND)  
Crocker Well East

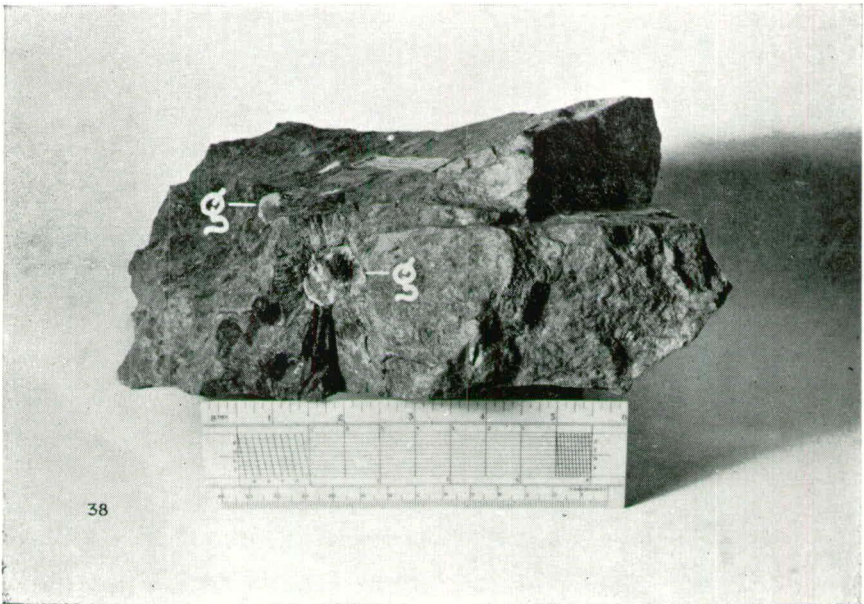


FIG. 38—ZONED GUMMITE (g) IN PEGMATITE  
Raven Hill felspar quarry—Old Boolcoomata (Out. 54)



FIG. 39—XENOTIME CRYSTAL (X) IN  
PEGMATITE  
Near Mount Victoria (C.W. 97)

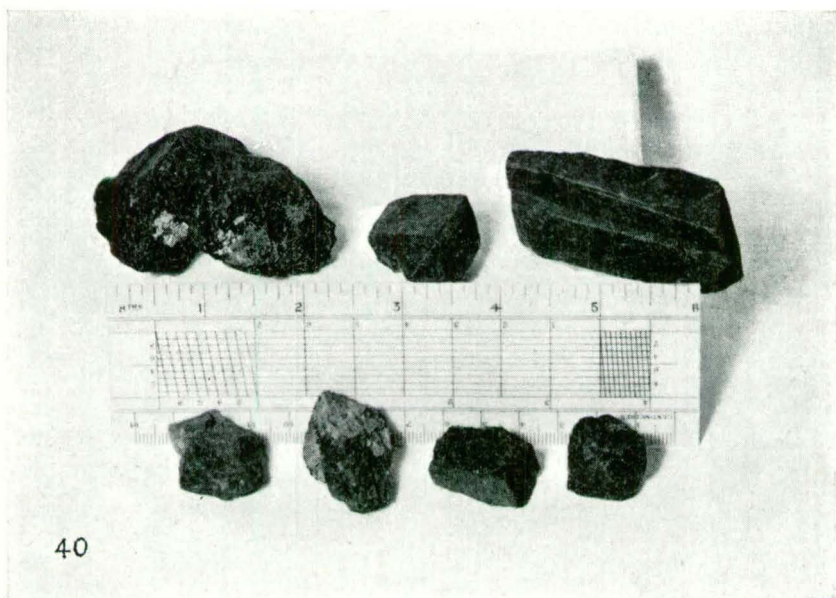


FIG. 40—RESIDUAL XENOTIME CRYSTALS WEATHERED OUT OF  
PEGMATITE  
Near Bimbowrie station (Out. 32)

The acid intrusive bodies consist of numerous pegmatites, aplitic granite, and porphyry dykes, evidencing intense igneous activity.

The basic intrusives comprise an early sill or plug-like amphibolite, usually talcose and much sheared with mineral elongation in the direction of regional schistosity; and a later amphibolite which transgresses both the gneisses and the lode channels. Acid intrusions include several phases of pegmatite introduction, one of which is a sodic aplitic type possibly genetically responsible for the introduction of the ore mineral.

The Archaean gneisses are folded in steep-limbed structures with east-northeast axial direction pitching generally at a low angle.

#### **Lode Structure**

Investigations so far have established three major lodes, namely Whip, Geiger, and Old Main. In close association and parallel in disposition are five smaller lodes which have been explored both by drilling and driving, namely Playford, Smith, Müller, Dickinson, and South Lodes. Besides these orebodies, there are prospects to the northeast of Bonython Hill, Taylor Hill, and Bristowe Hill; and to the southwest is another lode (Rutile lode) which has been intersected on the footwall side of Old Main lode. To the southeast are several minor lode-systems known as the Valley lode and the South Hill lodes, and to the northwest is a small lode-fracture on which a shaft (West shaft) was sunk by early prospectors.

#### **Lode Mineralization**

The uranium ore-mineral is davidite which occurs in intimate intergrowth with rutile, ilmenite, hematite, and magnetite, in an ore in which each of these minerals occurs in varying proportions. A detailed discussion of the intergrowth and exsolution phenomena is presented by Whittle.

The mineralization of each of the known lodes is essentially similar. Each shows a gradation from incipient sericite development by gradual stages towards coarse ilmenite-biotite growth. Four lode types are recognized, and the proportions of these types present varies from lode to lode. A typical lode channel commences as a shear in which there has been a segregation of augen of biotite and quartz enclosed in banded gneiss. Introduction of iron and titanium (with or without uranium) mineralization into these knots or augen produces an ore-type known locally as nodular or spotted ore. An increase in the degree of initial fracturing or brecciation allows a higher degree of replacement resulting in the so-called main-lode ore-type, which is a coarse intergrowth of bronze biotite, pinkish quartz, ilmenite, rutile, hematite, and davidite.

#### **Mine Development**

Following 10 years of intensive exploration by underground development and diamond drilling, the mine has been fully equipped with a main haulage shaft, crusher, and concentration plant, and was fully commissioned for scheduled production in November, 1954.

The main shaft has been sunk on the hanging wall of the lode system, and passes through it below the No. 6 level. Development is proceeding from the main shaft on No. 5 and No. 6 levels, while ore extraction is proceeding from the upper levels.

The lode system has been established over a length of 4,000ft. and to a vertical depth of 700ft. in one instance, but the pattern of ore-shoot behaviour within the lode channels is complex and is not yet fully understood.

### CROCKER WELL URANIUM DEPOSITS

*Location:—Six main deposits occur within an area of widespread uranium mineralization, six miles north of Plumbago station homestead, and 50 miles by graded station-tracks north and northwest of the rail heads at Yunta and Olary respectively. Out of counties, North-Eastern division.*

#### Regional Geological Setting

The uranium deposits lie within a tract of low hills 3 sq. miles in extent between the Ethudna Hill and Mount Victoria granite massifs. In this area the Archaean migmatite complex is featured by the predominance of a leucocratic granitoid rock of adamellite type, which differs markedly from the regional granitic rocks in its unusually uniform composition.

Uranium mineralization of the distinctive absite type is widespread within the boundaries of the adamellite zone (fig. 41). Although rarely found in actual outcrop, its presence in the bedrock is usually indicated by highly anomalous radioactivity due to a concentration of detrital grains of the ore mineral in the soil, or by the spread of the weathered-out material which has been, in some cases, transported considerable distances from the source rocks (fig. 42). Initial prospecting which led to the definition of the six main orebodies was entirely dependent on radiometric measurements over the area.

#### The Ore Mineral

The ore mineral—absite—is a complex uranium-thorium titanate of general composition  $2\text{UO}_3 \cdot \text{ThO}_2 \cdot 7\text{TiO}_2 \cdot 5\text{H}_2\text{O}$ , consisting essentially of 32 per cent  $\text{UO}_3$ , 13 per cent  $\text{ThO}_2$ , 35 per cent  $\text{TiO}_2$ , and 7 per cent combined water.

Details of the mineralogy and associations of absite are given on page 54, together with partial chemical analyses (table III).

#### Rock Types in Relation to Ore Localization

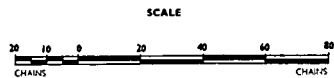
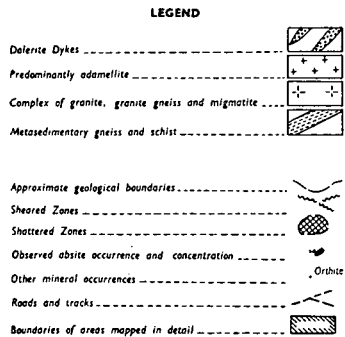
Detailed geological mapping of the principal uranium deposits, combined with petrographic studies, have led to the identification of six distinctive rock groups and variants which occur closely associated with adamellite in, and adjacent to, the mineralized areas. These belong to two main chronological sub-divisions which are discriminated in the field by the presence or otherwise of regional stress effects.

The oldest group, which pre-dated shearing, comprises Archaean metasediments intimately associated with hybrid granodiorite, and intruded or replaced by the locally predominant adamellite variety of the granitoid rocks. The adamellite has no clear-cut contacts with the similarly stressed granites of the district, but general field relationships suggest that it is a mobilized phase of the regional granite.

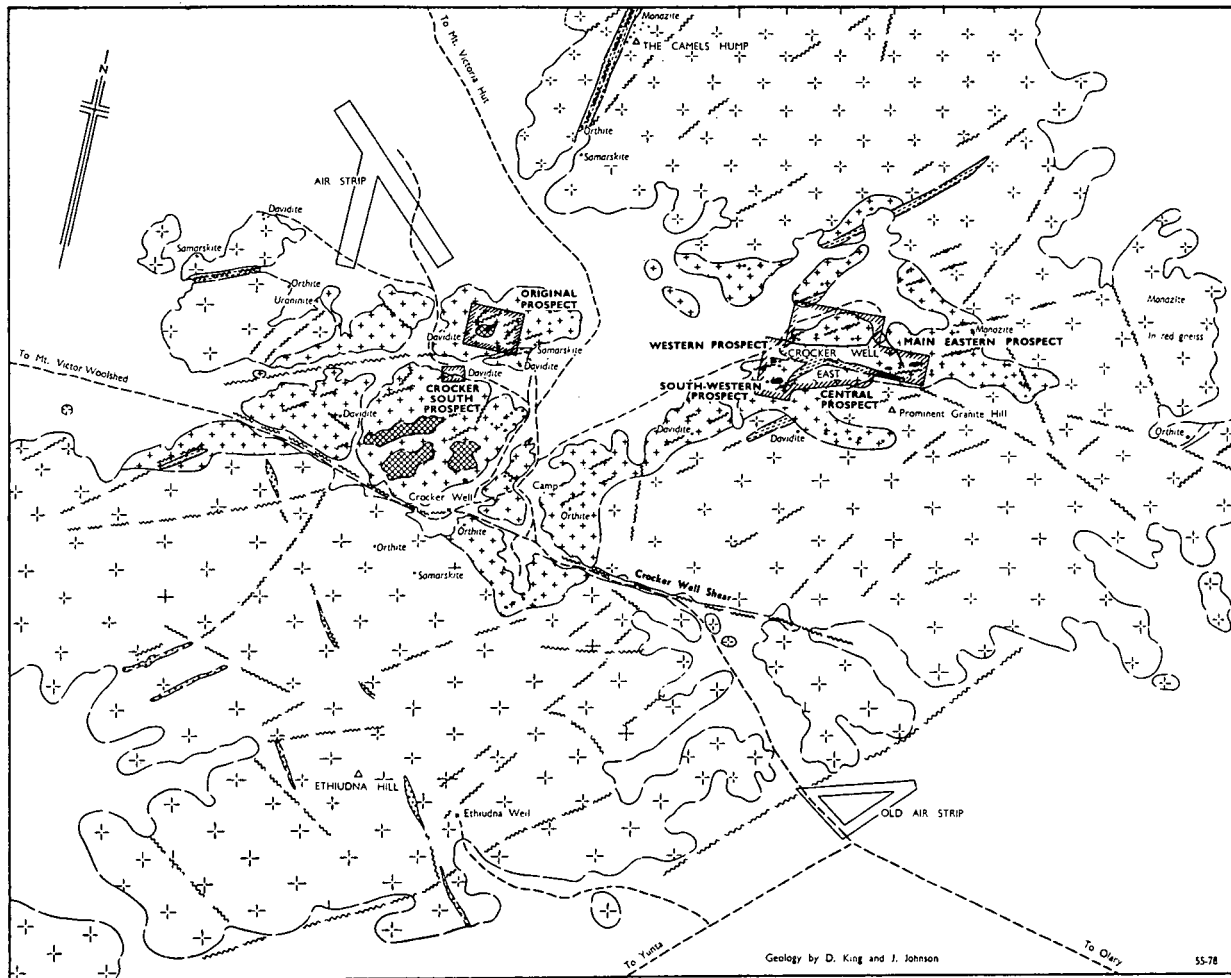
The younger unstressed group includes late-stage differentiates of the adamellite referred to as alaskite and alaskite-pegmatite, together with widespread pegmatites of the normal granitic type, and a few granodiorite dykes.

Each of the rock units enumerated above has a specific relation to ore distribution, the appreciation of which has materially assisted in directing mineral exploration. Of outstanding significance is the fact that adamellite is the host of all important absite deposits found to date. Metasediments bordering adamellite in some places contain trace amounts of the ore mineral, whereas the hybrid granodiorite is consistently barren. The alaskites carry absite as a minor accessory, indicating a genetic association with the mineralizing solutions or gases which led to the formation of the main orebodies. The granite pegmatites and granodiorite dykes clearly post-dated absite mineralization.

Geological and petrographic observations of the typical rocks are treated below in their chronological order.



S.A. Dept. of Mines.



Geology by D. King and J. Johnson

55-78

**FIG. 41—CROCKER WELL URANIUM DEPOSITS**  
Geological locality plan

### *Metasediments*

Micaceous schists and amphibolitic gneisses, grading to migmatites, which comprise a narrow east-west belt extending for over half a mile at Crocker Well East, and are also exposed as small outcrops at the southeastern margin of the Original Prospect.

### *Grey Mafic Granodiorite*

Hybrid granodioritic rocks consisting chiefly of albite-oligoclase, quartz, biotite, and magnetite are exposed as elongated bodies following the margins of the main belt of metasediments and as xenoliths (or skioliths) within the adamellite. Pyrite is a notable accessory constituent, and also occurs with biotite as a fissure filling in these rocks. Boundaries are gradational into metasediment, indicating transformation by metasomatic agencies.

### *Adamellite*

The predominant rock, adamellite, has been described in detail in an earlier report (King, 1954<sup>(a)</sup>), although at that stage its real significance as host rock to widespread uranium mineralization was not fully appreciated.

The adamellites are characteristically medium-grained and leucoeratic, and contain abundant quartz of a blue opaline variety. A typical sample from the wall rock of an absite vein at No. 2 shaft, Main Eastern Prospect, is described microscopically (Whittle, unpublished) as follows:

“This is a light-coloured rock with a typically granite texture consisting of hypauto-morphic inequigranular crystal. The mineral composition, in order of abundance, is albite, oligoclase, quartz, biotite, and microcline, with accessory apatite, monazite, magnetite, and zircon. The individual crystals are anhedral and medium grained.”

### *Alaskite and Alaskite-Pegmatite*

This group includes unstressed pegmatitic phases of the adamellite which may be locally observed as intrusive bodies into the mineralized area at the Original Prospect, and as replacement kernels in a biotite matrix to produce composite rocks known as pseudobreccia. Both alaskite and alaskite-pegmatite are similar in composition, consisting of equal amounts of sub-hedral potash feldspar and albite, and interstitial sagenetic quartz. The quartz is significantly the same opaline variety characteristic of the adamellite and in places occurs as segregations carrying absite. Absite is also present, together with rutile and ilmenite, as an accessory constituent of the alaskite.

### *Granodiorite Dykes*

At the Original Prospect, granodiorite dykes a few feet wide crop out, one of which was found to intersect mineralization in shaft C. The main mineral constituents are oligoclase, biotite, and quartz, and the accessories include apatite, zircon, rutile, ilmenite, monazite, and xenotime.

### *Granite-Pegmatites*

Coarse-grained feldspar-quartz pegmatite dykes and pegmatitic quartz veins, some carrying coarse black rutile, biotite, and magnetite, are of widespread occurrence throughout the area. Many are orientated in an ENE. direction following lines of weakness afforded by shear foliation. The distribution of the pegmatites, as shown in fig. 2, tends to coincide in a broad way with the mineralized areas, but absite has not been found as a constituent of these granite-pegmatites and the association is regarded as fortuitous.

### **Structural Controls**

The adamellite host rock is primarily even-grained and granular in texture, but rarely assumes a missive form of outcrop due to the presence of widespread fissuring and close-jointing caused by shearing in a WSW.-ENE. direction (fig. 41).

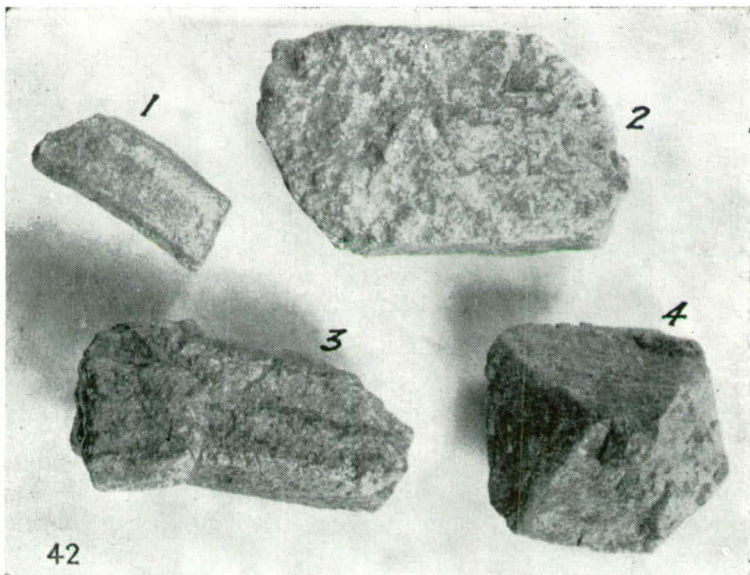


FIG. 42—RESIDUAL PSEUDOCRYSTALLINE ABSITE SLUGS FOUND IN SOIL

Nos. 1 and 3—Hexagonal  
 No. 2—Triclinic  
 No. 4—Octahedral  
 Main Eastern Prospect



FIG. 43—GENERAL VIEW OF THE MAIN EASTERN PROSPECT,  
 WITH DIAMOND-DRILLING PLANT IN OPERATION  
 Looking East

The intensity and distribution of stress effects are extremely variable, being mainly represented by a prominent fracture cleavage (or shear foliation) over a wide area, and by the local development of narrow and discontinuous shear zones and crush-breccia (fig. 45). Beyond the limits of the mineralized areas, two complementary sets of defined shear zones have been observed trending ESE. and NE., such as that along which the access track to the camp has been constructed.

The local concentration of absite in breccia and fracture zones related to shearing was first recognized as a result of surface mapping at the Original Prospect, and was subsequently confirmed by exploratory drilling. The adamellites adjacent to this deposit exhibit shearing in ENE. and NE. directions, and towards the central mineralized area become less regular in orientation and gradually merge into a lenticular zone of crush-breccia. Absite is mainly found in the form of interstitial "bunches", and smaller amounts of disseminated mineralization are found throughout the more extensive areas of partly fractured adamellite at the periphery of the breccia (fig. 44).

The deposits at Crocker Well East are similarly of the fracture-fill category, but the structural elements controlling ore localization are less clearly evident because the ore is more widely disseminated as isolated grains and narrow veinlets in openings of various types. The greatest concentrations are apparently at the eastern termination of strong ENE. shear zones in shear foliation planes and similarly directed fractures, and in strongly developed joints directed NNW.-SSE. (fig. 47). This jointing normal to shear foliation is common throughout the area.

The regional influence of tectonic structures on ore distribution is reflected in the general lenticular form and common orientation of the main deposits, each of which is directed ENE. parallel to the regional shear foliation. This fact has proved of some value in directing prospecting and exploration of known deposits, although relatively few of the widespread stressed or brecciated zones are actually mineralized.

#### Ore Genesis

There is conclusive evidence that the absite-type deposits are genetically related to the adamellite variety of the granitoid rocks, with which all the known deposits are so intimately associated.

Absite has, in fact, been identified microscopically as a minor primary constituent of the adamellite in some localities, although, as already indicated, it is more extensively found as a post-shear fracture filling, as isolated intergrowths with biotite and rutile (fig. 46), or in pegmatitic phases of the adamellite. The sporadic distribution of the ore in tight and discontinuous fissures provides evidence of the extreme mobility possessed by the mineralizing solutions or gases, but despite this there is no appreciable migration of the ore mineral into the wall rock, or into the surrounding terrain.

The ore and associated minerals are dominantly oxides, characteristic of high-temperature formation, and, except for apatite and traces of fluorite, there is a notable deficiency in minerals rich in volatiles, such as tourmaline or beryl, which are commonly found in granite differentiates elsewhere in the district.

Mineragraphic studies bearing on paragenesis of the ore reveal that biotite and apatite were formed simultaneously at the earliest stage of mineralization. The second stage involved feldspathization as locally observed in the pseudobreccia formation of the Original Prospect, and was followed by the introduction of alaskite and blue-quartz pegmatitic veins and segregations with some absite, and by the final deposition of rutile, absite, and davidite in various intergrowths.

These observations lead to the now generally accepted conclusions that the principal ore-deposits are due to a late-stage introduction of volatiles unusually rich in titanium and uranium immediately following the emplacement, cooling, and fracturing of the parent mass of adamellite. In many respects the type of

mineralization appears comparable to that of cassiterite in granitic rocks, both being characterized by irregular distribution of ore in bunches, in pegmatites and fissures, when the parent rock was largely consolidated.

Recent age determinations based on the uranium-lead isotopic method have shown that the absite mineralization dates back approximately 580 million years. This is in agreement with observed field relationships which indicate that the adamellite—and hence the mineralization—predate the Upper Proterozoic Sturtian Series (Adelaide System), as demonstrated by the presence of boulders of the adamellite (and the regional granites) in the Sturtian Tillite exposures six miles to the south, near Plumbago station.

#### **Grade Evaluation—Methods and Problems**

The sporadic distribution of the uranium mineral in the absite-type deposits makes reliable sampling exceedingly difficult. Bulk sampling, by shaft sinking and costeaning, is clearly the most desirable method, but very costly for general exploration purposes.

An initial surface appraisal of the Original Prospect was attempted by stripping overburden with a heavy bulldozer at regular intervals across the deposit, and by sampling bedrock exposed in this way. Although the project proved of some value in localizing the main area of mineralization, it was found that samples obtained were not strictly representative in that they did not account for the main ore-values concentrated in tight and deeply weathered fissures.

Some wagon drilling was carried out early in the investigation, but was discontinued when it became apparent that the presence of shallow groundwater prevented satisfactory dust recovery, and because of the general unsuitability of the rig in this type of ground.

Diamond drilling on a grid pattern has been used extensively in support of bulk sampling. The grade, as determined by assays of drill core and sludge and radiometric monitoring, however, show considerable discrepancies, and in the early stages could not be satisfactorily resolved. The problems associated with drill sampling are now more perfectly known. Experience has shown that recovery of representative core or sludge is quite impracticable in this particular type of deposit, but a reasonably accurate evaluation is being obtained by radiometric monitoring of the holes. Diamond drilling is being continued on this principle as the main form of exploration.

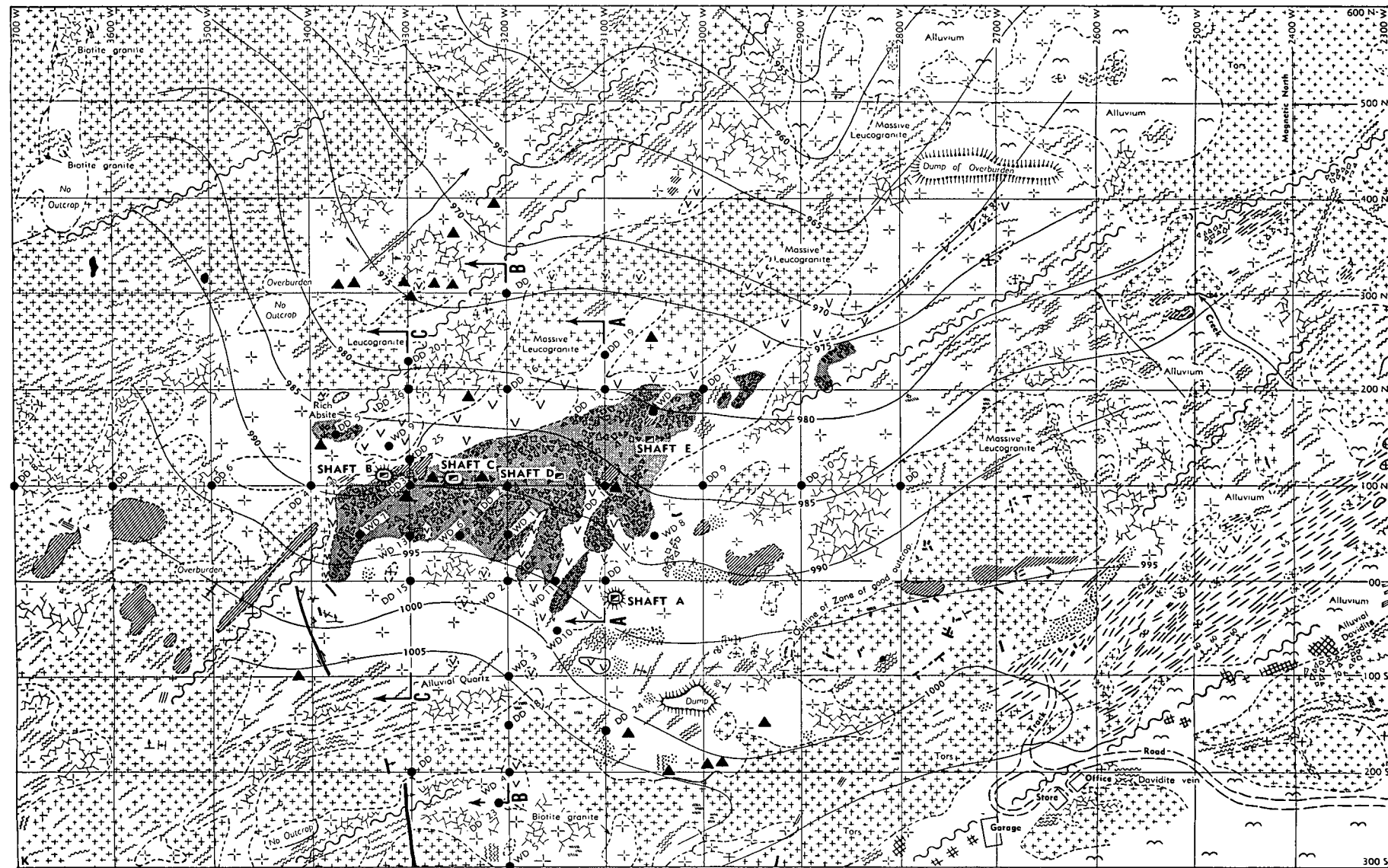
The following is a review of the main grade-evaluation methods adopted and the inaccuracies associated with them.

#### *Assays of Diamond-Drill Cores*

According to usual practice, the whole of the core recovered from each borehole is split longitudinally; one half is subdivided on the basis of the geological and radiometric borehole logs into fractions for assay, and the other half retained for record purposes. Assay results thus obtained (table VI) are known to be consistently lower than the true grade because of the unavoidable loss of the ore mineral during actual drilling due to its highly brittle nature and its usual occurrence as weakly bonded grains in natural fractures. In almost all cases the core is found to be broken at intersections of absite slugs, with only remnants of the mineral adhering to the faces of the fracture.

#### *Recovery of Diamond-Drill Sludges*

Sludges recovered from boreholes were assayed in bulk for each hole and show at least 50 per cent higher uranium values than the split core samples. Even these results are believed to be conservative as in general there is a considerable loss of water (and sludge) in the fractured rock where the mineral generally occurs.

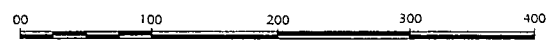


- PRE-SHEARING**
- Adamellite pegmatite massive outcrops
  - fractured and deeply weathered
  - Metasedimentary gneiss
- POST-SHEARING**
- Alaskite and alaskite-pegmatite
  - Grey granodiorite
  - Basic Rock microdiorite

- Pegmatite quartz felspar
- Quartz veins
- Absite residual in soil
- Biotite
- Mineralized breccia main absite concentration

- Strike and Dip of shear foliation
- Shear foliation
- Shear Zone
- Jointing Strike
- Dip
- Vertical
- Irregularly shattered zone

SCALE IN FEET



S.A. Dept. of Mines US-337

Geology by D. King

Contour Interval 5 feet assumed datum

**FIG. 44—CROCKER WELL—ORIGINAL PROSPECT**  
Surface geological plan

The practice of cementing holes where there is no water return reduces the sludge loss to some extent, but this measure cannot account for the water and sludge that escape before the necessity for cementing is realized. In fact, the bulk of the sludge recovered is that from the massive and weakly mineralized portions of the adamellite host rock.

#### *Radiometric Borehole Logging*

Borehole monitoring performed by the Geophysical Section of the Geological Survey Branch has been used extensively in providing additional evidence of grade, and is becoming increasingly important in the evaluation of these deposits (King and Webb, 1954). This technique has revealed significant radiometric anomalies in many of the boreholes, and, from an early stage, led to a belief that true grade is reasonably higher than shown by drill-core sampling. The equipment in use has the following specifications:

Geiger tube . . . . .	Cintel No. G.M. 4 x 5. Length 10½ in., diameter ¾ in. Ethyl formate argon filled. Operating voltage approx. 1,250.
Probe . . . . .	1½ in. overall diameter brass tube. 5 S.W.G. gauge wall thickness.

Prior to 1955, radiometric-probe results were translated into grade by applying a conversion factor calculated from a theoretical comparison of radiometric recordings and actual grade of better-known deposits (*e.g.*, Radium Hill) in which allowances were made for differences in gamma-ray activity (absite as compared with davidite) and for their respective content of thorium. Experimental calibration of the equipment was also conducted using a large drum packed with typical ore of known grade. The standard adopted as a result of these researches was that 2,100 counts per minute are equivalent to 1 lb. of  $U_3O_8$  per long ton.

The irregular size and distribution of the ore mineral affect the reliability of the procedure in estimating grade from borehole-probe results, particularly as the probe effectively measures radioactivity only within a 5 in. radius of boreholes in the adamellite host rock. Statistical analyses have shown that reliable results cannot be expected over limited footages, but that the probable error decreases to reasonable limits—less than 10 per cent—if the grade is presented as an overall average for each borehole. An exploration programme has lately been completed at the Main Eastern Prospect which was primarily designed to provide a standard reference for more accurately assessing overall grade by radiometric monitoring. This involved the sinking of a shaft (No. 1 shaft) on a closely drilled and radiometrically logged site, purposely carried out in an area of submarginal-grade rock representative of the major reserves of these deposits. The initial boring consisted of four vertical 50-ft. holes (E.C.S. series) at symmetrically placed points within an area of 6 by 4 ft., at sufficiently close intervals to ensure that the borehole monitoring which followed would be representative of the bulk sample obtained by shaft sinking.

The weighted average grade-value of the ore broken in the shaft was determined by three methods as follows:

	$U_3O_8$ lb. per long ton
Drill core assays . . . . .	0.2
Radiometric borehole logging . . . . .	1.1
Chemical assay of bulk ore (actual grade) . .	1.7

Apart from clearly demonstrating that drilling provides highly unsatisfactory samples due to loss of much of the ore mineral, these results showed that the factor used for converting radiometric borehole-logs to equivalent grade over a reasonable length of testing (200 ft.) underestimated the true grade by the ratio of 1.1 to 1.7, and that actually 1,360 counts per minute (rather than 2,100 c.p.m. as previously assumed) should be equated to absite ore assaying 1 lb.  $U_3O_8$  per long ton. This ratio was considered applicable to the usual dissemination-type ore which forms the bulk of the reserves.

During recent underground development at the Main Eastern Prospect, underground probing experiments were carried out in which development headings were probed before firing. In this case, the 12 rock-drill holes in each face were probed and the results combined to produce an average count to represent the cut. After each cut was fired, a bulk sample of half the broken material was obtained and sent for assay. After 29 cuts had been probed and sampled, the results were statistically analyzed and indicated that a more reliable conversion factor was of the order of 2,600 counts per minute per pound  $U_3O_8$  per long ton. This more conservative figure has since been used to estimate the grade of all the Crocker Well East prospects.

### The Original Prospect

#### Geology

At this deposit, absite mineralization is mainly localized within a lenticular zone of coarsely brecciated adamellite which is locally developed in an area of intense ENE. shearing (fig. 44). The periphery of the breccia is marked by the presence of intrusive alaskite bodies, commonly containing absite as an accessory mineral.

The breccia consists of angular adamellite blocks in a matrix of schistose biotite and irregular-shaped kernels of unstressed alaskite. This fragmentary-looking structure (pseudobreccia) within the matrix is clearly not of tectonic origin. The richest absite values occur within these interstitial fillings—together with apatite—in alaskite and blue-quartz veinlets, and as sporadic grains and bunches up to a ton in weight (King, 1954<sup>(a)</sup>).

The mineralized breccia covers an area of some 50,000 sq. ft. in ground plan, and is surrounded by a more extensive area of fractured and weakly mineralized adamellite.

A small area of outcropping mineralized adamellite and migmatite known as the Crocker South Prospect is located 300yds. southwest of the main deposit at the margin of an alluvial flat, and is of particular interest in being one of the few places where absite and davidite are found in intergrowth.

#### Development

Exploration commenced in January, 1952, when series of trenches were excavated across the deposit by bulldozer to facilitate geological and radiometric surveys, and sampling of the bedrock. Shaft sinking was then undertaken, five shafts totalling 160ft. being sunk and sampled, and ore parcels submitted for metallurgical research.

TABLE IV  
CHEMICAL ASSAYS OF BULK SHAFT-SAMPLES  
*Original Prospect*

Location	Footage	Chemical assay ( $U_3O_8$ ) lb./long ton
Shaft A . . . . .	0—20	1.8
Shaft B . . . . .	0—20	3.5
	20—50	2.0
Shaft C . . . . .	0—30	1.1
Shaft D . . . . .	0—40	1.0
Shaft E . . . . .	0—20	1.3

Diamond and wagon drilling commenced in March, 1953. Wagon drilling proved of limited value and was discontinued after 13 holes (822ft.) had been completed; but an intensive programme of diamond drilling, totalling 21 holes (2,859ft.) was carried on until November, 1953. Initially, vertical bores were sunk within the known limits of the breccia structure (table V); subsequently a wider network of holes was spread with the object of testing the general dissemination of ore in the surrounding area, and finally, three angle-holes were drilled to crosscut the breccia.



FIG. 45—TYPICAL SHEAR ZONE IN ADAMELLITE  
Crocker Well East—Looking southwest from co-ordinates 4450N : 1400E

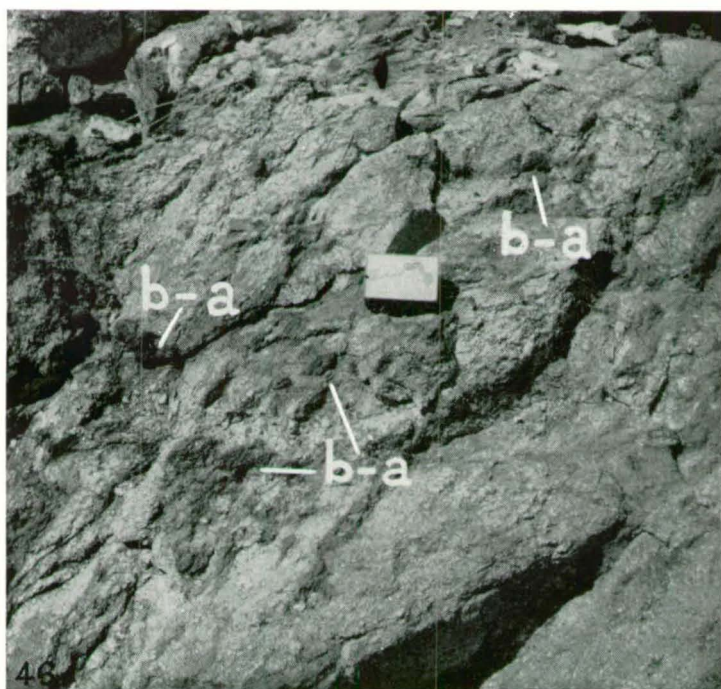


FIG. 46—BIOTITE-ABSITE INTERGROWTHS (b-a) IN FRACTURED  
ADAMELLITE  
Crocker Well East—Co-ordinates 4600N : 1300E

More recently one borehole (No. C.S.1) was drilled beneath the outcrop and adjacent alluvium at the nearby Crocker South Prospect as a purely exploratory measure, but no mineralization of ore-grade was intersected.

#### Ore Reserves

Trench sampling and subsequent diamond drilling confirmed the view that the most significant absite mineralization is confined to the breccia zone. It was also shown that the breccia has no great extent vertically.

The following estimate of ore reserves is, therefore, applied to the breccia zone.

#### Grade

Undoubtedly the most reliable figures available on grade are those provided by bulk sampling from the five shafts. These range from 1.0 to 3.5 lb. with a mean of 1.65 lb. (table IV). This latter figure may be unduly weighted by the relatively high grade obtained from shaft B, and the fact that three of the shafts were sunk on surface anomalies, but on the other hand the very nature of the mineralization would suggest that rich pockets would be a normal expectation.

The figures obtained from drilling are, for reasons already discussed, considered very conservative. Radiometric bore-log computations based on the latest conversion factor suggest a grade of between 1.5 to 2.3 pounds.

It would seem a fair appraisal to suggest from the above figures that the breccia zone would provide a mean grade of 1.5 lb.  $U_3O_8$  per long ton.

#### Tonnage Estimate

Accepting the geologically mapped limits of the breccia zone as the limits of ore, there is a surface area equivalent to 3,000 tons per vertical foot available. Cross-sections constructed on the basis of the three crosscutting boreholes indicate that the breccia is limited in depth, a reasonable mean depth being 120ft. On this basis it might be expected that the deposit could yield 360,000 tons of ore.

TABLE V  
ASSAYS OF CORE FROM VERTICAL BOREHOLES WITHIN THE BRECCIA ZONE  
*Original Prospect*

Bore No.	Footage	Assays ( $U_3O_8$ )		
		Core (chemical)	Sludge (chemical)	Borehole logging
1	0—10	0.4	—	1.7
2	0—90	0.6	—	2.2
3	0—120	0.5	0.5	1.5
4	0—100	0.2	0.7	2.3
5	0—120	0.9	0.8	1.9
Weighted means . . . . .		0.6	0.7	1.9

#### Crocker Well East Prospects

##### Geology

The four separate prospects at Crocker Well East are the main centres of mineralization—as defined by the spread of detrital absite—within an extensive and only partly tested area of weakly mineralized adamellite (fig. 47). In these deposits the ore mineral occurs associated mainly with rutile as disseminated pellets and sporadic veinlets in widely spaced shear foliation planes and joints. In this respect the deposits resemble the marginal area of the mineralized breccia at the Original Prospect, and it might be expected that ore concentrations in similar structures will be found in depth at Crocker Well East.

Davidite has been found to occur in appreciable amounts intergrown with absite, and independently, in a number of borehole samples from the Crocker Well East Prospects.

#### *Development*

Exploration of the Crocker Well East Prospects commenced immediately after their discovery in September, 1953. Detailed geological and isorad maps were prepared showing also the distribution of detrital absite in the soil (figs. 47 and 49). These results, together with a consideration of the surface topographic contours, formed the basic data for designing a pattern drilling programme which followed.

The first phase of diamond drilling was undertaken as the most convenient method of establishing the source of the rich surface-shoals. A total of 21 holes (3,206ft.) of the E.C. series were sunk, of which nine are located at the Main Eastern Prospect (fig. 43), six at the Southwestern Prospect, and four at the Central Prospect (table VI). Each hole is directed northerly at a depression of 45 deg. to a usual target depth of 150ft., the inclined holes being chosen because of the steep southerly dip of observed geological structures, and the steep inclination of known mineralized fissures (fig. 48).

TABLE VI  
SUMMARY OF DIAMOND-DRILLING RESULTS  
*Crocker Well East Prospects*

Log	Bore No.	Depth	Weighted average grade	
			Estimated by rad. probe	Core assay (rad.)
		ft.	lb. U <sub>3</sub> O <sub>8</sub> /ton	lb. U <sub>3</sub> O <sub>8</sub> /ton
Main Eastern Prospect . . . . .	EC 1	179	1.3	2.7
	EC 2	149	1.1	0.11
	EC 3	177	1.4	0.89
	EC 4	150	1.0	0.11
	EC 5	150	0.4	0.15
	EC 6	150	1.0	0.15
	EC 7	150	0.8	0.13
	EC 8	150	0.6	0.23
	EC 9	130	0.4	0.09
		Overall weighted average grade		0.95
Southwestern Prospect . . . . .	EC 14	170	0.9	0.71
	EC 15	150	0.95	0.29
	EC 16	150	1.0	0.29
	EC 17	150	1.0	0.52
	EC 21	150	0.95	0.16
	EC 22	150	0.9	0.63
		Overall weighted average grade		0.95
Central Prospect . . . . .	EC 10	150	1.1	0.74
	EC 11	151	1.3	0.52
	EC 12	150	0.5	0.17
	EC 13	150	0.7	0.15
		Overall weighted average grade		0.90
Western Prospect . . . . .	EC 18	150	0.4	0.20
	EC 19	150	0.3	0.07
		Overall weighted average grade		0.35

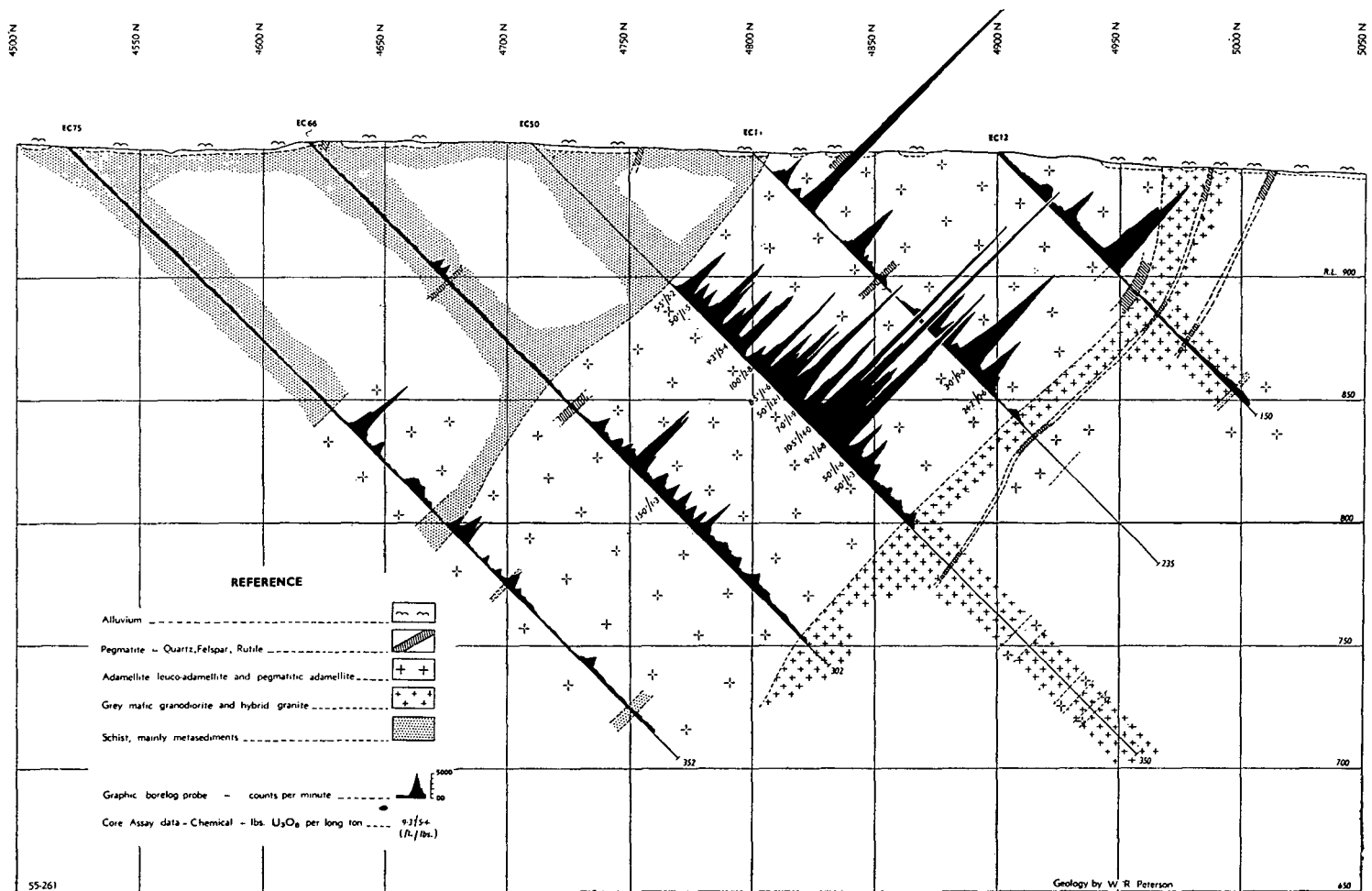


FIG. 48.—CROCKER WELL—MAIN EASTERN PROSPECT  
Cross-section showing bore-log probes

The next stage of the investigation involved shaft sinking in two localities at the Main Eastern Prospect, primarily as a confirmation of grades. No. 1 shaft—to a depth of 43ft.—is located in an area of general dissemination-type ore where some additional vertical drilling (E.C.S. series) and borehole monitoring was undertaken, and served a dual purpose in providing a bulk sample representing the major ore-reserves of the deposits, and also a means of correlating radiometric borehole results. No. 2 shaft—to a depth of 44ft.—is sunk on an absite vein at the eastern end of the deposit (fig. 49).

#### *Ore Reserves*

Current drilling has revealed that absite mineralization is widely disseminated throughout the whole of the areas tested, with a few vein concentrations of only minor importance. These very extensive deposits of submarginal grade are considered here as potential ore-reserves.

Present evidence indicates that of the four areas drilled, the Main Eastern Prospect and Southwestern Prospect are the largest. The Central Prospect is small by comparison, and the Western Prospect is too low in grade to qualify as ore reserves. Extensions of the pattern diamond-drilling programme now in progress (June, 1955) are expected to materially increase the volume of proven ore reserves described below.

#### *Grade*

Radiometric monitoring suggests that the average grade along individual boreholes varies within the limits of 0.4 and 1.4 lb. with a consistent overall figure of 0.9 lb. for each of the three main deposits. By comparison, the weighted average core assay is 0.5 pound.

The only large parcel of presumably representative ore from the deposits (68 ton from No. 1 shaft) assayed 1.7 lb., higher in fact than any of the values otherwise indicated at the shaft site.

Actual grade is probably slightly in excess of 1 lb.  $U_3O_8$  per long ton.

#### *Tonnage Estimates*

Estimated tonnages per vertical foot of depth to June, 1955, are as follow:

	Surface area sq. ft.	Tonnage per vertical foot tons
Main Eastern Prospect ..	70,000	6,000
Southwestern Prospect ..	42,500	3,500
Central Prospect .. ..	30,000	2,500
Total . . . . .	142,500	12,000

There are indications that the mineralized zone maintains its dimensions to a depth of at least 100 feet.

#### **Metallurgical Investigations**

Detailed ore-treatment investigations have been carried out on parcels of the low-grade Crocker Well ore by the Metallurgical Branch (Smith, 1955).

The coarse grain-size of the absite and its high specific gravity relative to the gangue suggested that gravity concentration—using jigs or shaking tables—could be a satisfactory method of treatment. Tests showed, however, that high recoveries could only be achieved by this method at the expense of the grade of concentrate, and all attempts to raise the latter resulted in high tailing-losses.



FIG. 50—RADIUM HILL MINE  
Showing headframe, crusher-station (at right), storage bins, and concentrator

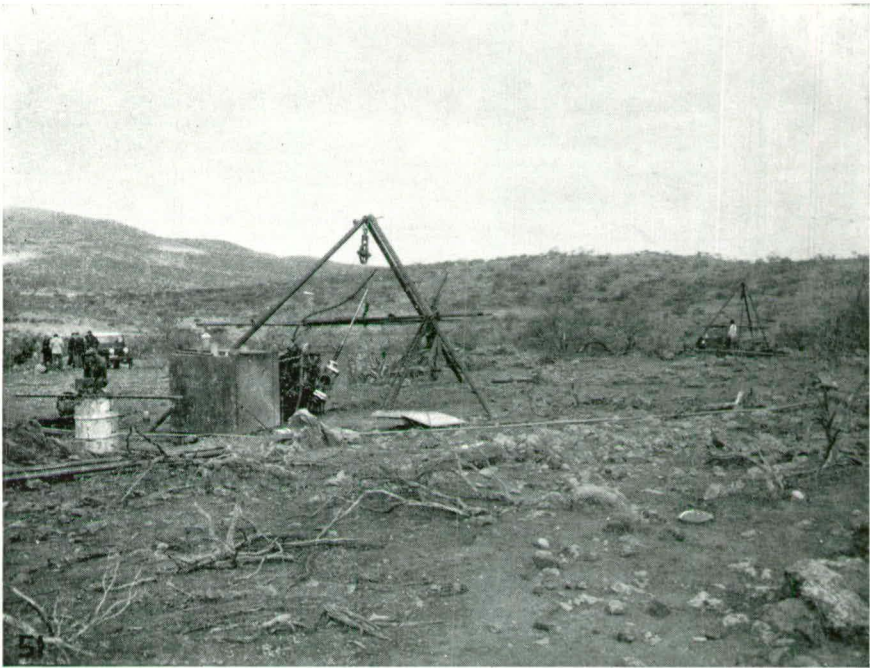


FIG. 51—DIAMOND-DRILLING PLANTS OPERATING AT THE MOUNT VICTORIA  
MINE SITE  
View looking east—Main-lode outcrops are a few yards to the left of the foreground

*To face page 70]*

More satisfactory results have been obtained by flotation methods. Samples assaying between 1 and 3 lb.  $U_3O_8$  were treated by batch flotation in the laboratory, using fuel oil with emulsifying agents, and a concentration grade of approximately 120 lb.  $U_3O_8$  was achieved. Continuous flotation of the same-grade ore in a pilot plant, at rates of 100 and 1,000 lb. per hour, indicate that actual recoveries between 80 and 90 per cent could be expected, giving a concentrate of between 80 and 100 lb.  $U_3O_8$  per ton.

#### General Appraisal

The ore mineral has many favourable features, particularly in regard to its high uranium content (32 per cent  $UO_3$ ) and its relatively simple and inexpensive metallurgy.

At the present stage of exploration, a considerable volume of mineralized ground has been indicated, the bulk of which is of a grade somewhat in excess of 1 lb.  $U_3O_8$  per long ton. Included also are a few rich zones which could provide perhaps several thousand tons of high-grade concentrate by selective mining.

Further diamond drilling and underground exploration is being undertaken in an effort to establish actual reserves.

#### MOUNT VICTORIA URANIUM DEPOSIT

*Location:—The Mount Victoria uranium mine is situated 12 miles north of Plumbago station and about 4 miles east-southeast of Glenorchy station. The Crocker Well uranium deposits lie about 6 miles south of the Mount Victoria mine. Out of counties, North-Eastern division.*

#### Introduction

Shortly after the discovery of the Mount Victoria uranium deposit in March, 1954 (see Chapter 1) a programme of four short exploratory diamond-drill holes sunk beneath the mineralized outcrops provided some highly encouraging results (Pitman, 1954<sup>(a)</sup>), and the drilling programme was gradually expanded to included a total of 39 boreholes with progressively increased target depths.

As the definition of the orebodies progressed, a successful method for upgrading the complex ore—similar to that adopted at Radium Hill—was developed by the Metallurgical Branch. Initially, experimental metallurgical work was performed on rejected fractions of drill-core samples, but later a bulk sample was obtainable from a 40-ft. inclined shaft (No. 1 shaft) for testing on a pilot-plant scale.

At the present stage (June, 1955), sufficient ore reserves have been defined by drilling to justify a mining operation. Mining estimates have been prepared by A. T. Armstrong (State Mining Engineer). The design and location of a concentrating mill to be erected near the mine site is in the hands of the Metallurgical Branch, and the provision of a suitable water supply for the mill and domestic requirements is being undertaken by boring in the locality.

The geological investigations and diamond drilling at Mount Victoria were the responsibility of one of the authors (D. King) and W. R. Peterson (a geologist seconded from the U.S. Atomic Energy Commission), under the direction of L. W. Parkin (Chief Geologist). E. Clothier (Technical Assistant) assisted materially in the preparation of plans and ore-reserve compilations.

#### Surface Geology

The deposit lies in an area of prominent granitic hills separated by extensive stretches of alluvial flats. The mineralized outcrops are situated on the crest of a low spur, 300yds. wide, between southerly draining watercourses at the fringe of the Windamerta Hill granite ranges. To the south, there is an open flat comprising portion of a longitudinal valley  $\frac{1}{2}$  mile wide which separates the Windamerta Hill range from the prominent Mount Victoria granite massif.

Davidite was detected at the surface in several elongated outcrops of schistose biotite rock lying within an area of poorly exposed granite and granitized metasediments.

The deposit consists essentially of four outcropping bodies of the mineralized rock, each with an east-west strike and southerly dip. The northern, or Main lode, is the largest, extending laterally east-west for a distance of 250ft. at an average width of 10ft. Of the others, the South limb is 100ft. long and converges to meet the Main lode at its eastern extremity. Both the Central lode and the South lode are elliptical in surface plan, the largest dimensions being 45ft. and 40ft. respectively.

The Central lode is interpreted as a westerly extension of the South limb.

In addition to the main area of mineralization described above (and in fig. 52), several small exposures of davidite-biotite lode rock have been mapped at distances of 70, 220, and 300ft. to the southwest of the Main lode outcrop, at the margin of a narrow alluviated belt along the line of strike of the Central and Main lodes. Similar mineralization is also known to occur over a short strike length beneath alluvium at two localities in the southeastern part of the prospect area, in a gully 500ft. south of the Main lode.

The granitized metasediment country-rock of the mine area is chiefly represented at the surface by displaced boulder fragments embedded in soil, the only reliable outcrops consisting predominantly of the more resistant granitic and pegmatitic components of the complex which have no particular orientation. The lodes exhibit a well-defined schistosity, or fracture cleavage, indicative of locally intense shearing, but there is no evidence of any fracture system extending laterally beyond the relatively abrupt terminations of individual mineralized outcrops.

In at least one place (co-ords 240W : 200S) the Main lode is disrupted by aplitic granite which appears to have post-dated lode emplacement.

Numerous minor occurrences of uranium and rare-earth minerals have been identified during systematic ground surveys of the surrounding areas (*see* plate IV). Half a mile west of the mine, coarse davidite aggregates may be observed in pegmatitic quartz veins over a wide area. Samarskite occurs as a joint filling  $\frac{1}{4}$  mile to the northeast, and uranophane-stained fractured granite and migmatite is common in the Talbot Creek locality farther north. South of the mine, xenotime and monazite are relatively abundant in pegmatites at the periphery of the Mount Victoria granite massif.

#### Lode Minerals

The mineral composition and paragenesis of the Mount Victoria orebodies is remarkably similar to that of the Radium Hill lodes.

The lode rock consists of disseminated daviditic iron-titanium minerals in a matrix of medium-grained biotite, albitic feldspar, and apatite (fig. 53). The biotite, which constitutes 50-80 per cent of the rock, is mostly orientated parallel to the lode dip, but there are also a number of flakes lying across the schistosity which effectively bind the rock into a felted and compact form. Unstressed segregations of albite up to a few inches in diameter replace biotite in a random manner, and apatite and subordinate orthite and monazite are widely disseminated in the biotite as small grains.

Impure davidite, rutile, and hematite occur as composite granules and irregular segregations replacing, or partly replacing, the biotitic matrix. In most of the grains, davidite is the host to minute inclusions of rutile and hematite, but others are equi-granular intergrowths of davidite and rutile. These complex ores have a steel-grey metallic appearance, but davidite with a high lustre and conchoidal fracture resembling that of the pure mineral is found locally in albite segregations (fig. 53).



A complete chemical assay of this lustrous davidite from the Mount Victoria mine (No. 1 shaft) is given in table II (*see* page 53).

Granular magnetite-pyrite rock occurs at the margins of the lodes, and as narrow veins parallel to foliation in the hanging-wall migmatites. In all observed cases, no davidite or biotite is associated with these veins.

Small amounts of chalcopyrite, bornite, covellite, and pyrrhotite are associated with davidite and with the magnetite-pyrite veins, while molybdenite is a rare lode-mineral. Some pyrite is partly replaced by enargite.

Sulphide aggregates intersect the daviditic ore and are thus later in the paragenetic sequence.

#### **Diamond Drilling**

Exploration of the Mount Victoria deposit by diamond drilling commenced in April, 1954, and at the present time (June, 1955) 39 boreholes have been completed representing a total footage of 5,178 feet.

The drilling was designed to follow a systematic grid-pattern at progressively increasing depths. The boreholes are all directed north in a plane normal to the lode dip, and are spaced at increasing distances from the main mineralized outcrop along each 50-ft. north-south grid-line extending from 450W to 100W. The initial boreholes were depressed at 45 degrees, but in the deeper testing it was found practical and more economical to drill two holes at different angles from the same site.

The location and depression of each borehole is indicated on the surface plan (fig. 52). A typical geological cross-section normal to the plane of the lodes, along grid line 200W, is shown in fig. 55.

In addition to the programme described above, two relatively short exploratory boreholes (Nos. V.H. 27 and 28) have been drilled on weakly mineralized zones south of the main area, and other holes are in progress to further test these occurrences.

#### **Interpretation of Drilling**

##### *Country-Rock Structure*

Diamond drilling in the mine area has indicated that the hanging-wall country-rock comprises mainly albite-biotite-cordierite gneisses and foliated migmatitic granites which have a persistent east-west orientation and southerly dip. The foliation is inherently related to former bedding planes as testified by the way it describes minor fold structures, but in addition to this usual case in which feldspathization has involved a simple replacement of bedding, there are some examples of introduced veinlets with pygmatic folds, unrelated to sedimentary structures.

There is also abundant evidence of shearing along narrow zones conformable with the bedding foliation. The stress effects are chiefly represented by a succession of narrow sericitic fractures, which in some places are partly replaced by biotite or magnetite, and by peculiar granitized breccia. These features are illustrated in fig. 54.

The footwall consists predominantly of massive leucogranite.

##### *Lode Structure*

The orebodies are tabular-shaped lodes which persist to depths of up to three or four times their strike length. The lodes dip to the south at angles decreasing from 65 deg. near the surface to 45 deg. at depths greater than 100ft. down dip, and are generally conformable with the country-rock structure. This applies particularly to the Main lode, as the South limb and Central lode which are considered to be disjointed portions of the one orebody, are slightly transected to bedding foliation. The Main lode and South limb converge at the eastern end of the

outcrops, and also at 200ft. down dip along co-ords. 250 W and 200W. Similarly, the Main lode and Central lode, which are 45ft. apart in the outcrop, converge at a depth of 70ft. down dip along co-ord 400W. The South lode is parallel to the Main lode, to a considerable depth, and lies 50ft. stratigraphically above it.

At a depth of approximately 450ft. down dip, both the Main lode and South lode diverge into two branches, separated by 10 to 24ft. of country-rock.

The lode walls are sharply defined by a shear contact with barren migmatite, a feature which is now well exposed in No. 1 shaft where the hanging wall is a smooth undulating surface marked by numerous flutings and slickenside structures. Lenticular remnants of country-rock with sheared boundaries can be observed within the lode formation in this opening.

The pitch of the mineralization in the lode channels is near vertical, the reserves of ore-grade lying between co-ords. 400W and 150W. In the plane of the lodes, the widths of ore and degree of mineralization decrease gradually to the westward, whereas to the east the termination is abrupt.

On the limited evidence available, uranium mineralization appears to be reasonably consistent in distribution within the lodes, with a tendency towards enrichment of ore-shoots in lode swellings.

#### *Lode Dimensions*

At the present stage (June, 1955) diamond drilling has defined the approximate dimensions of the Main lode system to a depth of 850ft. down dip, and the South lode (hanging-wall lode) to 540ft. down dip. An interpretation of the lode-structure contours based on diamond-drill results is illustrated in fig. 56.

The following approximate figures provide an indication of the size of the ore-bodies as determined from existing evidence, and demonstrate that, in a general way, the surface outcrop is an average cross-section of the deposit at least to the depths quoted.

		Depth (down dip) ft.	Average width ft.	Average length ft.	
Main lode system	{	Main lode . . .	850	6.06	250
		South lode . . .	540	6.75	100
		Central lode . . .	350	3.5	50
Hidden lodes . . . . .		Near surface	22.6	?	

The deepest borehole (V.H. 29-80) intersected the Main lode—after passing through the South lode—at a depth of 850ft. down dip. This borehole was depressed at 80 deg. to test the lode at 1,000ft. down dip, but a survey revealed a gradual flattening to 60 deg. at 990 feet.\*

#### *Controls in Ore Localization*

The geological setting of the lode system is interpreted from only fragmentary data, and the following discussion of the sequence and controls of ore localization is consequently subject to revision as development proceeds.

On the available evidence, mineralization is considered to be localized along a system of south-dipping, sub-parallel, and branching fracture zones which assume a similar attitude to relief bedding foliation in the migmatite country-rock. The effects of shearing are reflected in one of several ways:

- (a) Zones of granite breccia (of undefined orientation) which are cemented by fine-grained granitic material.
- (b) Numerous narrow fracture-partings in the hanging-wall migmatites characterized by sericite-muscovite development or replacement by either schistose biotite or granular magnetite-pyrite rock.

---

\* This is the only borehole that has been surveyed, and it is to be understood that no allowance has been made for other probable borehole deflections in compiling the geological cross-sections and ore-reserve estimates.

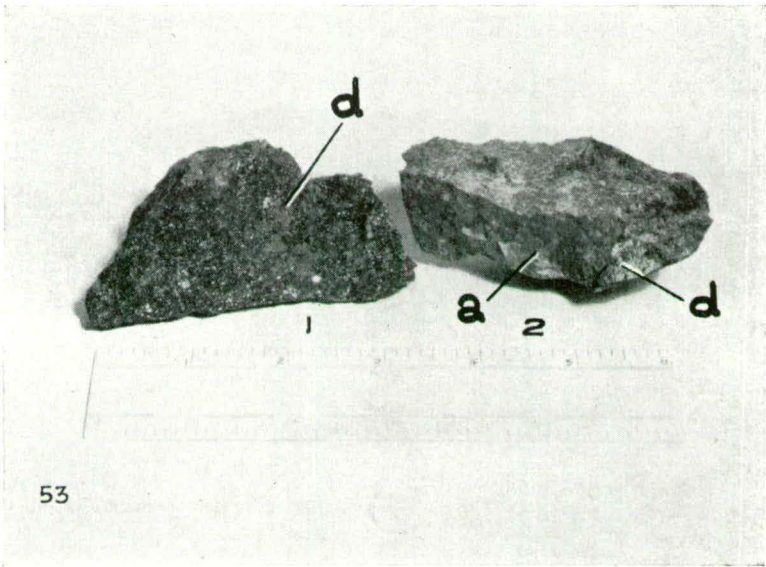


FIG. 53—SAMPLES OF LODE ROCK—No. 1 SHAFT, MOUNT VICTORIA MINE

- 1—Typical davidite-biotite lode rock—Steel-grey davidite (d) can be observed as irregular replacement in right central portion of specimen  
2—Davidite grain (d) in albite segregation (a)—The davidite appears white due to reflected light

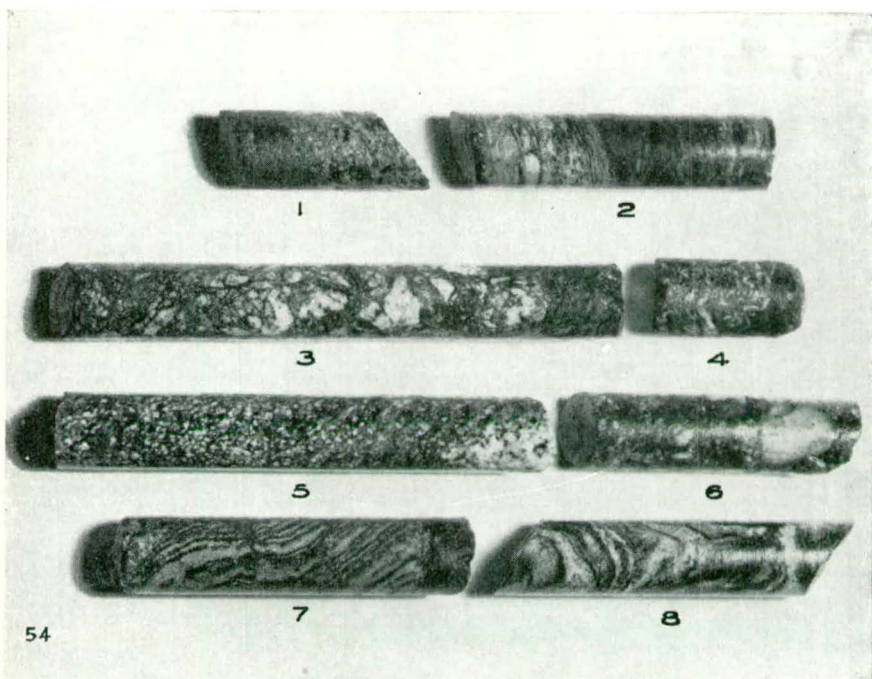


FIG. 54—CORE SAMPLES FROM BOREHOLES—MOUNT VICTORIA MINE

- 1—Typical sharp contact of biotite-davidite lode rock with granite-migmatite—Main lode hanging wall (Bore VH 28-45, at 162 feet)
- 2—Magnetite-pyrite veins along foliation of granite-migmatite in the hanging wall (Bore VH 17, at 150 feet)
- 3—Granitized breccia (or pseudobreccia) in migmatite—Contact of breccia with adjacent migmatite (R.H.S.) is irregular but sharp (Bore VH 11-70, at 158 feet)
- 4—Ptygmatically folded felspar veinlets in biotitic migmatite (Bore VH 11-70, at 175½ feet)
- 5—Granular migmatite consisting predominantly of biotite and sodic felspar (Bore VH 11, at 123 feet)
- 6—Quartz fragment in granitized breccia matrix (Bore VH 20-60, at 27 feet)
- 7—Minor folding in bedding foliation of migmatite—Magnetite-pyrite mineralization crosscutting bedding at right end of specimen (Bore VH 17, at 135 feet)
- 8—Minor folding in bedding foliation of migmatite (Bore VH 26-45, at 133 feet)

(c) The biotite-davidite lode formations with internal schistosity and well-defined fracture-plane walls.

The lineation of the slickensides in fracture planes throughout the area indicates slippage down dip (normal faulting) which, perhaps significantly, corresponds with the pitch of mineralization.

The mineralogy and texture of the lode rock is strongly suggestive of granitic parentage. The gangue of intergrown biotite and apatite, with disseminated monazite and orthite, exhibit replacement phenomena in the nature of a greisen produced by pneumatolysis. The validity of this conclusion is supported by the presence of coarse and relatively pure davidite in unstressed albite segregations in the lode rock, and the ubiquitous occurrence of davidite in pegmatite in this region generally.

The main uranium-titanium daviditic complexes, and the sulphides, which partially or completely replace the biotitic lode rock, were clearly introduced by successive waves of mineralization under conditions grading from the pneumatolytic to the hydrothermal stage.

A small body of aplitic granite appears to crosscut the Main lode in the surface outcrop, and although no other similar bodies were revealed by boring, development may prove the presence of post-mineralization granitic intrusions.

#### Grade Analysis

The evaluation of grade of the orebodies has been wholly dependent on assays of diamond-drill core, supported by radiometric borehole logging and a limited amount of bulk sampling. Details of the sampling methods used, and the order and reliability of the results obtained, are summarized below.

#### Outcrop Sampling

In the early stages of the investigation a suite of eight chip samples taken from regular intervals along the lode outcrops assayed from 3.6 to 11.0 lb.  $U_3O_8$  per long ton (R. K. Pitman, 1954<sup>(a)</sup>).

#### Assays of Drill Core

Diamond drilling has provided a highly satisfactory method of grade evaluation.

Core recovery of the lode rock has, in general, been greater than 95 per cent, and there is no significant loss of the ore mineral which is firmly fixed in the biotitic matrix of the lode rock. Selected portions of the bore cores, including all lode rock, have been split and suitably subdivided into fractions for assay.

The overall grade of the four separate orebodies or branches, weighted by length of core, have been calculated from drill-core assays and are as follows:

Main lode . . . . .	6.95 lb. $U_3O_8$ per long ton	(0.31 per cent)
South lode . . . . .	5.2 lb. $U_3O_8$ per long ton	(0.23 per cent)
Central lode . . . . .	4.54 lb. $U_3O_8$ per long ton	(0.20 per cent)
Buried lodes . . . . .	2.9 lb. $U_3O_8$ per long ton	(0.13 per cent)

The grades of individual samples lie mostly within the range of 4.0 to 7.0 lb., up to a maximum of 12.8 lb. (bore V.H. 7-70). The estimated figure of 6.95 lb. for the Main lode is weighted over a total length of 151.47ft. of core samples, but much less data is available for the subordinate lodes. As the boreholes are symmetrically placed, areas of influence are approximately equal, except that there is a somewhat closer spacing in the upper portions of the lodes.

The consistency of grade of the drill-core samples suggests that the core assays may be accepted as a reliable indication of the grade of this deposit.

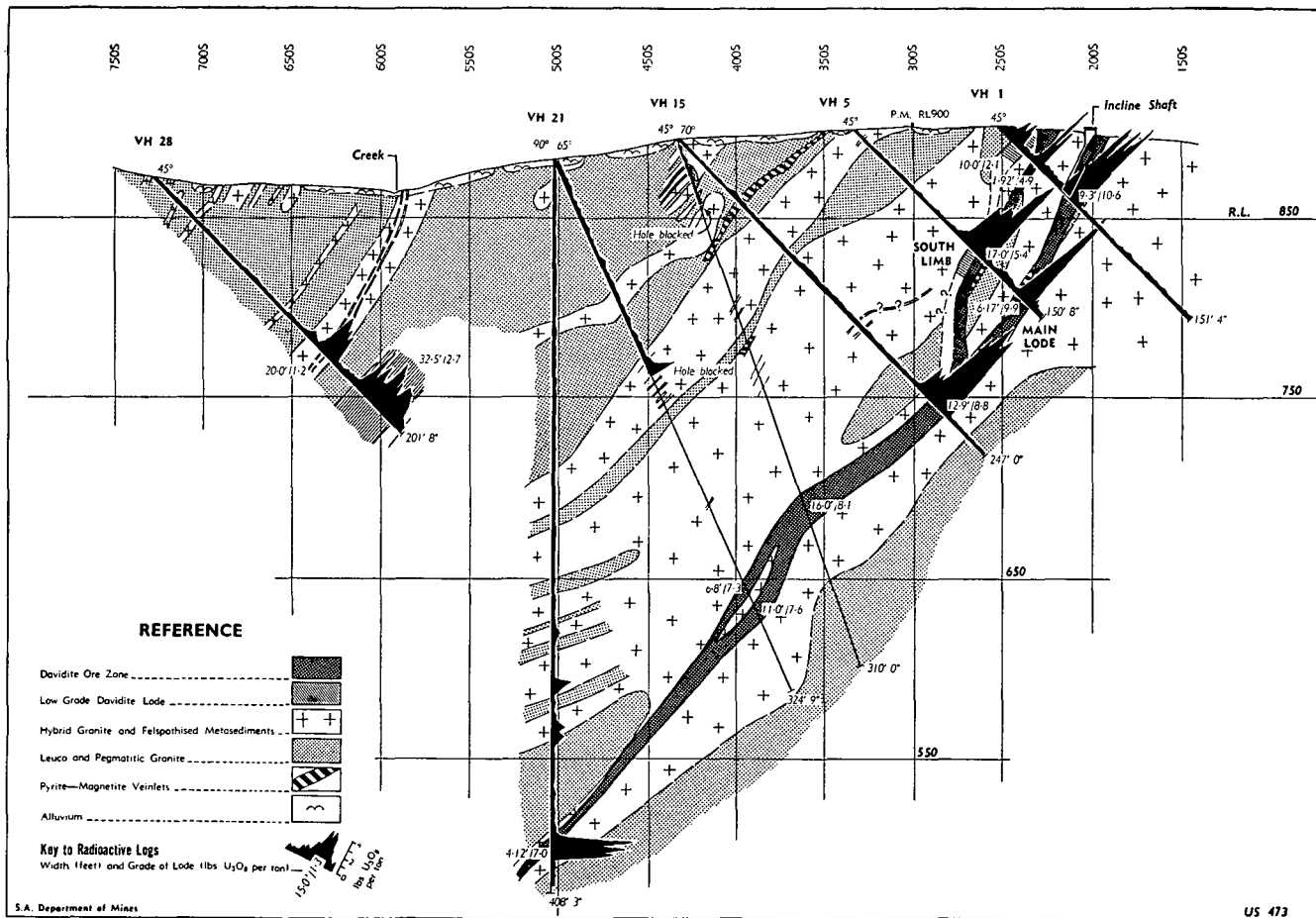


FIG. 55—MOUNT VICTORIA URANIUM DEPOSIT  
Geological cross-section along boreholes—Grid line 200W

### Radiometric Borehole Logging

Each borehole has been radiometrically logged soon after completion, and the results expressed graphically on the geological cross-section (*see fig. 55*).

The calibration figure applied to the ore of this deposit is the same as that used at Radium Hill, namely, 1,800 counts per minute is equivalent to 1 lb. uranium oxide per long ton. The background reading is of the order of 300 counts per minute.

All anomalies in the graphs can be directly related to davidite mineralization observed in the core samples, and the lode widths and grades determined by these investigations correspond very closely to those obtained by drill-core assays.

### Bulk Sample

A 37-ton ore parcel raised from 20 to 40ft. in the only mine opening at No. 1 incline shaft, on the eastern outcrop of the Main lode, was prepared for assay by the Metallurgical Branch. The grade was established by chemical assay to be 6.3 lb of  $U_3O_8$  per long ton.

### Ore Reserves

The following estimates of ore reserves based on diamond drilling refer to the orebodies of the Main, South, and Central lodes (Main lode system), and two small lower-grade lenses in the hanging wall that are not exposed at the surface. The estimates are based on cross-sections drawn normal to the lode dip at 50-ft. intervals (35ft. vertically) using the maximum lode width obtained from the nearest borehole intersection, and applying a conversion factor of 12 cub. ft. per ton.

### Definitions

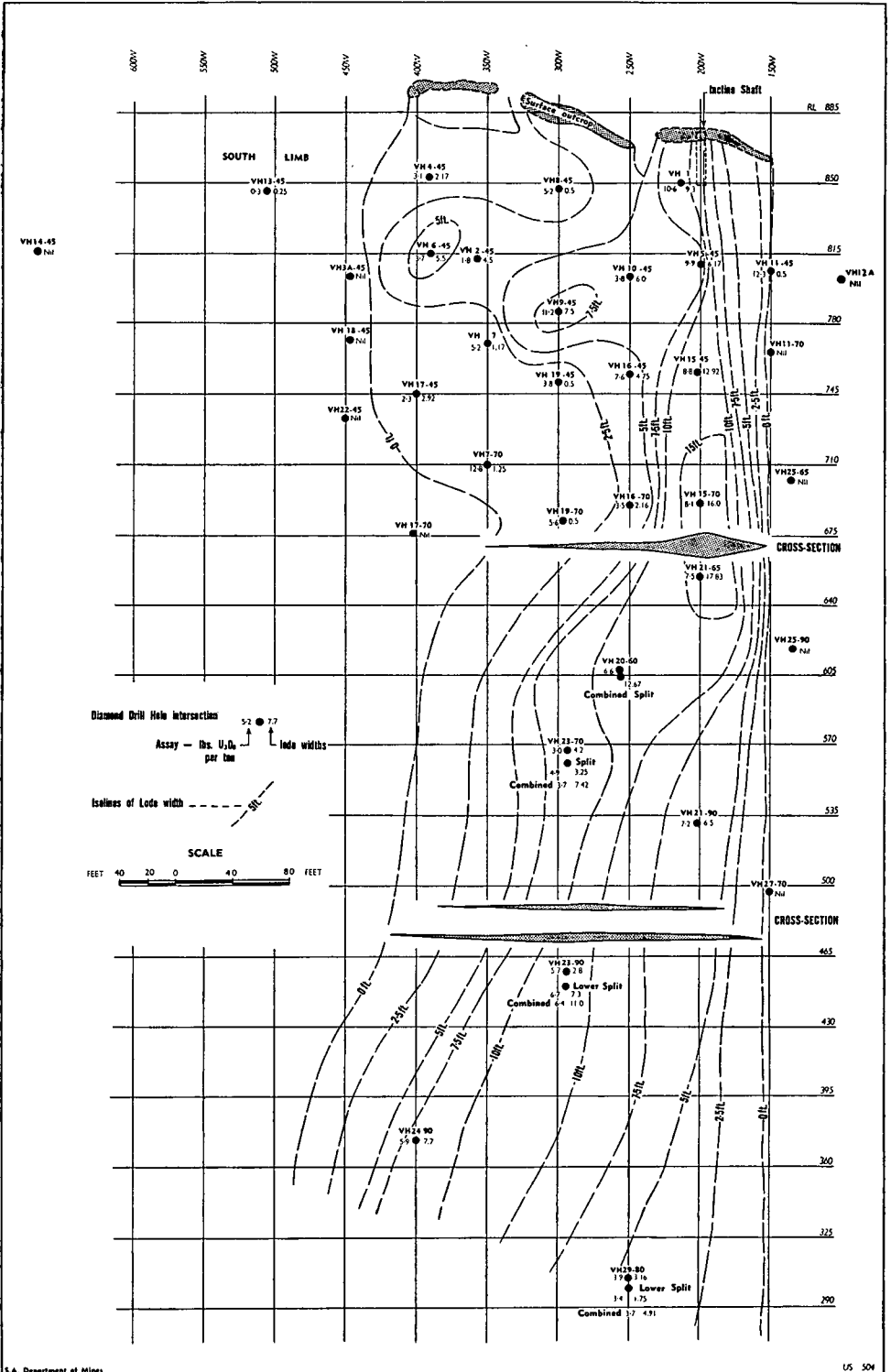
The term "probable ore" is used to define a conservative interpretation of all known borehole facts, but assumes continuity of mineralization between the seven main grid-lines (150W to 450W). It does not take into account the possible presence of later-crosscutting granitic bodies. Reserves of these specifications apply only to the Main lode, where sufficient factual data is available to permit a reasonably accurate three-dimensional definition of the orebody.

The term "possible ore" is applied to additional potential reserves apparent from a more liberal interpretation of available data relating to the Main lode. The several hanging-wall lodes (Central lode and South limb-South lode) are also placed in this category because of insufficiency of information concerning them.

### Tabulation of Ore Reserves\*

\* These figures are extracted from detailed reports filed in the Security Registry of the Department of Mines

	Probable ore Tons Grade (lb. $U_3O_8$ )	Possible ore Tons Grade (lb. $U_3O_8$ )
Main lode { Minor R.L. 640-430 ..... Bodies R.L. 360-290 ..... Main body .....	7,900 } 2,000 } 6.95 58,000 }	2,400 } 4,300 } Assume 5.0 12,800 }
Central lode .....	— —	5,600 4.54
South lode { Minor upper body ..... (Below R.L. 605) Lower .....	— — — —	3,100 1,700
South limb { Main body (above R.L. 780) ...	— —	10,100 5.2



**FIG. 56—MOUNT VICTORIA URANIUM DEPOSIT**  
 Longitudinal projection along the main lode

Total probable ore reserves = 67,900 tons (Main lode) of grade of 6.95 lb. (0.31 per cent)  $U_3O_8$ .

Total possible ore reserves = 40,000 tons of approximate overall grade of 5.0 lb. (0.22 per cent)  $U_3O_8$ .

Total reserves (all categories) = 107,900 long tons of approximate overall grade of 6.0 lb. (0.27 per cent)  $U_3O_8$ .

The probable reserves of the Main lode represent 90 to 100 tons per inclined foot of lode depth.

## OTHER SIGNIFICANT URANIUM DEPOSITS

### Spring Hill Uranium Prospect

*Location:*—On the northern slopes of Spring Hill, in Toweroo bore paddock, Glenorchy station, and approximately 12 miles NNW. by rough track from Glenorchy homestead. Out of counties, North-Eastern division.

#### Introduction

The uranium prospect at Spring Hill was discovered by a private prospector, Mrs. M. E. J. Talbot, in November, 1953. A preliminary geological report on the deposit was submitted in April, 1954 (King, 1954<sup>(c)</sup>), in which recommendations were made for further testing of the deposit by diamond drilling. A uranium discovery reward was subsequently granted to Mrs. Talbot by the Government.

#### Surface Geology

Spring Hill is an outlier of Archaean rocks along the northwestern margin of the Plumbago-Glenorchy ranges, where they terminate against the southern boundary of the Lake Frome Plains (plate I). A few miles to the west, Proterozoic Adelaide System rocks unconformably overlie the basement to form the Toolaby Hills.

The Archaean rocks in the mineralized area are dominantly metasedimentary micaceous schists and gneisses, locally intruded or replaced by small isolated bodies of pale-pink leucogranite and related pegmatite dykes. Bedding in the metasediments can be observed in places striking east-west, with a steep northerly dip, but generally the bedding is obliterated by a superimposed foliation caused by regional shearing. The shear foliation (or schistosity) trends in a variable NNE.-NE. direction and dips at a steep angle to the northwest. The granitic rocks are also somewhat affected by shearing.

Davidite mineralization is localized in highly fractured hybrid granite and granitized metasediments which are unusually deeply weathered and distinctive in outcrop due to a superficial staining of yellow-brown iron oxides (*see* fig. 59). The uranium mineral is found mainly within an area of  $\frac{1}{2}$  acre, wherein the mineralized outcrops and individual veinlets are distributed with no apparent regularity. Narrow and isolated veinlets of davidite were also observed 150ft. west of the main exposures and there are local points of abnormal radioactivity in coarse biotite clots over a wide area surrounding the deposit.

The davidite occupies fissures which appear to have formed by partial brecciation during shearing, and less commonly it is found in joint planes. The deposit is considered to be of the pegmatitic-pneumatolytic type, deposited from highly mobile mineralizing solutions or gases at a late stage of granite emplacement or granitization.

#### Ore Mineral and Association

The ore mineral is grey metallic  *daviditic ilmenite*, superficially stained with (?)  *carnotite*, occurring in the form of coarse-grained aggregates associated with bronze biotite in irregular veinlets and segregations measuring up to several inches in width. At one place (co-ords 190N-390W) the davidite is present as pseudocrystalline forms in a pegmatitic quartz vein.

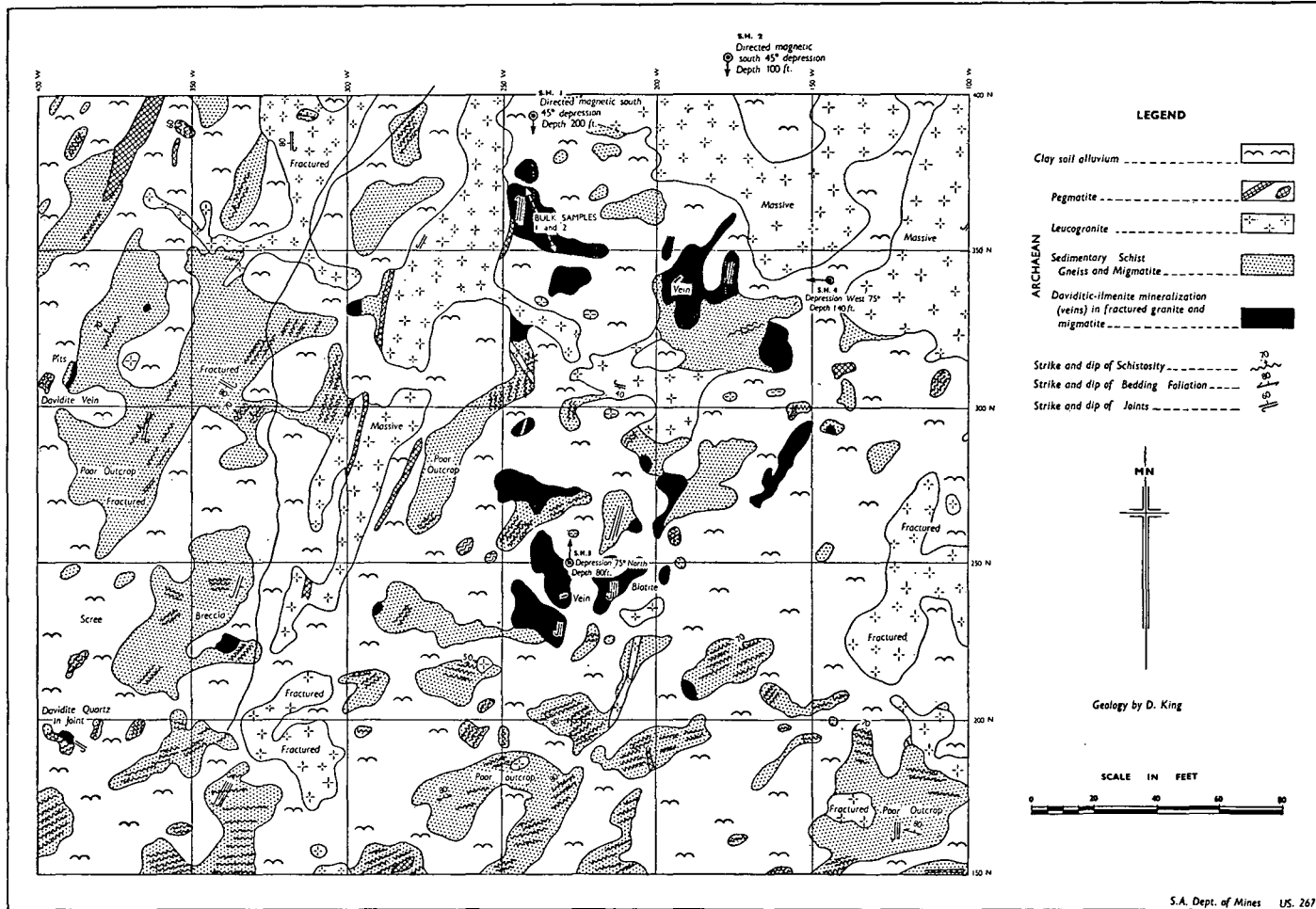


FIG. 57—SPRING HILL URANIUM PROSPECT  
Surface geological plan

A chemical assay of hand-picked daviditic ilmenite from the main outcrop showed 6.9 per cent  $U_3O_8$  (see table II, page 53).

Clusters of small yellow grains of *thor-brannerite* were found associated with rutile and davidite in borehole samples.

### Diamond Drilling

Four diamond-drill holes were put down to test the main area of mineralization to vertical depths ranging up to 100 feet.

In the absence of any regular surface structure, the initial boreholes Nos. S.H.1 and S.H.2 were designed on the assumption that the mineralization is steeply dipping, concordant with the enclosing metasedimentary rocks. These holes intersected only barren granite. Two additional boreholes, No. S.H.3 and S.H.4, were subsequently drilled on the assumption of a shallow pitch to the south or east and each disclosed some mineralization.

The location of borehole sites are indicated on the surface plan (fig. 57), and cross-sections along the boreholes are shown on fig. 58.

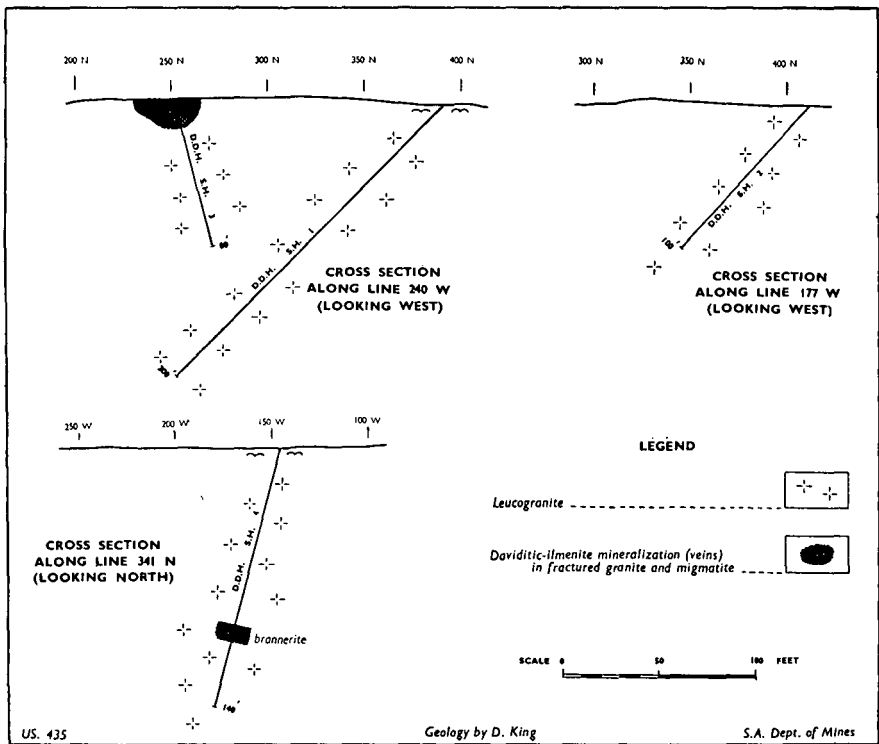


FIG. 58—SPRING HILL URANIUM PROSPECT  
Cross-sections along boreholes

### Ore Reserves and Grade

The area of importance as a uranium prospect is roughly triangular in ground plan, covering 11,000 sq. ft., bounded by co-ords. 385N : 250W, 300N : 120W, and 215N : 250W (fig. 57). Here the uranium-bearing rocks comprise 10 separate outcrops, each of the order of 150 to 200 sq. ft. in surface area and amounting to 20 per cent of the total area. The remainder is largely covered by alluvium.

As a preliminary indication of the grade of the deposit, chemical samples were cut from the largest exposure of the mineralized rock. Repeat samples, each of approximately 10 lb. weight, ranged in grade from 4 to 10 lb. (0.045-0.45 per cent)  $U_3O_8$  per ton. The considerable variation of the assay results illustrates the unreliability of small-scale surface sampling in this type of deposit.

Additional information on tonnage and grade provided by the diamond drilling is summarized in table VII.

TABLE VII  
SUMMARY OF DIAMOND-DRILLING RESULTS  
*Spring Hill Uranium Prospect*

Bore No.	Borehole depth	Ore intersections		Grade			
		From	To	Radiometric	Chemical		
	ft.	ft.	in.	ft.	in.	lb. $U_3O_8$ /long ton	lb. $U_3O_8$ /long ton
S.H. 1 .....	200	Nil		—		—	—
S.H. 2 .....	100	Nil		—		—	—
S.H. 3 .....	80	0	0	4	0	1.6	1.5
		4	0	5	0	9.2	8.7
		5	0	9	0	1.8	1.8
		9	0	10	2	7.6	7.4
		10	2	17	0	2.4	2.1
Overall 17ft. at 2.6 lb. $U_3O_8$ per ton (chemical)							
S.H. 4 .....	140	95	6	96	4	2.0	—
		96	4	99	4	—	—
		99	4	100	10	—	—
		100	10	103	6	—	—
		103	6	103	10	—	—
Overall 8ft. 4in. at 1.4 lb. $U_3O_8$ per ton (radiometric)							

The drilling results indicate that the mineralization is flat-lying and sporadic with the deposit underlain at shallow depth by an extensive body of barren granite. The shallow pitch—which is to the southeast at an angle of 5-15 deg.—accounts for the apparent lack of structure in the surface exposures.

The tonnage available for open-cut excavation would be of the order of 1,000 tons of about 7 lb. (0.3 per cent) grade.

#### Mindamereeka Hill Uranium Prospect

*Location:—The deposit lies on the southern slopes of a steep hill near Mindamereeka trig, 1½ miles NE. of Plumbago head station, and approximately 4 miles ESE. of the Department of Mines camp at Crocker Well. There is a graded track from Plumbago station to within a few hundred yards of the prospect. Out of counties, North-Eastern division.*

#### Introduction

The uranium prospect was found by one of the authors (B. Campana) and H. E. Campana (Departmental Prospector), during the regional geological and radioactivity survey of the Archaean rocks near Plumbago station. A preliminary report on the deposit was submitted on 21st August, 1953 (Campana, 1953<sup>(a)</sup>).

FIG. 59—SPRING HILL  
URANIUM PROSPECT  
General view of the main  
mineralized area—Out-  
crop rich in davidite (d)  
in left foreground



FIG. 60—MINDAMEREKA HILL  
URANIUM PROSPECT  
Boring plant site P.P.I.—Peg marks main  
area of radioactivity, and borehole collar  
is indicated by a shovel

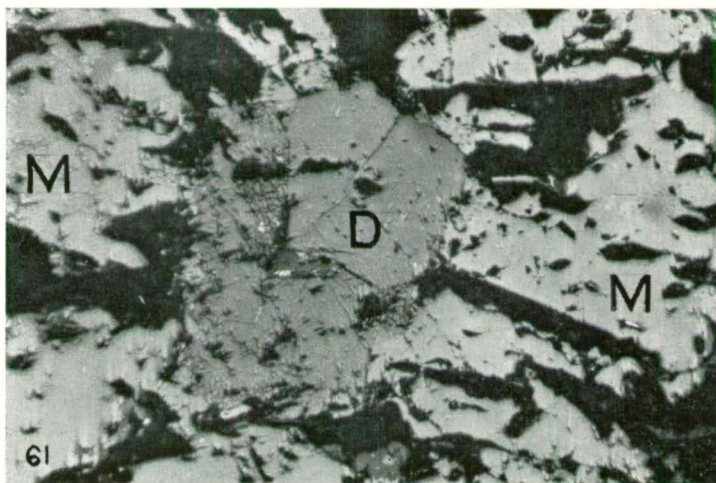


FIG. 61—MINDAMEREKA HILL URANIUM PROSPECT  
Photomicrograph showing davidite (D) enclosed in titaniferous magne-  
tite (M) of siliceous zone in pegmatite—Specimen from diamond-drill  
hole P.P.I., at 41 feet

Abnormal radioactivity is restricted to an outcrop of massive granitic rocks measuring 100ft. square. Secondary uranium minerals are commonly found as a staining on the under surfaces of exfoliated slabs of weathered rock. These indications were regarded as sufficient justification to test the uranium values of the unweathered rock in depth, and an exploratory diamond-drill hole (P.P.1) was sunk into the outcrop to obtain representative samples for grade evaluation of the deposit.

### *Surface Geology*

The area mapped in detail (fig. 62) measures 200ft. (E.-W.) by 150ft., and largely comprises an isolated prominent exposure of massive granite and granite-pegmatite with bare exfoliated surfaces, and containing xenolithic remnants of partly granitized amphibolitic quartzite. The outcrops are surrounded by thick boulder-scrce material (fig. 60).

The dominant granitic rock is a fine-grained sodic leucogranite, unusually low in biotite content and generally consistent in appearance and composition throughout the area of outcrop. Jointing is developed strongly in places, usually in a regular pattern formed by the intersection of vertical joints directed  $10^{\circ}$  N. and  $100^{\circ}$  N.

Coarse-grained felspar-quartz pegmatitic apophyses and veinlets, some carrying clots of coarse biotite and magnetite, are of widespread occurrence, intersecting mainly the leucogranites and also the metasediment xenoliths. The pegmatites commonly follow joint fractures in the leucogranite, and in a general way their orientation conforms to that of the major jointing directions; their emplacement was therefore subsequent to the consolidation of the leucogranite.

The uraniferous mineralization is associated with the pegmatites.

The Chief Mineralogist and Petrologist (A. W. G. Whittle) examined samples of the major rock types obtained from borehole P.P.1, (Pet. Lab. Rep. 41/53) and reports as follows:

“A typically banded specimen of epidote-actinolite gneiss was taken at 123ft. It is a fine-grained gneiss consisting of quartz, albite, diopside, and garnet. The diopside is variously unalitized to actinolite. Albite is the major rock constituent and it includes an abundance of finer rounded embayed quartz grains. Actinolite is spread through the rock as coarse flakes intergrown with equally coarse epidote. Sphene is small in size, but euhedral and very abundant. There are many large apatites.

“Leucogranite from 55ft. is a fine evenly granular quartz-albite composed largely of subhedral albite and very fine granular quartz. Ultrafine muscovite is closely associated with albite, whereas apatite is abundant amongst the quartz. Another specimen from 92ft. is composed largely of microcline, perthite, and quartz, with subordinate albite. Accessory minerals are abundant and include sphene, apatite, chloritized biotite, and opaque mineral.

“Pegmatite from 19ft. consists essentially of very coarse subhedral microcline and perthite, both of which include minute albite crystals in small total amount as inclusions. Quartz is largely interstitial to felspar and is in the form of fine granules of irregular shape. Large brown biotites are prominent and these carry many coarsely crystalline apatites as inclusions.

“These examinations indicate that the granitic rocks are partly primary intrusives, as for example the sample from 19ft., but are mainly of metasomatic origin and result from the albitization of country-rock rich in quartz—probably quartzite—and containing enough calcareous and ferromagnesian impurity to produce epidote, diopside, actinolite, etc., in the rocks at certain horizons.”

### *Uranium Minerals*

The uranium mineralization is a disseminated pegmatitic type, confined mainly to the borders of pegmatitic apophyses, particularly in association with segregations and veinlets of quartz.

The primary uranium mineral, davidite, in granular form, is found in outcropping siliceous pegmatite at one place (co-ords 155N : 230W). Metatorbernite is associated with biotite in pegmatite at co-ordinates 153N : 265W, and in many other portions of the outcrop there is abnormal radioactivity due to stains of uranophane (and ?carnotite) beneath weathered and exfoliated surfaces of the pegmatite.

The radioactive constituent of fresh pegmatitic rock obtained from boring was determined as davidite by Whittle. He reports as follows (Pet. Lab. Rep. 41/53) :

“The active mineral is found in a strongly quartzitic portion of core between 40 and 43ft. Quartz is intergrown with an abundance of black biotite in irregular bands or segregations. Titaniferous magnetite, brown in incident light, is most plentifully disseminated through the quartz, particularly in the biotite portions where it is intergrown with biotite.

“The radioactive mineral is a form of davidite occurring as minute grains (0.1mm. size) enclosed within the magnetite crystals (*see* fig. 61). Ultrafine pyrite is usually found associated with the davidite and often forms a contact zone between davidite and the enclosing magnetite. The davidite is a mineral of high reflectance; it is isotropic and has a density within the range 3.9-4.5. More precise data is indeterminate because of the minute size of the grains.”

#### *Diamond Drilling*

An exploratory diamond-drill borehole No. P.P.1 (serial No. D.D. 98/53) was sunk beneath the outcrop as a means of obtaining unweathered samples of the uraniferous granitic rocks.

The bore collar is located at the only suitably accessible point in the area at co-ordinates 130N:162W (R.L.985.8) and directed 60° W. of N. at 10 deg. depression for a distance of 150 ft. (fig. 62). The primary target of the hole was to intersect the highly radioactive rock in the vicinity of co-ordinates 150N:200W (R.L. 993.0), which it did at a distance of 43ft., and at a depth of 17ft. beneath the natural surface (fig. 62).

The geological log of the core is as follows :

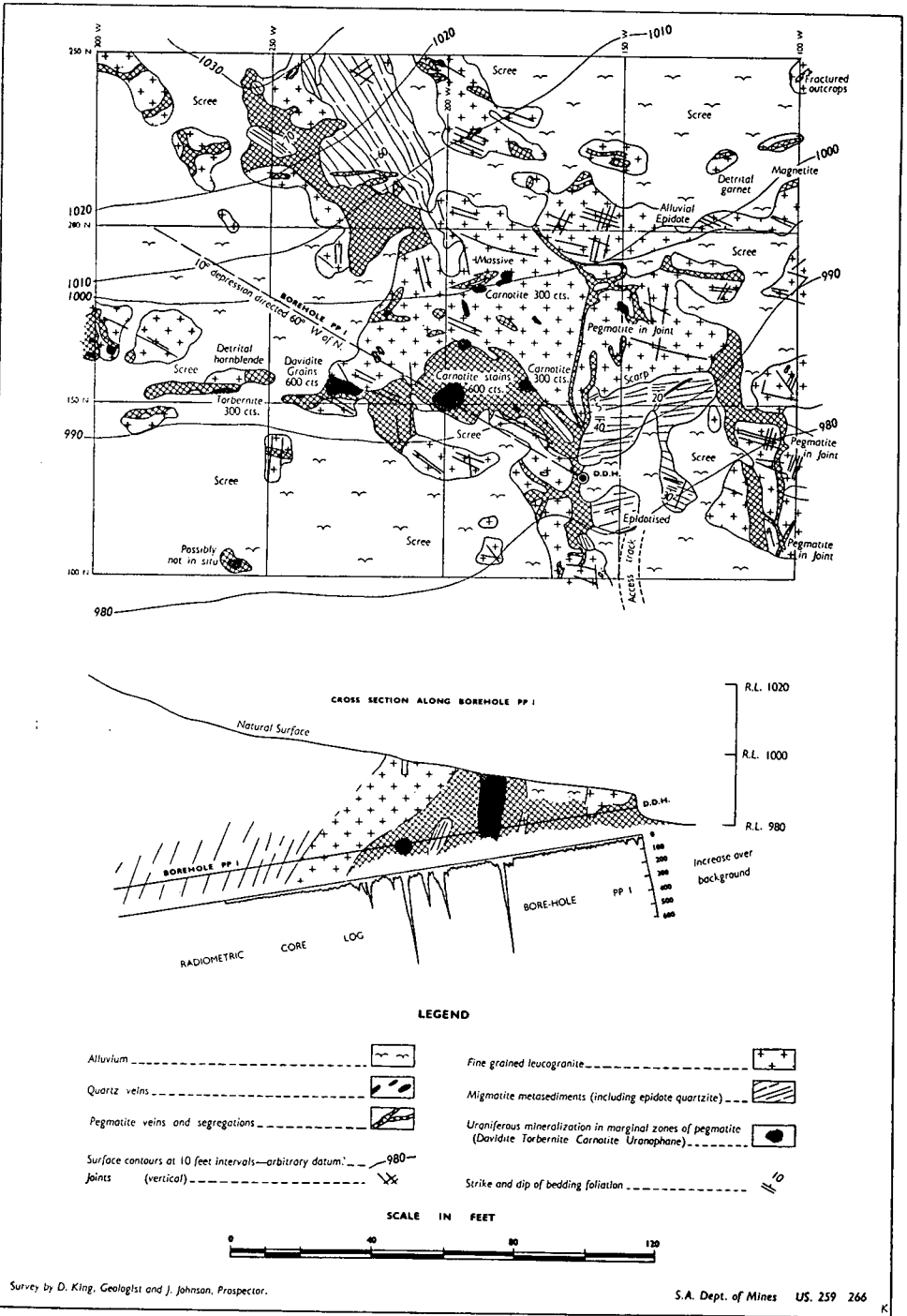
ft.	in.	ft.	in.		
0	0	—	12	0	Pale-coloured felspar-quartz pegmatite.
12	0	—	13	6	Fine-grained leucogranite.
13	6	—	32	0	Felspar-quartz pegmatite; with coarse biotite clots.
32	0	—	32	9	Fine-grained leucogranite.
32	9	—	40	6	Felspar-quartz pegmatite; with coarse biotite clots.
40	6	—	43	0	Quartzose pegmatite.
43	0	—	55	6	Pale-coloured felspar-quartz pegmatite.
55	6	—	58	0	Epidote-quartz-biotite gneiss-migmatite.
58	0	—	63	2	Pale-coloured felspar-quartz pegmatite.
63	2	—	80	0	Coarse felspar-quartz pegmatite; with biotite clots.
80	0	—	96	0	Fine-grained leucogranite—massive.
96	0	—	138	0	Epidotized gneiss and epidote-quartzite.
138	0	—	150	0	Amphibolitic epidote-quartzites—pegmatized.

#### *Assays*

No surface sampling was undertaken due to the secondary nature of the superficial minerals, but the core from borehole P.P.1. provided representative and reliable material for assay purposes.

The shallow angle of inclination of the borehole prevented the usual practice of probing the hole by portable borehole radiometric logging equipment, and the selection of samples for assay was based upon the results of a radiometric core-log prepared in the laboratory by the Analytical Section. The results of this examination, shown graphically in fig. 62, indicates significant anomalies between depths of 37 to 85ft., and particularly high counts at approximately 42ft., *i.e.*, vertically below the highly radioactive outcrop at co-ordinates 150N:200W.

All significant radioactive portions of the core were sampled for radiometric assay, and results are tabulated below.



**FIG. 62—MINDAMEREKA HILL URANIUM PROSPECT**  
**Geological plan and section**

## BOREHOLE P.P. 1

Footage				Radiometric assays (U <sub>3</sub> O <sub>8</sub> )		
ft.	in.	ft.	in.	lb./long ton	per cent	
37	0	—	38	6	0.6	0.025
38	6	—	42	6	3.8	0.17
57	6	—	60	0	2.0	0.09
60	0	—	61	6	1.6	0.07
61	6	—	66	0	2.5	0.11
66	0	—	67	6	0.9	0.04
67	6	—	71	0	0.5	0.02
71	0	—	81	0	1.3	0.06
81	0	—	84	6	0.1	0.005

The weighted average U<sub>3</sub>O<sub>8</sub> content of the total 32.5ft. of rock assayed is 1.5 lb./long ton (0.07 per cent). On the basis of radiometric core-log, the remainder of the core (118ft.) can be regarded as carrying no uranium values.

### Windamerta North Uranium Prospect

*Location:—On a granitic ridge 1½ miles SE. of Glenorchy homestead and 1½ miles W. of Windamerta Hill. Access from the Department of Mines camp at Crocker Well is by station track to Victoria Hut out-station. From this point a poor track leads northerly into the prospect, the distance from the camp being about 9 miles. Out of counties, North-Eastern division.*

#### Introduction

Radioactive minerals were discovered near Windamerta Hill (B. Campana) in the course of regional geological mapping of the Glenorchy military sheet. A preliminary report describes the new uranium occurrences, and indicates the need for an economic appraisal of the prospect.

Subsequent airborne scintillation surveys failed to locate any anomalies in the prospect area. Examination was continued by ground geological survey and diamond drilling but no significant mineralization was disclosed.

#### Surface Geology

The Archaean rocks in this locality consist largely of irregular bodies of granite and pegmatite, which intrude metasediments. The metamorphic rocks consist mainly of amphibole-epidote-quartzites, sillimanite-biotite schists and granitic gneiss. Uranium mineralization is confined to a jointed granite and to biotite mica schists.

The mica schists grade through migmatite to mica diorite, depending on the intensity of shearing and feldspathization, but are shown as a unit on the plan (fig. 63). The strongest radioactivity is found in a highly sheared mica schist, over a strike length of 20ft. and a width of 6ft. Weakly mineralized extensions of the sheared zone are observed over a distance of 200ft. Samples of the radioactive schists were examined by Whittle who reported as follows:

“This is a quartz-felspar-chlorite schist in which albicase is dominant. Magnetite and apatite are abundant. A little secondary uranium mineral occurs as 0.05mm. ovoids in chlorite aggregates. Another sample carries bright-yellow encrustations along schistosity surfaces which consist of finely fibrous masses of uranophane.”

In the jointed granite, uranophane is found sporadically in joints and other irregular fractures as stains and coatings. Whittle described the granite as follows:

“This is a fine- to medium-grained xenomorphic granular rock of a composition near to adamellite. Its content of albite is near the sum of microcline, perthite, and orthoclase. The rock is considerably fractured but otherwise structureless. It is rich in biotite which occurs in scattered aggregates, or as fine flakes in rock fractures. Uranophane and gummite (respectively yellow and orange) occur in fractures and among biotite aggregates. No primary uranium mineral is present but secondary mineral is abundant.”

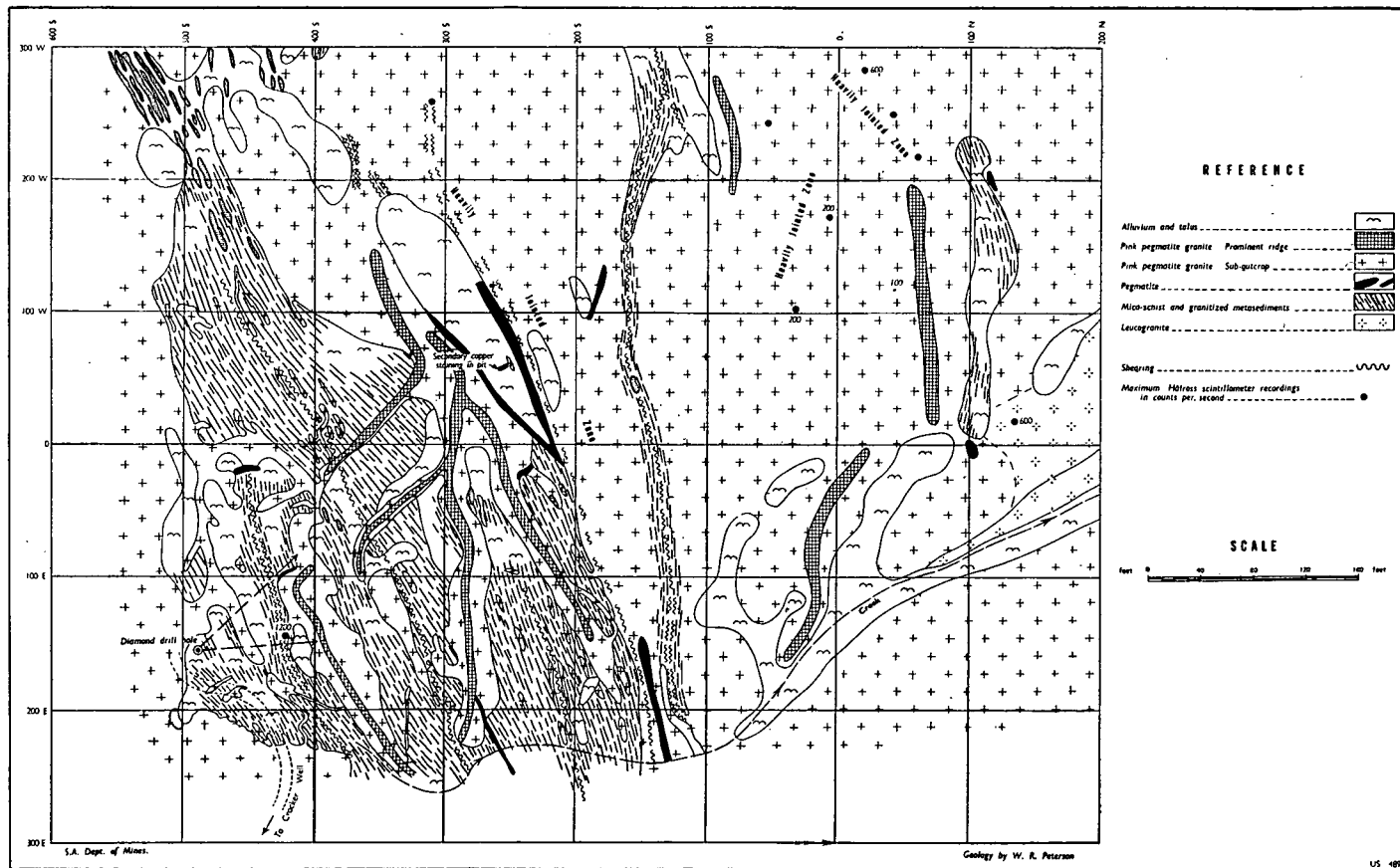


FIG. 63—WINDAMERTA NORTH URANIUM PROSPECT  
Geological plan

### *Radioactivity*

In the jointed granite, the general scintillometer background count is 100 c.p.s., though limited areas of uranophane in joint planes give readings of 500 to 600 c.p.s. Selected samples of uranophane-bearing material from surface exposures limited to 1 or 2ft. diameter assay less than 2.0 lb.  $\text{U}_3\text{O}_8$  per ton.

Significant radioactivity in the mica schist is confined to a small zone where counts of 1,000 per second are obtained at the outcrop. A sample taken across a width of 6ft. of this radioactive zone assayed 6.5 lb.  $\text{U}_3\text{O}_8$  per ton.

### *Diamond Drilling*

No diamond drilling was considered warranted in the jointed granite, but holes were drilled to test the schist zone at depths of 35 and 50ft. below the outcrop.

Borehole No. W.N. 1, depressed 30 deg. on a northerly course, cut schist material from 44ft 10in. to 61ft. 4in. No uranium minerals were detected in the core, and only slight radioactivity was recorded, from 56 to 59½ft. The hole was stopped at 94ft. 7 inches.

Borehole No. W.N. 2 was drilled in a northwest direction, depressed 40 deg. from the same site as No. 1 hole. It was planned to cut the same shear 50ft. west from the first intersection. No radioactivity was detected in the core, nor was any schist disclosed. The hole was completely at 118ft. 7 inches.

### **Windamerta South Uranium Prospect**

*Location:—On the south slope of a prominent outcrop about 1½ miles southeast of Glenorchy homestead; it lies about ½ mile SW. of the Windamerta North Prospect, and can be reached by a poor track leading northwest from Victoria Hut out-station. Out of counties, North-Eastern division.*

### *Introduction*

Radioactivity was discovered at the Windamerta South locality in 1953, during regional mapping in the district. A report (Campana, 1953<sup>(b)</sup>) describes the occurrence and recommends closer examination.

Surface mapping of the radioactive deposits, together with outcrop sampling, was undertaken shortly afterwards. Assays of samples from several localities ranged from 1.2 to 7.2 lb.  $\text{U}_3\text{O}_8$  per ton. Diamond drilling was planned to test the shear zone at moderate depth, results of this testing being given below.

### *Geology*

The area surrounding the deposits consists of irregular bodies of granite—and their later pegmatitic phases—intruding altered sediments now represented by amphibolitic quartzites, biotite-muscovite-sericite schists and complex migmatites.

In the area mapped in detail (fig. 64) the oldest rocks of the complex consist of metasediments and migmatites invaded by leucogranite. Mineralization occurs at irregular intervals along a narrow east-west shear zone extending for 500ft. parallel to well-developed jointing and lineations in these host rocks. A prominent dyke-like body of later coarse porphyritic granite transgresses the migmatites and the mineralized zone.

Surface rocks were described by A. W. G. Whittle as follows:

“Coarse porphyritic transgressive granite. This is a biotite granite of normal potash-rich composition consisting of microcline and perthite (with poikilitic quartz), albite, aggregates of biotite, muscovite, and pleochroic zircon.

“Mineralized shear rock. This is a quartz-felspar-biotite gneiss rich in albiclaste. Apatite and magnetite are abundant. Ill-defined lit-par-lit injections of granodiorite material occur in the rock. Fluorite is abundant. Uranophane and gummite occur in considerable amount along fractures in the rock. Secondary calcite occurs in small amount.

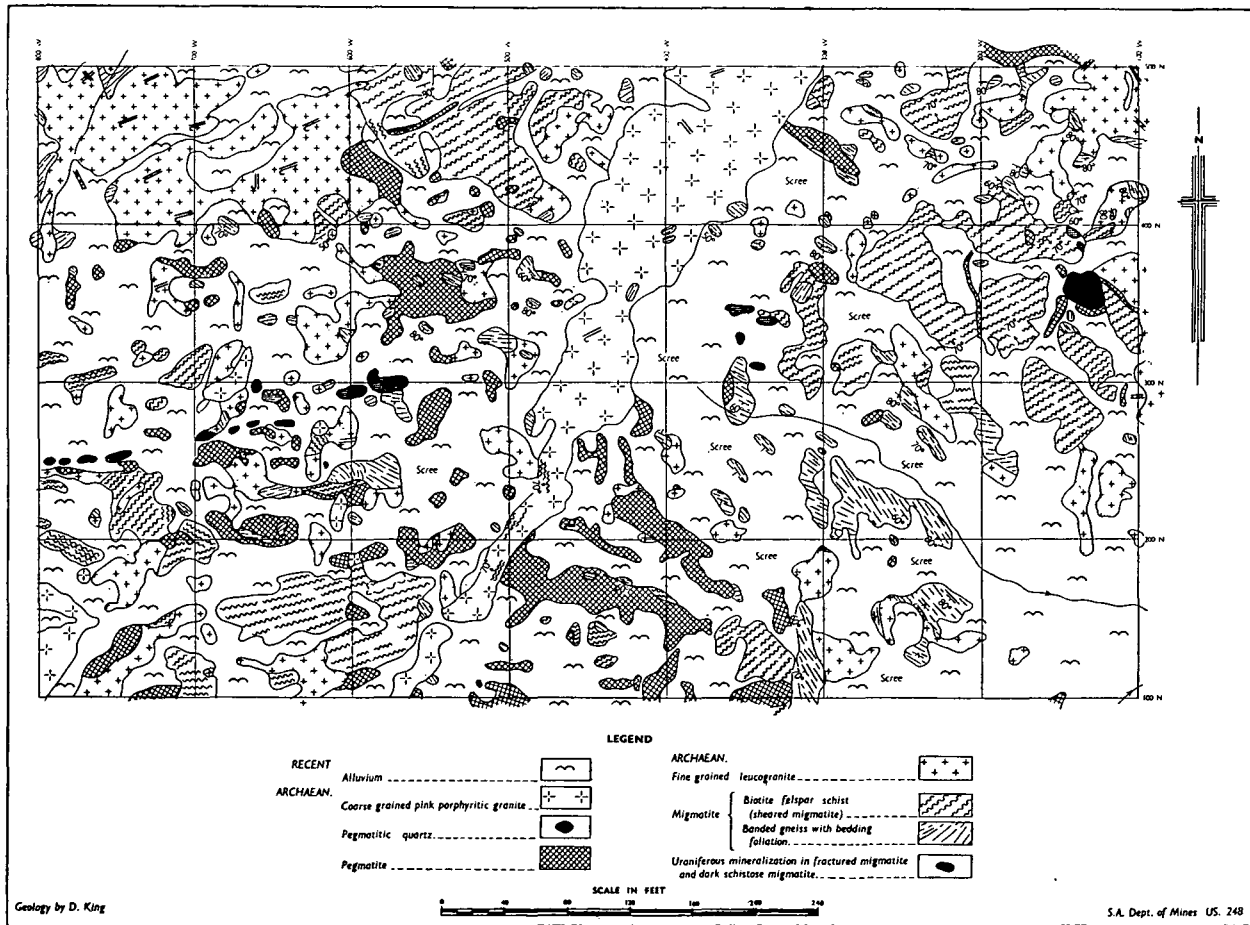


FIG. 64—WINDAMERTA SOUTH URANIUM PROSPECT  
Geological plan

“Highly radioactive sample. The host rock is fine-grained quartz-felspar-biotite schist. Numerous minute grains of limonitic opaque minerals which may be altered primary uranium minerals. The radioactive mineral present is related to uranophane, namely, beta-uranotil, and occurs as minute grains and fibrous clusters.”

Mineralization appears to be associated with pegmatites which are related to the older leucogranite. Later granitic intrusions along with broken weathered outcrops and talus areas make geological interpretation difficult.

#### *Diamond Drilling*

Boreholes Nos. W.S.1 and W.S.3 were drilled to intersect radioactive “highs” at vertical depths of 40 and 25ft. respectively. Slight radioactivity only was detected in the first hole, in a zone of migmatite from 38 to 54ft. The remainder of the core was granite. Hole No. W.S.3 cut granite only, in the total depth of 100ft. 9 inches.

Borehole No. W.S.2 (depressed 45 deg.) was located to intersect the eastern end of a radioactive shear outcrop between the depths of 30 and 80ft. An outcrop sampled assayed 1.2 lb  $U_3O_8$  per ton, but examination of the core revealed slight radioactivity only at 60ft., but at 129ft. a small slug of highly radioactive black mineral was recovered. The Chief Mineralogist reported as follows:

“The core consists of two rock types. One end of the sample is of fine even-grained albicase-quartz-biotite gneiss containing apatite, magnetite, and pyrite as small grains. It contains very little radioactive material.

“The other end is a coarse-grained granodiorite crosscutting the foliation of the finer-grained gneiss. Pyrite grains 1cm. wide, containing a little chalcopyrite, are abundant in the grandiorite. A primary radioactive mineral is located in fine fractures in pyrite or in biotite-filled fractures in the host rock. It is dark grey in reflected light, and has a fine-grained colloform texture. Positive identification of the mineral is difficult because of its fine texture. It is isotropic, reacts to nitric acid, and is probably pitchblende.”

This borehole was completed at 158ft. 7in. in granite. No core samples were assayed, and no further testing undertaken.

#### **Jagged Rocks Uranium Prospect**

*Location:—About 2½ miles NNW. of Glenorchy homestead, from which it can be reached by a fair track. Out of counties, North-Eastern division.*

#### *Introduction*

Davidite was discovered by a departmental prospector (T. Amtmanis) while testing Archaean rocks exposed in the Glenorchy area. Mineralization was found to be confined to two small outcrops separated by a wide expanse of alluvium. Diamond drilling was designed to test the possibility of finding a concealed orebody.

#### *Geology*

The prospect area is composed of Archaean metasediments represented by feldspathized quartz schists and granitoid rocks consisting of pegmatitic granite, mica diorities, and later pegmatites. Feldspathization and assimilation of the metasediments has formed dark biotite-rich migmatites characterized by coarse-grained grey felspar. Radioactivity is confined to these migmatites in two surface outcrops, separated by 1,200ft. of alluvial flat. Davidite in small nodular disseminations, partly replacing fine granular intergrowths of rutile and hematite, is the radioactive mineral.

The davidite-bearing migmatites occur along the same line of strike and their petrographic similarity suggested an extension below the alluvial area.

### *Diamond Drilling*

Diamond drilling, totalling 641ft. in three holes, failed to prove any significant body of uranium mineralization below the alluvial area.

Boreholes Nos. 1 and 2 were located on the eastern outcrop while No. 3 was drilled below the eastern area of radioactivity.

Borehole No. 1—depressed 35 deg. S.—was planned to cut the vertical projection of a radioactive high at a depth of 40ft. A weakly radioactive intersection from 33½ to 40½ft., not correlated with the outcrop occurrences, was confirmed by radiometric logging, calculated grades of  $U_3O_8$  being 4.5 lb. per ton (34-35ft.) and 3.0 lb per ton (38-39ft.). The remainder of the hole was not abnormally radioactive.

Borehole No. 2—depressed 30 deg. on a bearing S. 60° W.—was planned to test along the strike of the radioactive zone extending westerly from the outcrop. Core examination disclosed davidite at 172ft. and from 245ft. 6in. to 248ft. 5in., grades calculated from radiometric probing being 3.5 lb.  $U_3O_8$  per ton at each point.

Borehole No. 3 was depressed 45 deg. on a bearing N. 16° W. to intersect the downward projection of a highly radioactive outcrop at a vertical depth of 30ft. No mineralization was detected either in the core, or by radiometric probing.

### *Results*

In the eastern outcrop a small tonnage of mineralized ground was discovered comprising the main radioactive outcrop and the intersection in borehole No. 1. No downward extensions were disclosed by diamond drilling.

It was concluded that this prospect is too small to justify any further drilling. However, it is considered that the wide expanse of alluvium should be tested for concealed deposits by geophysical methods.

## **Copper-Cobalt-Tungsten Mineral Deposits**

### **INTRODUCTION**

Copper is the most common of the metallic minerals found in the basement rocks, and cobalt and tungsten are locally of some interest. Practically all payable copper and cobalt production has come from secondarily enriched zones and there are no known cases where primary sulphide deposits are of consistent or overall workable grade. The presence of small rich supergene concentrations is evidently a result of prolonged regional stability under arid conditions, throughout the Quaternary Period, as demonstrated by the coincidence of water-level with the boundary of supergene and sulphide ore in many of the old mine workings.

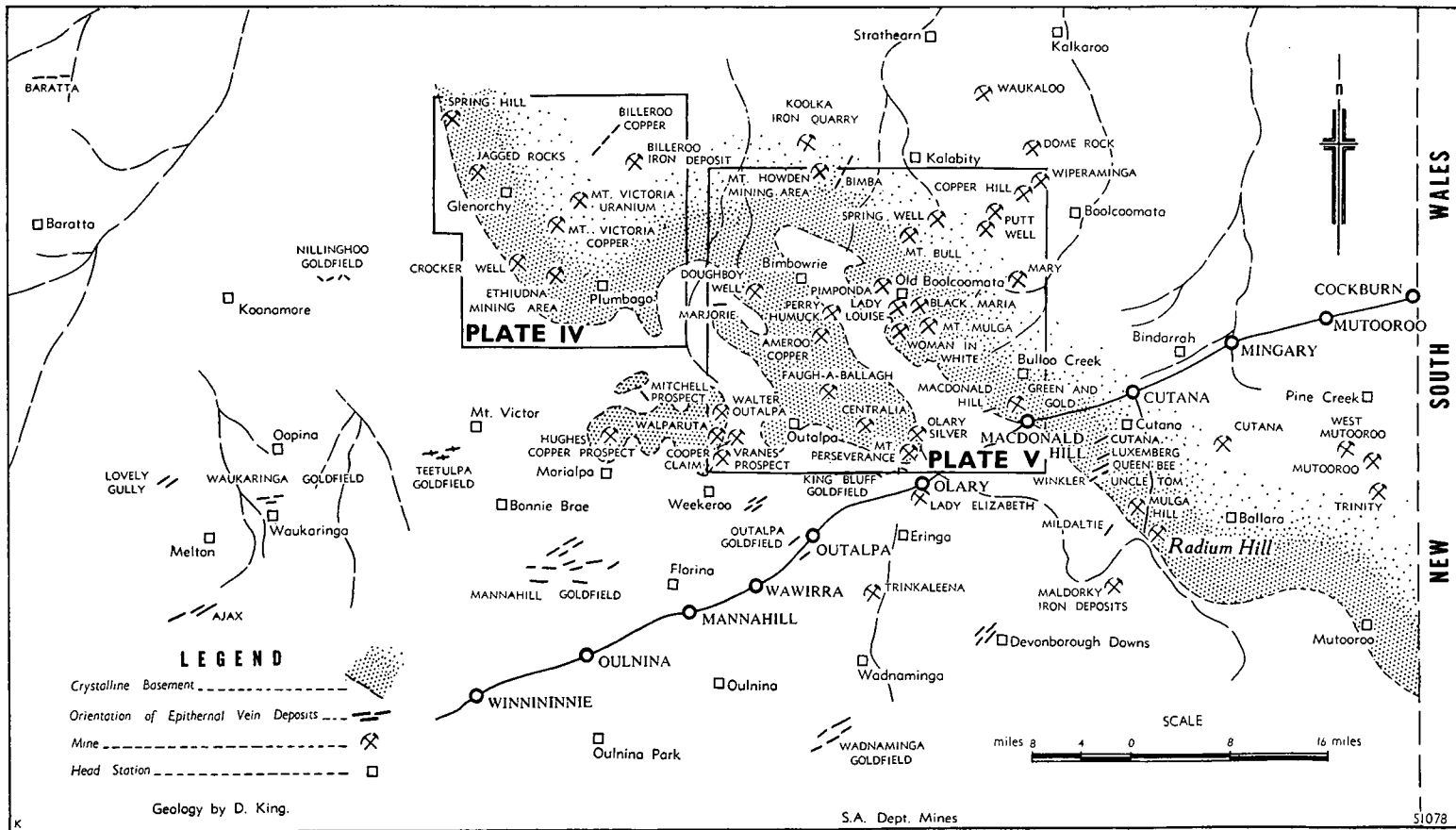
The locations of the known copper-cobalt and scheelite occurrences and mining areas in relation to the broader geological subdivisions are shown in fig. 65.

Production figures from the various small mines and prospects are incomplete owing to the lack of early systematic records.

On the evidence of the present study, none of the old mining fields or new discoveries of metalliferous deposits justify further development, but the additional data has led to a number of conclusions on metallogeny and mineralization controls which should materially assist in the future search for minerals.

### **MINERALIZATION CONTROLS**

At an early stage in the regional geological study of the area it became apparent that many of the copper deposits of the crystalline basement formations are localized within particular metasedimentary horizons characterized by a comparatively high lime content (Campana, 1953<sup>(a)</sup>). In due course the real significance of this relationship was established beyond any doubt and was successfully applied



**FIG. 65—LOCALITY PLAN OF THE OLARY PROVINCE**  
**Showing metalliferous ore deposits**

in the search for further mineral deposits. It has now become a well-established feature that cobalt and scheelite mineralization of the replacement type has also favoured particularly the lime-bearing sediments which are so characteristic of the Ethiudna Group of the Archaean sediments previously described.

The detailed account of copper-cobalt-nickel-scheelite deposits in the Ethiudna area which is presented in the following pages clearly demonstrates the influence of the lime silicate (tremolite-diopside rock) and calcareous quartzite beds in precipitating these minerals from the ore-bearing solutions. Reference is also made to the cobalt deposits at Mount Howden and scheelite at Old Boolcoomata, both of which are in altered limestones at the same stratigraphic level. Minor copper-gold showings at the Woman in White mine and Putt Well are typical of the many deposits found following the strike of epidote-actinolite quartzite beds, and the cobaltiferous copper deposits at Dome Rock are also truly replacement bodies in quartzite and slate of the Ethiudna Group. Several examples of copper mineralization in bedded iron formations at a somewhat higher stratigraphic level have been observed; these are interbedded with weakly calcareous (epidotitic) sediments. Here again the calcareous environment appears to have largely influenced the precipitation of the copper minerals.

A number of cupriferous deposits occur in amphibolite rocks. Some of these amphibolites are unquestionably of sedimentary parentage and could be high-grade variants of the Ethiudna Group rocks. The massive pyrite-chalcopyrite lodes at the Mutooroo mines, for example, follow the strike of amphibolites which are believed to be of sedimentary origin because of their great continuity, constancy of thickness, and absolute parallelism with the structural lines of the country-rocks. The probability that the sulphides are localized along strike faults is strongly suggested by a replacement breccia structure peculiar to the lode rock in these orebodies.

It is also significant that large deposits of barite and baritic iron ore, accompanied by feeble copper metallization, are present at intervals along a stratigraphically conformable horizon within the Ethiudna Group extending from Weekeroo (Walparuta barite mines) through Ameroo Hill (Out. 38 and 47) and Old Boolcoomata (Mount Mulga barite-copper mine) to near Meningie Well (Out. 91) and Dome Rock (Dome Rock barite mine). In these deposits there is striking evidence in the form of relict bedding structures to indicate that barite deposition involved partial or complete replacement of sedimentary layers, principally quartzites (Dickinson, 1950). A genetic relationship of the barite and copper deposition of the same general replacement type is evidenced by the presence of copper stainings and sulphides in the barite of all except one (Out. 91) of the outcrops. The copper content is too small to make ore, and economic interest centres chiefly on the barite. These occurrences are treated in detail below.

The association of base metal occurrences with altered calcareous horizons is also prominent in the Broken Hill district. Near Silverton, for example, silver-lead and scheelite occurrences are found repeatedly along an amphibolitic formation known as the Etlewood Limestone. This horizon is the stratigraphic equivalent of the Broken Hill lode horizon in which the famous silver-lead-zinc deposit occurs (Williams, 1952; Thomson, 1952). This evidence gives weight to the conception that many of the base-metal deposits of the Archaean rocks in the Olary-Broken Hill region may be genetically and stratigraphically related. It is considered probable that a calcareous formation within the Archaean sequence, which may laterally vary to some extent in sedimentary and metamorphic characters—provided a general control for mineral deposition during granite emplacement or granitization. In the Olary Province this formation is represented by the Ethiudna Group, which is tentatively correlated with the Broken Hill Group.

## METALLIFEROUS DEPOSITS WITH STRATIGRAPHIC CONTROLS

### Copper-Cobalt-Tungsten Deposits in Calc-Silicate Rocks of the Ethjudna Group

#### *The Ethjudna Mines*

The Ethjudna base-metal occurrences are situated in a low range of outcropping crystalline rocks 2 to 3 miles southeast of Ethjudna Hill and three miles west of Mindamereeka Hill, on Plumbago station property. In this area there are numerous occurrences of copper-cobalt-nickel and graphite deposits which were found and worked by prospectors soon after the first pastoral leases were taken up. Most of the old workings are located on four mineral claims shown on the geological plan (fig. 66). They include the principal mine on Mineral Claim 9726, Piper shaft on Claim 9757, and Lookout Hill workings on Claim 9759, and numerous shallow prospecting excavations in copper and graphite on Claim 9758. Other mineral occurrences were found as a result of the geological investigation, including a significant cobalt-nickel prospect at Ethjudna East and widespread scheelite mineralization.

The Ethjudna mine was later known as the New Year Gift mine.

#### *Stratigraphy*

The importance of stratigraphy in controlling mineral localization at the Ethjudna mines was recognized at an early stage of the regional geological work in the area, when it was observed that the productive workings are confined to distinctive bedded formations consisting of tremolite-diopside-garnet skarn rocks overlain by a massive quartzite.

The calc-silicate rocks and the "hanging-wall" quartzite marker bed are interstratified with a considerable thickness of well-bedded and highly folded sandstone-quartzites, epidote-diopside quartzites, remnants of thin dolomitic beds, and mica schists—intruded by pegmatitic leucogranite and pegmatite. In places, the sandstones grade to albitites and microclinites due to feldspathization accompanying granite emplacement. This succession is described in detail in Part I.

#### *Mineralogy*

The tremolite calc-silicate formation is of particular importance because of the widespread occurrences of primary ore minerals as disseminations in the matrix of these rocks. The following minerals have been identified, occurring in this way:

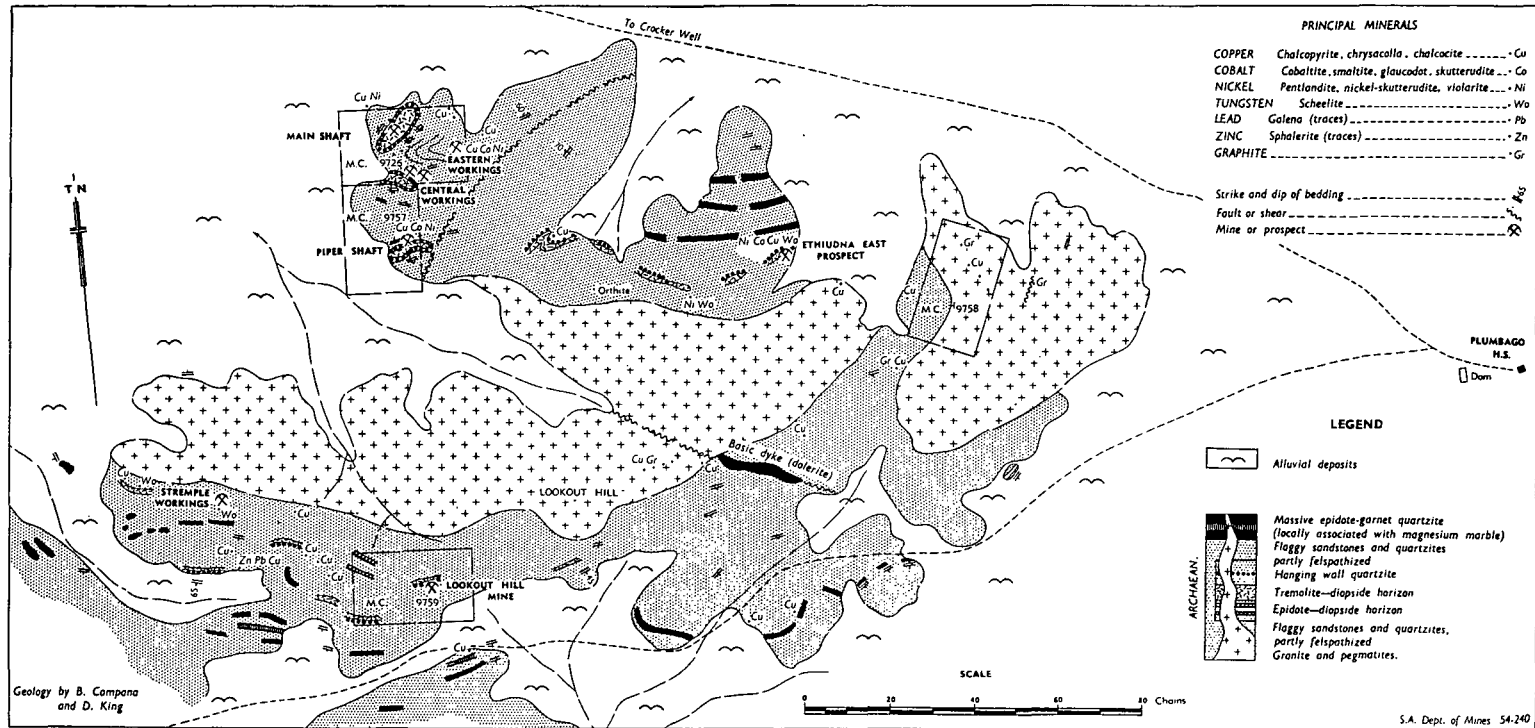
Copper . . . . .	Chalcopyrite.
Cobalt . . . . .	Cobaltite, smaltite, glaucodot, skutterudite.
Nickel . . . . .	Pentlandite, nickel-skutterudite, violarite.
Lead . . . . .	Galena (traces).
Zinc . . . . .	Sphalerite (traces).
Iron . . . . .	Pyrite, pyrrhotite, magnetite, arsenopyrite, loellingite.
Molybdenum . . . . .	Molybdenite (traces).
Tungsten . . . . .	Scheelite.

The granite and pegmatites intruding the sequence at any level are generally uniform in character, being featured by a conspicuous paucity of mafic elements, and varying only in grain size from a medium-grained leucogranite to pegmatitic granite and pegmatite.

In some areas extensive granite bosses completely replace metasediments without any notable structural disturbance of the intruded beds whereas the smaller pegmatitic bodies as a rule follow planes of weakness afforded by bedding, in a lit-par-lit pattern concordant with folding (fig. 67).

#### *Structure*

The Ethjudna mine area is structurally composed of an antiline which, despite a complex history, is clearly recognizable by geometric and stratigraphic criteria. The axial strike of the fold is east-west, with an easterly pitch. In the area mapped,



**FIG. 66—ETHIUDNA MINING AREA**  
Regional geological plan

both the northern and the southern limbs of the fold are outlined by the mineralized sequence described above, and their respective dips correspond to a normal anticline.

On the north limb there are numerous overturned drag folds which do not conform to the general structural pattern of the major folding and are believed to have been superimposed during a subsequent orogeny of Early Palaeozoic Age. This minor folding particularly affects the tremolite-marble horizons in the area of the main mine workings (figs. 66 and 69). Here the mineralized beds are folded into three tight and overturned anticlines which have a northeast axial strike, and are separated by broader synclinal troughs. The most important productive mines on Claims 9726 and 9757 are each located on the northern (or normal) limbs of these folds, suggesting that the structural setting may have locally played a role in mineral enrichment within the favourable horizons.

The south limb of the fold is, by contrast, regular in strike and dip through the whole of the mapped area, displaced only by two minor faults.

The lowest beds of the anticlinal core are almost entirely digested by granite intrusives.

Zones of strong shearing with no appreciable displacement intersect the folded succession. The major ones are directed NW.-SE. and NE.-SW., and in at least one example are intruded by unstressed dolerite dykes.

#### *Mine Workings*

Mining operations in the Ethudna area were mainly carried out from 1889 to 1908, during a period of widespread mineral search in the State. The workings were reopened in 1914 and further developed by the New Year Gift Cobalt Nickel and Copper Mining Syndicate, N.L., but these enterprises were short-lived with no notable economic results.

There are no reliable records of production from the deposits. It is known, however, that the mixed ore raised was not amenable to treatment in local smelters, and a parcel of 8 tons shipped to England in 1900 yielded 16 per cent copper and 4 per cent cobalt.

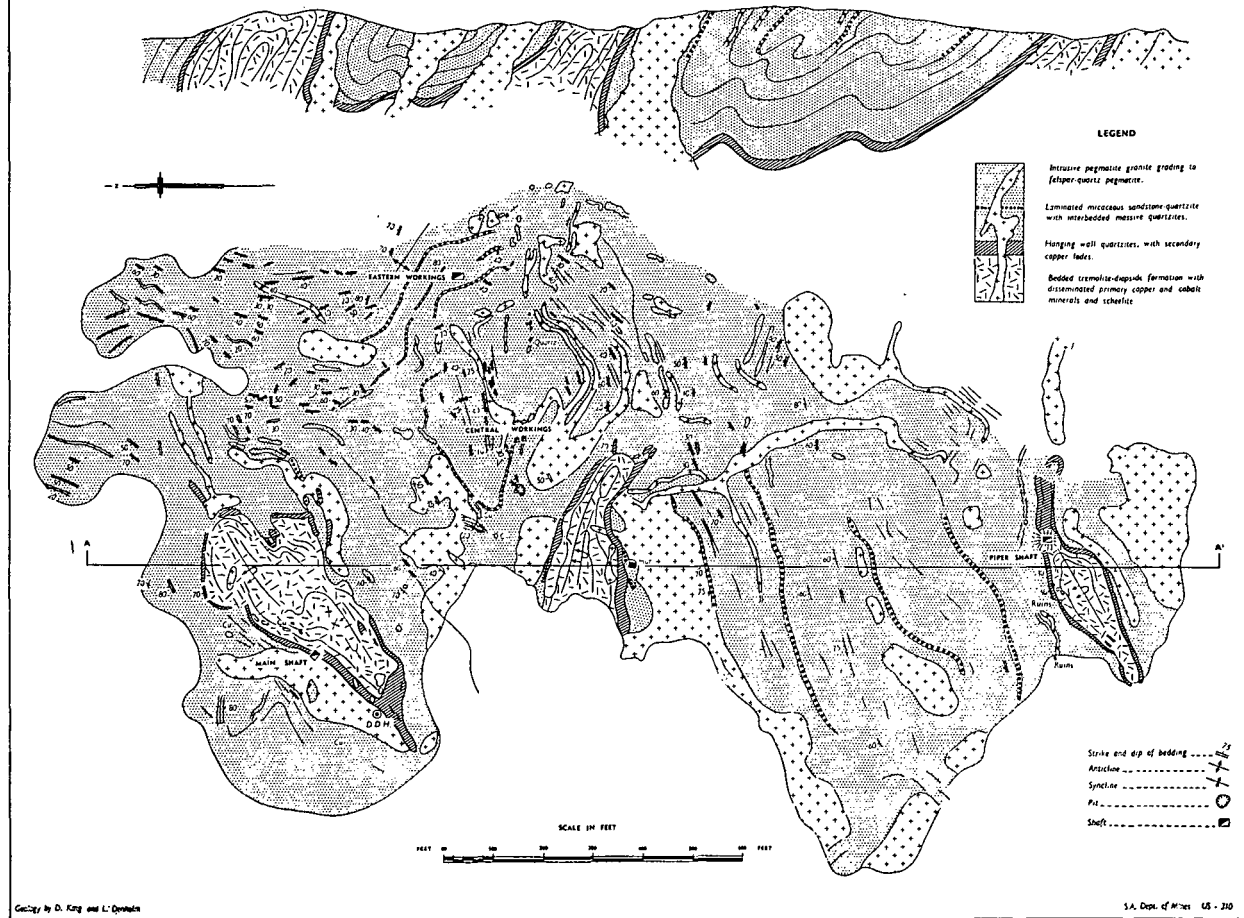
The chief productive mines (Mineral Claims 9726 and 9757) are shown on the detailed geological plan (fig. 67) and the regional geological plan (fig. 66).

Details of the mine workings are as follows:

*Main Shaft Area (Mineral Claim 9726)*—The deepest workings are located in the northwest corner of the block where the mineralized beds are exposed on the crest of a closed overturned anticline. Weak copper mineralization is evident at the surface in the hanging-wall quartzite of the northern limb, extending in outcrop for 350ft. in a NE.-SE. direction.

A shaft known as the Main shaft has been sunk on the underlie down the quartzite to a depth of 110ft., following a cupriferous lode 2ft. wide, dipping to the north at angles increasing from 45 deg. near the surface to vertical in depth (fig. 68). The ore mineral is chrysocolla, associated with traces of secondary nickel and cobalt. A typical sample of the lode from near the base of the shaft assayed 1.9 per cent copper, 0.12 per cent cobalt, and 0.01 per cent nickel. Diopside marble is exposed on the footwall.

At the western nose of the same fold-structure numerous shallow pits have been excavated and backfilled with mullock. Secondary copper ores are abundant in the dump material, as well as traces of scheelite. An exploratory diamond-drill hole (bore No. E.M.L.1) was sunk here by the Department of Mines in 1951. After intersecting granite and remnants of the hanging-wall quartzite—containing only small amounts of chrysocolla in joint fissures—the borehole penetrated the tremolite-marble layers in which were found dispersed grains of primary sulphides, chalcopyrite, pyrite, and pyrrhotite. Sulphides and scheelite were found to occur similarly in the underlying feldspathized sandstones.



**FIG. 87—ETHIUDNA MINE—MAIN WORKINGS**  
 Detailed geological plan and cross-section

*The Central Workings*—These workings are 400ft. southeast of the Main shaft and comprise an east-west line of shallow excavations up to 25ft. deep and extending laterally for 200ft. These follow traces of copper developed in the bedding planes of the flaggy sandstones, at a stratigraphic level a few feet above the massive hanging-wall quartzite, and along the north-dipping limb of another overturned anticline. The ore mineral is chrysocolla, with some cuprite veins and traces of native copper.

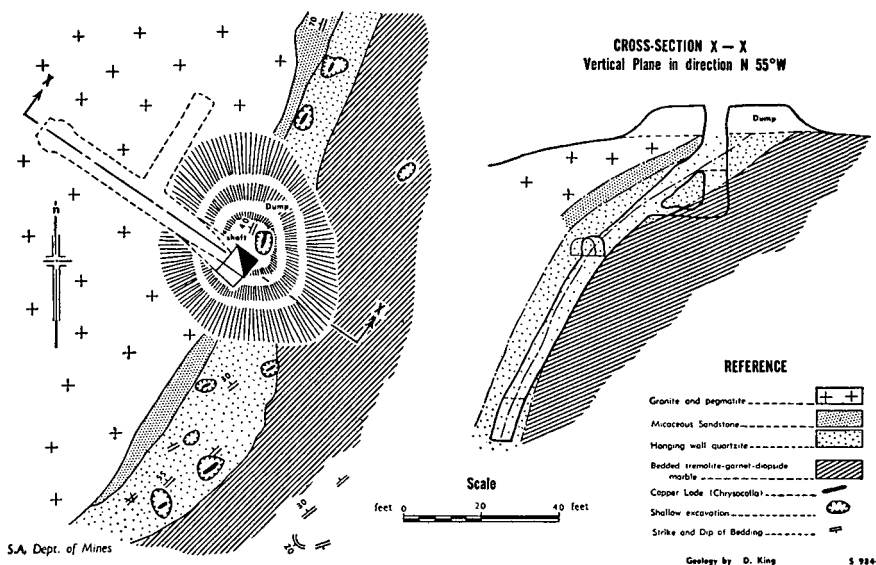


FIG. 68—ETHJUDNA MINE—MAIN SHAFT  
Geological plan and cross-section

*Eastern Workings*—In the southeast corner of Mineral Claim 9726, a 40-ft. shaft has been sunk on the underlie at 45 deg. to the west in the upper flaggy sandstones. It follows a zone of low-grade copper-manganese mineralization of 2ft. width. Bunches of cobalt ore were also reported from this mine, particularly in the footwall at 20ft. depth where samples assaying 1.0 per cent Cu, 0.1 per cent Ni, and 3.5 per cent Co were taken during this survey.

At a distance of 60ft. to the west, another shaft was sunk vertically to 25ft., but with insufficient depth to cut the mineralized bed.

*Piper Shaft (Mineral Claim 9757)*—The workings here known as Piper shaft (fig. 70) consist of a shaft sunk vertically to 20ft. and 30ft. on the underlie at 45 deg. along a copper-cobalt-manganese lode, some 2ft. wide, in the hanging-wall quartzite—again on the north limb of a third overturned anticlinal fold. The lower 12ft. of the shaft is backfilled with mullock, at the upper level of which, drives extend 40ft. to the west and 20ft. to the east.

The best-grade ore reported is from the back of the drive adjacent to the shaft, and assayed 12.2 per cent Cu, 0.2 per cent Ni, and 0.5 per cent Co. The copper ore is chrysocolla associated with psilomelane. Cobalt is consistently present in assayed samples, but neither primary cobalt minerals nor cobalt bloom have been identified. The cobalt and associated traces of nickel are believed to be mainly contained in black earthy segregations as cobalt asbolan. A sample of this material from the western extremity of the drive assayed 1.6 per cent Cu, 0.3 per cent Ni, 0.25 per cent Co, and 0.8 per cent manganese.

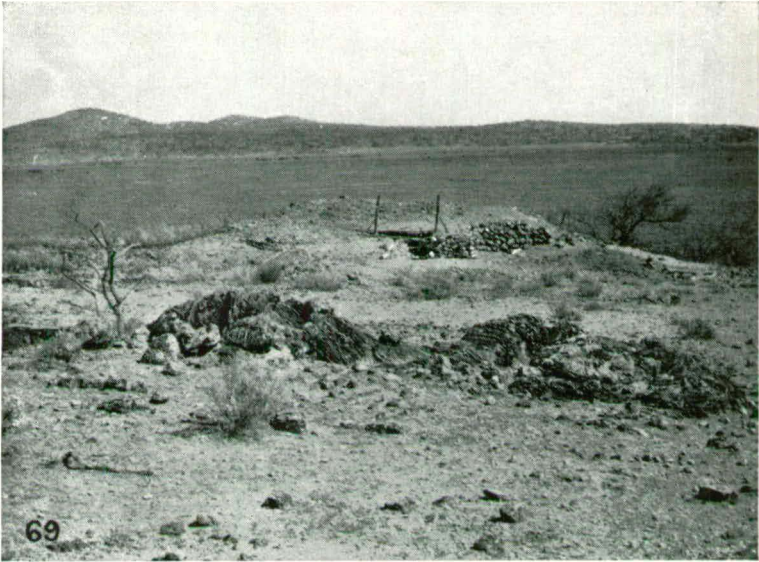


FIG. 69—ETHIUDNA MINE MAIN SHAFT  
Drag-folded tremolite-diopside rock in foreground

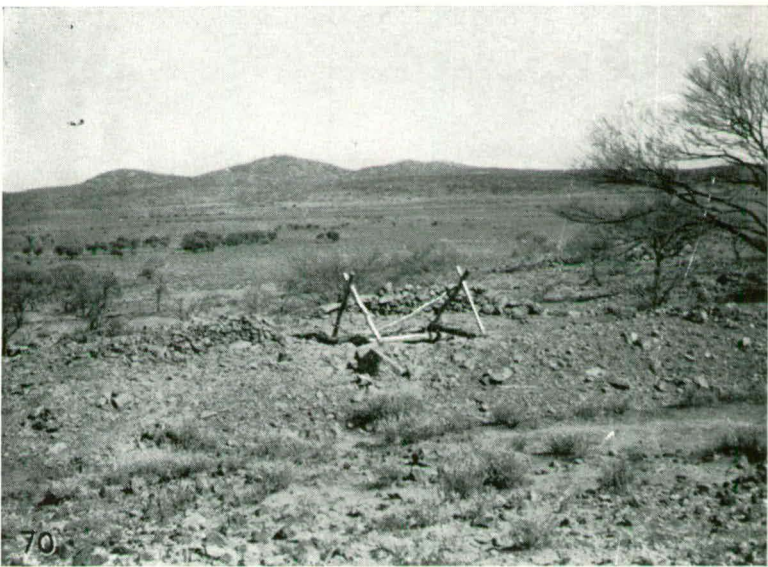


FIG. 70—ETHIUDNA MINING AREA—PIPER SHAFT  
Ethiudna Hill in central background

*Lookout Hill Mine (Mineral Claim 9759)*—A shaft 47ft. deep has been sunk on flat-dipping tremolite-vesuvianite-garnet rocks carrying traces of malachite, chrysocolla and chalcocite. The mineralized formation in this area is surrounded by granite, which was also intersected in the lower levels of the shaft. The mine was abandoned without any production.

In another small outcrop of the tremolite rock—distant 1 mile to the west from the Lookout Hill mine—small amounts of galena, sphalerite, and chalcopyrite have been observed.

*Mineral Claim 9758*—Numerous shallow prospecting pits were sunk into chrysocolla-graphite veinlets outcropping on this property. These were the first mineral discoveries in the district,\* but proved to be of no economic significance.

*Stempel Workings*—In the southwestern portion of the area—at 1 mile west of the Lookout Hill mine—a shaft was sunk to approximately 50ft. in sheared granite and feldspathized sandstones showing malachite staining. The mineralized shear extends 100ft. in a NE.-SW. direction, but the ore grade is apparently very low.

At 300ft. southeast of the shaft, the basal epidotes of the measured section are exposed as a small outlier surrounded by granite. This outcrop contains disseminated scheelite with an overall grade of 0.32 per cent tungstic oxide.

*Ethiudna East Cobalt Deposit*—This occurrence was located in 1953 by J. Johnson (Technical Assistant) whilst engaged in a detailed ground survey of the mineralized tremolite-marble horizon.

At the surface, rich cobaltite, smaltite, and glaucodot disseminations are locally found in siliceous bands of the tremolite-marble bed, with erythrite staining along joint fissures. Associated minerals are chalcopyrite, bornite, chalcocite, jeffersonite, andradite, colourless garnet, sphene, and apatite. The same rocks also carry small veins of axinite.

The structural and stratigraphic setting of the deposit is shown in fig. 71.

Diamond-drill holes sunk into the tremolite rocks at this deposit revealed that weakly disseminated mineralization persists in depth, but with a greater development of nickel-bearing minerals than in the outcrop. Nickeliferous minerals—pentlandite and violarite—were identified in the core, occurring in close association with pyrrhotite, chalcopyrite, loellingite, and pyrite. The ore grade is very low. A typical sample of the core from 38 to 52ft. in borehole E.E.C.1 (fig. 71) assayed 0.25 per cent copper, 0.001 per cent nickel, and no cobalt.

Scheelite is found as a detrital mineral on the surface and as minute grains throughout the borehole samples.

A similar occurrence of cobalt-nickel and tungsten minerals is found in the same type of rocks  $\frac{1}{2}$  mile to the west of the Ethiudna East Prospect. Minerals identified are glaucodot, nickeliferous skutterudite, and scheelite.

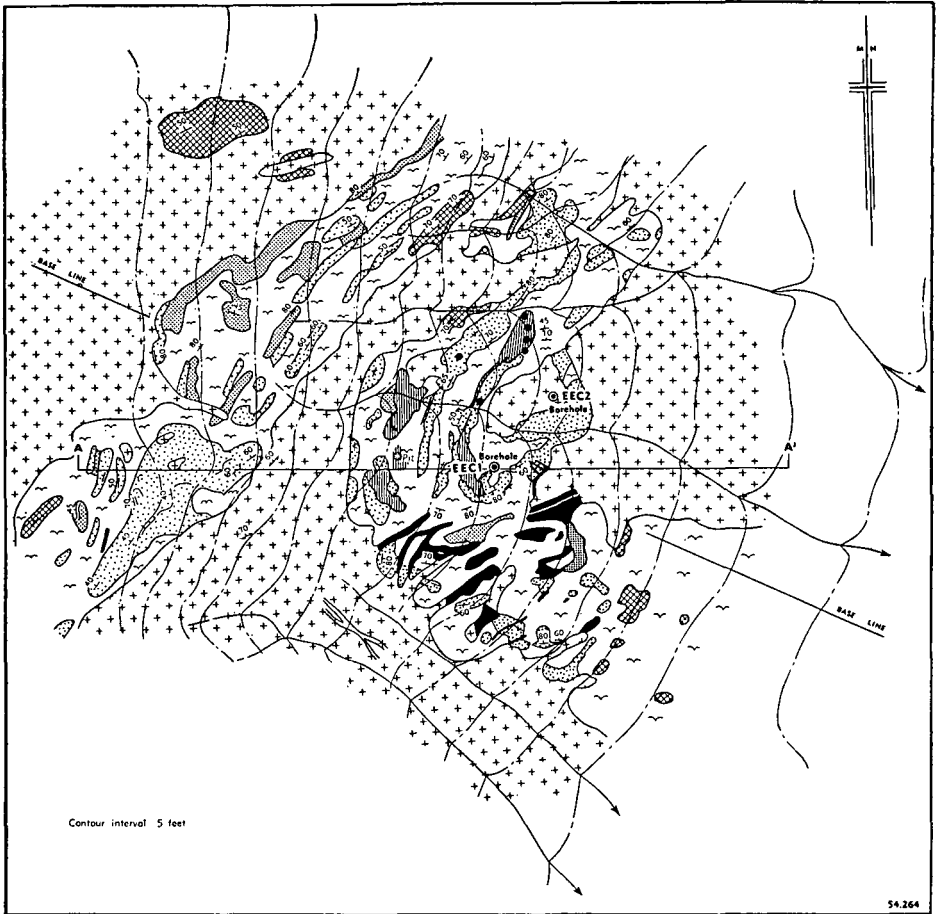
#### *Ore Localization*

The primary ore minerals are found as interstitial disseminated grains in altered limestones, now represented by tremolite-diopside and marble formations, and to a lesser extent in calcareous sandstones altered to epidote-diopside-garnet quartzite.

Mining was largely restricted to enrichments of secondary minerals in the hanging-wall quartzite and overlying feldspathized sandstones. In the main mining area, the secondary enrichment is more commonly found in the normal limbs of overturned anticlines.

The writers consider that the primary mineralization is related to the emplacement of granite bodies, the deposits being of the contact-pyrometasmatic type.

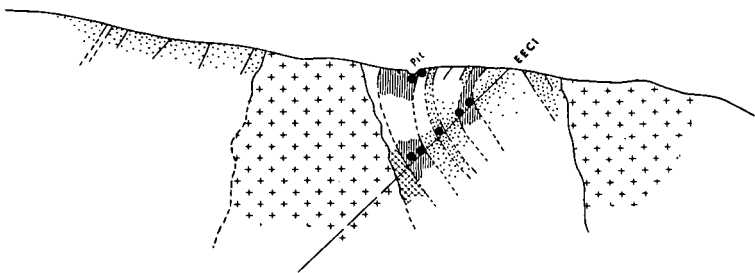
\* Plumbago sheep station derives its name from the occurrences of graphite (or plumbago) in this area.



54.264

Mapping by E. A. Clothier and A. J. Wennerbom

CROSS SECTION A—A'



REFERENCE

Gneissic granite, pegmatitic granite, pegmatite	+	Coarsely crystalline tremolite	▨
White metaquartzites	▨	Quartz veins and fractured quartzite	▨
Banded diopside, actinolite, epidote metaquartzites	▨	Alluvium	▨
Diopside, garnet tremolite, marble grading to pure calcite	▨	Copper-cobalt-nickel mineralization	●
Baite feldspar schist	▨	Gneissosity	~

SCALE IN FEET

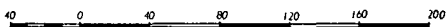
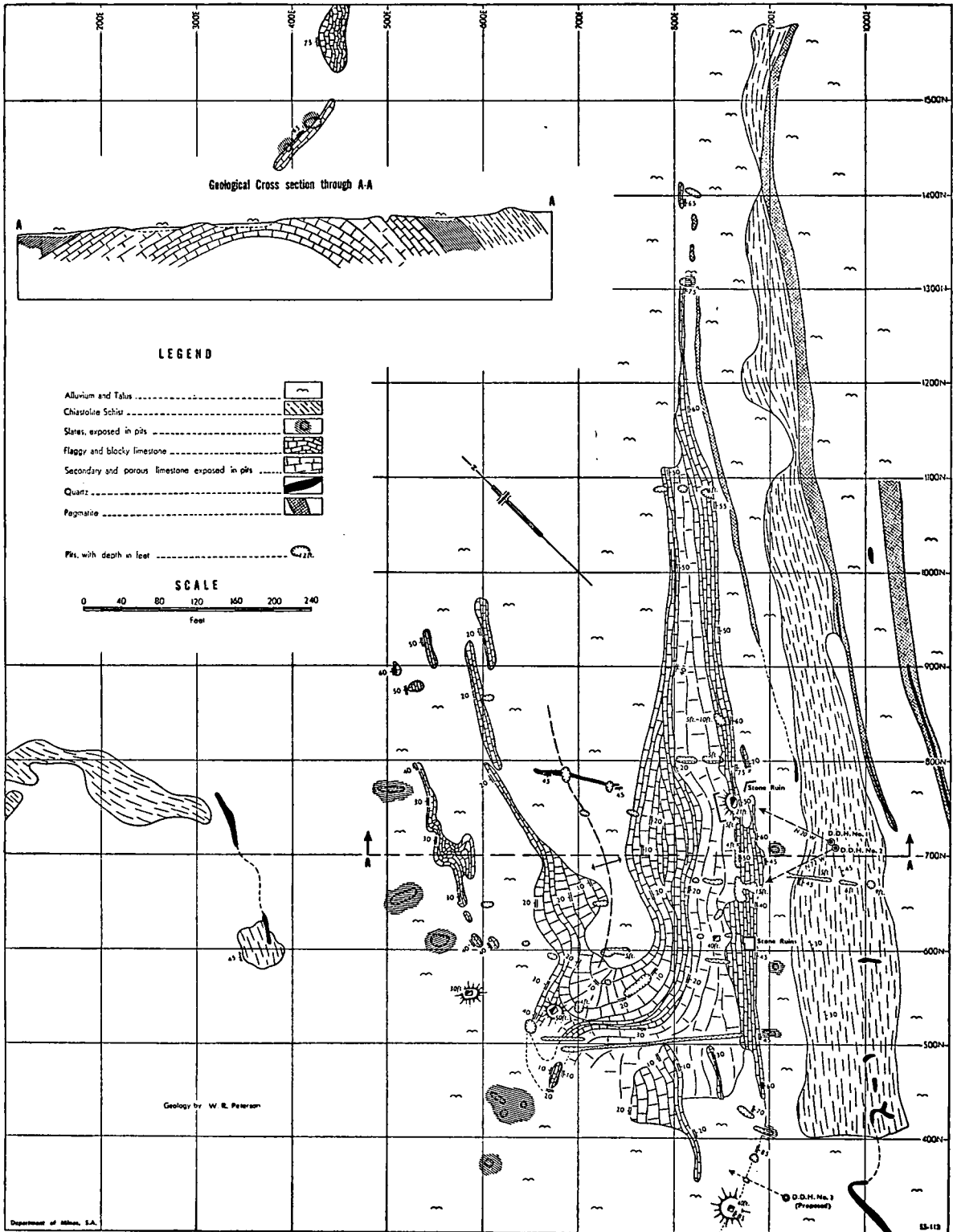


FIG. 71—ETHIUDNA EAST COBALT DEPOSIT  
Detailed geological plan and cross-section



**FIG. 72—MOUNT HOWDEN COBALT MINE**  
Surface geological plan and cross-section

*Mount Howden Cobalt Mine*

The Mount Howden (Cooke) workings are situated on the northern side of a low ridge at 7 miles west of Kalabity station and  $\frac{1}{2}$  mile west of the Bimba copper mine.

Following the discovery of the property in about 1890, by prospector G. R. Howden, a few tons of high-grade erythrite ore were obtained from the outcrops during initial mining operations. In 1900, the field was taken over by the South Australian Cobalt and Nickel Company, and a considerable amount of prospecting and development work with limited output was carried out along the strike of the ore-bearing horizon. The property was subsequently leased by J. H. Cooke who worked it intermittently until 1914, during which time small parcels of hand-dressed ore, averaging 14 per cent cobalt and 0.5 per cent nickel, were consigned overseas.

As shown on the geological plan (fig. 72) the cobalt workings are mainly confined to a relatively small area in an impure-marble bed 20ft. wide, on the eastern limb of a gentle south-pitching anticlinal fold. Secondary copper stainings are more widely distributed within the same bed over an exposed strike length of 1,500 feet.

An underlying marble bed of similar thickness, and exposures of both beds on the western limb of the fold, have been thoroughly prospected by pits without revealing any significant copper or cobalt mineralization. Above the marble beds are schistose slates grading to chialstolite schists.

The ore raised mainly comprised secondary concentrations of erythrite and earthy cobalt oxides from a 30-ft. underlie shaft (Pump shaft) and adjacent small stopes. Grade decreased appreciably at depths of 20-30ft., where only a few seams of primary ore, averaging 1in. in width, were encountered as fillings in an irregular joint system. The ore minerals from this level are cobaltite, smaltite, galena, and chalcopyrite, with coarse calcite gangue. Weakly cobaltiferous pyrite is associated with the ore.

*Distribution of Scheelite*

The search for scheelite was initiated following the detection of this mineral in the Ettlewood Limestones of the Broken Hill district and in trace amounts in the Olary Province in the old mining fields at Waukaloo, Wiperaminga Hill, and Mutooroo, and near Old Boolcoomata (Sprigg, 1952). Subsequent systematic prospecting with ultra-violet lamps has revealed several other occurrences as disseminated replacements in the lime-silicate beds of the Ethjudna Group, and large areas of promising country remain virtually untested.

The most encouraging tungsten deposit found to date is the Old Boolcoomata Scheelite Prospect located 2 miles southeast of the station homestead. Here scheelite occurs as disseminations in former bedding laminae along with fluorite and pyrite in outcropping remnants of an actinolite-epidote-garnet marble over a NE.-SW. strike length of some 2,500ft. (Peterson, 1955). The mineralized skarn is interbedded with carphosiderite which has been mined locally for use in pigment manufacture (Solomon, 1952) and is intimately invaded and replaced by granite-pegmatite (fig. 73).

Measured widths of the intermittent skarn remnants vary from 10 to 30ft. Eight grab samples were taken from the larger outcrops at localities where scheelite was detected by ultra-violet lamp. These assayed from 0.02 to 0.22 per cent  $WO_3$ , averaging 0.1 per cent  $WO_3$ , the latter figure being regarded as representative of the overall reserves. Samples of several pound weight from selected areas assayed as high as 2.29 per cent  $WO_3$ .

Other areas where small amounts of scheelite were detected in garnetiferous lime-silicate rocks are 4 miles southeast of Old Boolcoomata woolshed (Out. 59),  $\frac{1}{2}$  mile

southeast of Ameroo Hill (Out. 63), and in several localities in the tremolite-diopside bed of the Ethudna mining area. Scheelite was also recognized as inclusions in aggregates of magnetite crystals in the dumps of the Mount Victoria copper mine.

In all these occurrences, the richest concentrations of scheelite are invariably in proximity to intrusive pegmatite bodies, and copper and iron sulphides are common associations. There are, however, no known occurrences of either wolfram or scheelite in pegmatites of the Province.

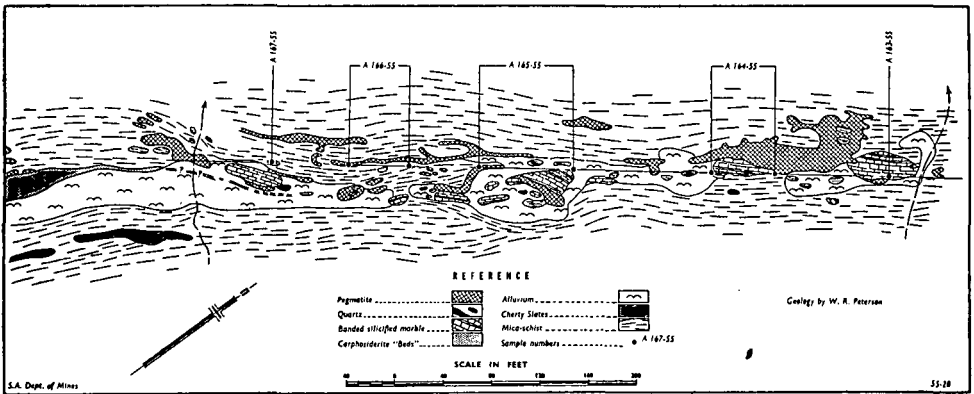


FIG. 73—OLD BOOLCOOMATA SCHEELITE PROSPECT  
Surface geological plan

### Copper Deposits in Epidote-Actinolite Quartzite

The cupriferous deposits occurring within epidote-actinolite quartzite are chiefly represented by weak and sporadic sulphide replacements along bedding planes and joint openings in the same way as in the Ethudna mine area (*see above*). Locally there are ore concentrations where structural elements provided ready access for mineralizing emanations, particularly in areas of tight folding such as at Dome Rock.

#### *Dome Rock Copper Mine*

This mine is located in slate, calcareous sandstone, and chialstolite schist of the Ethudna Group forming low rises 14 miles east of Kalabity station. Copper mineralization occurs in several small independent orebodies as replacements of particular beds—with little or no quartz gangue—in the axial planes of steep pitching folds, and in the overturned limbs of anticlinal drag folds (Dickinson, 1942).

The workings comprise three shafts, namely Crawford, Meehan, and Day shafts, together with numerous small pits and trenches, along a line extending for  $\frac{1}{4}$  mile in an ENE. direction. Main production has come from Meehan and Day shafts, especially in secondary ore, and totals 126 tons of copper from dressed ore of 20 per cent grade.

Groundwater level in the mine workings stands at approximately 200ft. below surface level, corresponding with the boundary of supergene and sulphide ore. The oxidized ore consists chiefly of chalcocite, tenorite, and cuprite, and some olivenite and chrysocolla. Primary minerals are chalcopyrite and pyrite, and traces of leaf gold adhering to manganese partings. Sulphide ore from the lower levels of Day shaft assayed 7 per cent copper.

White cobaltiferous pyrite was observed in the ore from Day shaft, and feeble stainings of erythrite in material from Meehan shaft (Mawson, 1923).

*Woman in White Copper Mine*

Situated  $1\frac{3}{4}$  miles SSE. of Old Boolcoomata homestead. The productive workings consist of a deep open cut in actinolite-quartzite on the normal limb of an anticlinal drag fold. The quartzite carries low-grade disseminations of chalcopyrite and gold, and secondary copper minerals covellite, chalcantinite, tenorite, malachite, azurite, and native copper. Limited amounts of groundwater in the abandoned opening are now saturated with copper sulphates. One and a half miles northeast of the mine, copper-stained quartzite, interbedded with garnet-actinolite rock, has been prospected by a small open cut (Out. 97).

*Putt Well Deposit*

Situated 10 miles northeast of Old Boolcoomata H.S. Shallow prospecting was carried out here for over  $1\frac{1}{2}$  miles along an east-west actinolite-quartzite bed containing malachite and very low gold-values in joint planes. There are similar low-grade copper deposits in jointed quartzite (Out. 76)  $1\frac{1}{2}$  miles north of the Putt Well workings.

*Meningie Well Deposit*

Located  $6\frac{1}{2}$  miles east-northeast of Old Boolcoomata H.S. One and a half miles southeast of Meningie Well an open cut (Out. 61) exposes narrow veinlets of jarositic limonite-epidote-quartzite. In other workings  $\frac{1}{2}$  mile east of Meningie Well, copper carbonates and pyrite occur as low-grade disseminations in gneissic metaquartzite (Out. 86).

*Raven Hill Copper Show*

This deposit is  $2\frac{1}{2}$  miles east of Old Boolcoomata H.S. This is a minor occurrence of copper carbonate associated with ironstone in small joints in epidote-quartzite. Some gold colours are reported to have been obtained from the small opening.

*Other Deposits*

Secondary copper stainings have also been opened up in drag-folded epidote-actinolite-quartzite 4 miles northeast of Outalpa station (*Faugh-A-Ballagh mine*) and at the northeast extremity of Wiperaminga Hill (*Wiperaminga mine*). Other poor copper deposits in a similar quartzite host were worked in the past (*Cooper claim*) and recently (*Walparuta mine*; Mansfield, 1956) near Weekeroo, and near Morialpa station (*Hughes copper prospect*).

**Copper Deposits in the Banded Iron Formation**

The following copper deposits occur in close association with massive hematite-quartz outcrops of the Banded Iron Formation

*Green and Gold Mine*

Situated  $1\frac{1}{2}$  miles northeast of MacDonald Hill siding. A shallow open cut has been sunk on a vein of magnetite, chalcopyrite, and malachite up to 1 ft. wide which intersects a thick body of banded ironstone. On the southwest face of the workings, the vein narrows to 1 in. width and carries visible flakes of gold.

*Perryhumuck Mine*

This mine is 4 miles southwest of Old Boolcoomata H.S. A deep shaft and three large pot-holes were sunk on a malachite-stained layer of granular magnetite-pyrite-actinolite rock in an ironstone bed. Chalcocite may be observed in samples from the shaft as an interstitial filling between magnetite and pyrite.

*Mount Bull Mine*

This show is located 6 miles north of Old Boolcoomata homestead. A deep shaft and two open excavations were sunk on low-grade impregnations of chrysocolla in quartzite, on the footwall of a massive banded hematite body forming the pinnacle of Pimpena Hill. On surface evidence it would appear that no saleable ore was produced.

*Other Deposits*

Small copper showings have been opened up in other isolated outcrops of the Banded Iron Formation at the *Mount Perseverance mine*, and *Olary silver mine*, near Olary, and at Billeroo and Koolka.

**Copper Deposits Associated with Amphibolite**

This is a rather arbitrary grouping of all deposits in which copper mineralization is found in association with amphibolite. In most cases poor outcrop conditions prevent direct observations of elements controlling ore localization, but in at least some examples it is evident that faulting has played an important role in channelling the mineralizing solutions.

*Mutooroo Copper Mine*

Situated 12 miles south of Cockburn. The Mutooroo mine is the largest of the copper mining fields in the North-Eastern division of the State. Discovered in 1887, mining and prospecting were actively pursued until 1893, during which period over 3,000 tons of rich secondary copper ore were despatched to smelters. Subsequently, mining was taken over by tributers, operating particularly on secondary copper zones at Mutooroo South, and was more recently followed by several short-lived attempts to precipitate copper from the mine water (fig. 75).

The country-rock is mainly poorly exposed kyanite- and garnet-bearing schist, and aplite, bordering extensive outcropping bodies of bedded amphibolite (fig. 74). Mineralization appears to follow zones of shearing along the strike of the schists (Knight, 1950<sup>(b)</sup>) extending discontinuously over a distance of some 6,000ft. in a NNE. direction. There are three main lodes, two at the south end of 1,400ft. and 400ft. length respectively, and one at the north end 1,700ft. long.

In the weathered zones, the lode rock consists of limonitic jasper with embedded ovoid granules of white quartz and secondary copper minerals, and in depth the lode minerals are essentially pyrite and granular quartz carrying weak disseminations of chalcopyrite. Stopping is all in the secondary zone, where the ore minerals are chalcocite, cuprite, chrysocolla, atacamite, erubescite, and copper carbonates, but there is some developmental work in the primary ore.

Each of the lodes is about 6ft. wide, with a 45-deg. westerly dip, and could yield an aggregate of 1,200 tons of ore per vertical foot of depth. Recent diamond drilling by the Department (Parkin, 1953), which explored the northern orebody at unworked depths, indicated that the grade of the massive sulphide ore averages less than 2 per cent copper and approximately 30 per cent sulphur, and at this grade neither the north nor south lodes could be economically reopened for production of copper or sulphur.

It has been suggested by geologists of The Zinc Corporation Limited that the Mutooroo orebodies may be correlated with the characteristically pyritic mineralization associated with aplite in the Pinnacles Group of the Broken Hill district.

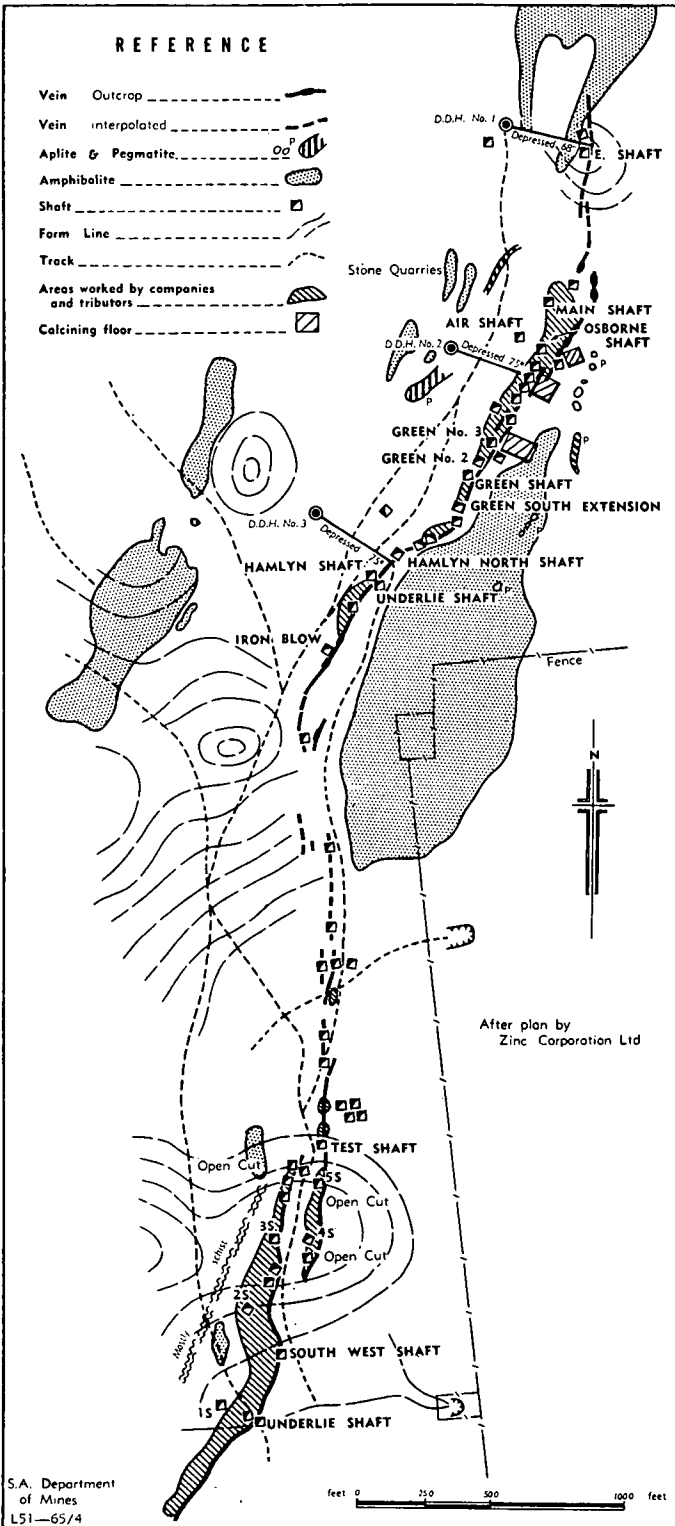
*Mutooroo West Copper Mine*

Situated 2 miles northwest of the Mutooroo mine.

Two inclined shafts, 200ft. apart, with connecting drives have been sunk to depths of approximately 160ft. on a massive pyritic lode dipping southwesterly, with hanging-wall aplite and amphibolite, and footwall biotite schist. The lode attains a maximum known width of 20ft. at the 160-ft. level, where it consists predominantly of pyrite with minor quartz and chalcopyrite, and at least 110 tons of ore assaying 3-4 per cent copper and 20-30 per cent sulphur were taken from this level. Groundwater level stands at 88 feet.

*Mount Victoria Copper Mine*

Situated 2 miles southwest of Mount Victoria. At this deposit a number of small mines were worked for copper and gold along a major NW.-SE. shear zone cutting massive granitoid rocks. Mineralization is associated with remnants (or intrusions) of basic amphibolite and occurs in the form of sporadic ore



**FIG. 74—MUTOOROO COPPER MINE**  
Surface plan

bunches and seams rather than as a definite lode formation. The ore minerals are chalcopyrite, cuprite, malachite, azurite, and free gold, and other minerals present include hematite, magnetite, pyrite, rutile, scheelite, and zeolite.

#### *Pimponda Mine*

Situated  $\frac{1}{2}$  mile northwest of Old Boolcoomata homestead.

The workings comprise a 40-ft. vertical shaft on a narrow quartz lode carrying small amounts of malachite, earthy cuprite, and gold. The vein follows a zone of NW.-SE. shearing marginal to amphibolite over a length of some 20 yards.

#### *Other Deposits*

At the *Waukaloo mine*, on Kalabity station, some small copper deposits occur in hornfelsic slate, in one case along the contact with a somewhat sheared amphibolite body, and in another along a barite-quartz vein following the regional schistosity. There are also small test-holes on malachite-stained amphibolite carrying radiating zeolite aggregates at the *Ameroo copper mine*, and in cupriferous schist adjacent to amphibolite at the *Black Maria mine*.

### **Pegmatitic Copper Deposits**

In three localities some mining work was done on copper-bearing deposits of pegmatitic type.

#### *Mary Copper Mine*

Located 12 miles ENE. of Old Boolcoomata station.

Mining operations extended over a distance of 200yds. along the NW.-SE. axis of an anticlinal fold in actinolite-quartzite and metasedimentary biotite gneiss. The main copper values were found in open cuts at the southeastern end of the workings, where the sediments are intersected by a narrow pegmatite\* carrying scattered disseminations of pyrite, chalcopyrite, bornite, and traces of molybdenite, the leaching of which has led to the formation of secondary concentrations of copper carbonate in the biotite-gneiss footwall. The same ore-bearing pegmatite was encountered in a 105ft. deep shaft in the central section of the workings.

#### *Trinity Mine*

This mine is  $2\frac{1}{2}$  miles south of the Mutooroo mine.

Four shafts were sunk on contorted biotite schist containing pegmatitic segregations stained with copper carbonates.

#### *Mulga Hill Mine*

Situated 3 miles northwest of Radium Hill.

Exploratory test-holes along a pegmatitic zone show copper-stained feldspar and micaceous hematite extending over a length of about 8 chains.

### **Industrial Mineral Deposits**

The minerals described in this chapter include industrially important non-metallics, silicates, and ores of the minor metals which have been mined in the Province, or occur in sufficient amounts to be considered as possible future sources of raw materials. The most common uses and approximate current prices (on rail at Olary) of the minerals dealt with, are itemized in table VIII, together with details of past production, to December, 1954.

The production figures indicate that, with the exception of feldspar, only relatively minor quantities of the various industrial minerals have been marketed from the numerous deposits—both large and small—which occur in the area. This is largely due to the distant geographic situation of the deposits in relation to industrial centres at Port Pirie (176 miles) and Adelaide (258 miles), which is a particularly pertinent factor in the case of the low- to medium-priced materials†.

\* Information supplied by J. E. Johnson (Technical Assistant).

† Rail freight from Olary to Port Pirie and Adelaide is £2 17s. 6d. and £3 8s. per ton respectively as at June, 1955.



FIG. 75—GENERAL VIEW OF THE MUTOOROO MINING AREA—  
LOOKING SOUTH FROM THE OLD MAIN SHAFT  
The line of lode is marked by dumps extending into the background—  
Leaching-vats and precipitation canals at right



FIG. 76—A PINNACLE OF THE ARCHAEOAN BANDED HEMATITE-  
QUARTZ FORMATION  
Billeroo Area

In some cases, particularly in regard to aluminium-silicate refractories, graphite, and barite, very large low-grade deposits have been established, and the ultimate successful exploitation of these reserves will largely depend upon improved beneficiation techniques producing an acceptable product.

### COMMERCIALLY IMPORTANT PEGMATITE MINERALS

Mining of pegmatite felspar and by-product beryl has been carried on intermittently in the area since about 1932\*, chiefly from pegmatites within a short distance of the railhead at Olary. The quarried felspar is a coarse perthite containing about 12 per cent potash and 3 per cent soda (table IX). The best-grade material is usually found as segregations around a quartz core in the central portion of the pegmatite dykes, but such zoning is irregular, and selective mining and hand-sorting are necessary to obtain a marketable product. Beryl is a minor constituent of many of these coarsely zoned pegmatites, and is found as large commercial-grade crystals assaying 11-14 per cent BeO, and measuring up to 5ft. in length and 2ft. in diameter. A detailed chemical analysis of one sample (Kleeman, 1944) revealed an absence of any potassium or the rarer alkalies (table IX). In places, some clusters of beryl prisms have a radial arrangement (fig. 80).

TABLE VIII  
PRODUCTION AND USES OF INDUSTRIAL MINERALS  
*Olary Province*

Mineral	Industrial uses	Approximate values, f.o.r. as at June, 1955	Recorded production (Olary Province)
Felspar . . . . .	Ceramics, glassware, abrasives	£5 per ton for second grade (usual) . .	tons 5,392
Beryl . . . . .	Beryllium metal . .	£15 per unit of contained beryllium (per cent per ton). Minimum grade 9.5 per cent	16
Tantalite- columbite	Tantalum and columbium metal	£1 10s. per pound of oxides. Minimum grade 30 per cent Ta-Cb	Traces observed
Mica . . . . .	Insulator, filler . . .	Best grade—£7 per pound. Scrap— £10 to £15 per ton	Trial parcels only
Apatite . . . . .	Fertilizer . . . . .	No demand . . . . .	70
Fluorite . . . . .	Flux, chemical . . . .	Queensland prices—£11 2s. 6d. per ton for 90 per cent CaF <sub>2</sub>	581
Sillimanite, andalusite, kyanite	Refractories . . . . .	£7 10s. per ton . . . . .	602
Barite . . . . .	Paint, filler . . . . .	£3 to £6 per ton, depending on grade .	54
Carphosiderite.	Pigment, sulphuric acid manufacture	No demand . . . . .	10 (trial parcel)
Graphite . . . . .	Pigment, lubricants,	Ceylon prices—£30 to £290 per ton. Fines cheapest	Nil
Corundum . . .	Abrasive . . . . .	High price for suitable material (im- ported)	Nil
Tremolite . . .	Refractory (?) . . . . .	No known buyer . . . . .	Nil

The purchase prices of these industrial minerals range considerably with local demand.

\* Larger pegmatite deposits of felspar and beryl of the same general type are being worked at the Egebek mining field, 15 miles southeast of Cockburn, and approximately 10 miles within New South Wales territory. Tantalite is a rare constituent of these pegmatites, and is also found with wolfram, amblygonite, cassiterite, and microlite in pegmatites at the Euriovie Hills, north of Broken Hill, in New South Wales.

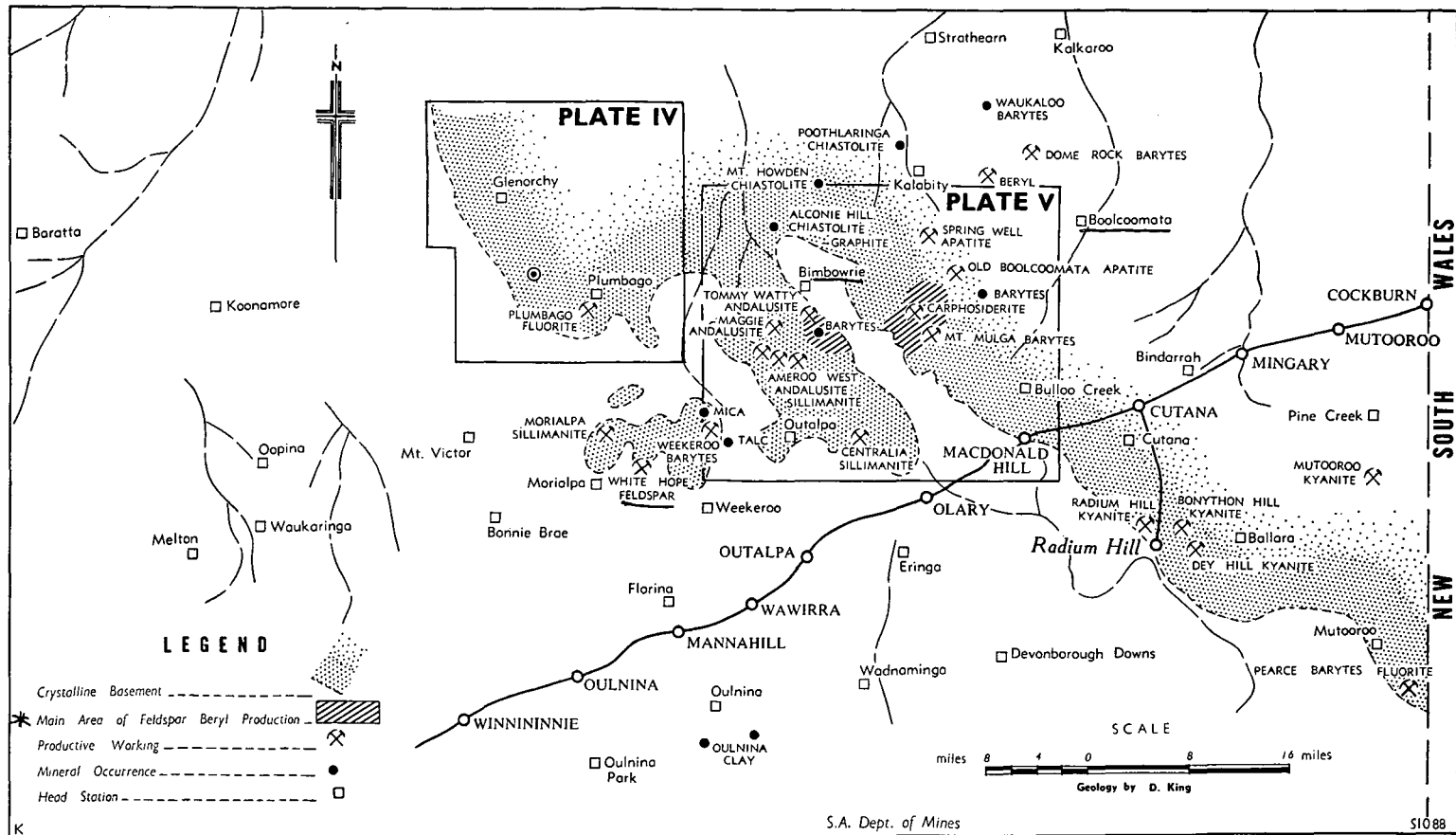


Fig. 77—LOCALITY PLAN OF THE OLARY PROVINCE  
Showing industrial mineral deposits

Quartz, albite, and muscovite are abundant in most of the pegmatites, and in one locality a small quantity of muscovite has been gouged from an outcrop. Biotite, tourmaline, pyrite, and chalcopyrite are usually minor constituents, and less commonly garnet, rutile, and ilmenite are present in small grains. Apatite and other complex phosphates are of ubiquitous occurrence in the beryl-bearing pegmatites, and are commonly present as very large aggregates or segregations.

The uranium minerals broeggerite, gummite, uranophane, and autunite have been observed in felspar-beryl workings at several localities (*e.g.* Out. 15 and 54, plate V) but beryl is absent in the numerous uranium and rare-earth pegmatites of the Plumbago-Glenorchy area. (*See* page 49.)

Small amounts of tantalum-columbium minerals have been observed in association with either beryl or uranium-bearing pegmatites, but no cassiterite, wolfram, or lithium minerals have been detected in the region.

### Felspar and Beryl

Felspar (and beryl) production has mainly come from numerous small open-cut workings in the Bimbowrie and Old Boolcoomata localities, and to the end of 1953 an aggregate of 5,392 tons was marketed for use in glass manufacture, abrasives, and special enamels. Beryl is usually too sparse to be mined independently, but a total of 16 tons has been produced in the Olary region as a subsidiary of felspar mining. Most of the felspar-beryl mining has been done by H. H. Lively of Olary. In recent years there has been a notable decline in output of these minerals due partly to the depletion of cheaply quarried supplies near the railhead, and partly to increased production from deposits nearer industrial centres.

Mining activity has centred around two main areas, in the vicinity of Old Boolcoomata (Dickinson, 1943<sup>(c)</sup>) and Bimbowrie station homesteads, and some beryl has also been gathered from outcrops near Wiperaminga Hill and Bimba Hill. The felspar workings consist of small open-cuts and quarries in segregations of limited dimensions, and are now mostly abandoned. The accurate location of all felspar and beryl workings in the main productive areas, and other occurrences (chiefly beryl) noted during the survey, are shown on the locality map (fig. 78).

### Old Boolcoomata Area

#### White Rock Deposit

This deposit (Mineral Claim 1947) is located 1 mile northeast of Cathedral Rock. A quarry 18ft. by 13ft. (Out. 1) is being worked for felspar and beryl at the present time. Another quarry 10ft. deep (Out. 2) on the same claim has produced felspar and beryl from quartz-rich pegmatites. The claim was formerly held by South Australian Silicates Syndicate. *see subsid?*

#### Raven Hill Deposit

This claim (Mineral Claim 1952) is 1 mile south of Cathedral Rock. An open cut 60ft deep (Out. 54) was an important felspar producer, but no beryl was encountered. Another pegmatite, 200yds. to the southwest, and on the same claim, is being opened up for future felspar production (Out. 113).

#### White Lady Deposit

Mineral Claim 1791 is located near the Woman in White quartz rock. A small excavation in felspar.

#### Gum Creek (Cold Tea) Deposit

This deposit (Mineral Lease 2675) is in the bed of a creek 2 miles east-northeast of Cathedral Rock (Out. 99). An exceptionally high-grade felspar was obtained from an open cut in the creek bed, now filled with gravel wash. Operations are continuing in a small way in the creek bank.

*Hamper Hut Deposit*

Mineral Claim 1730 is situated  $\frac{1}{2}$  mile southeast of the Woman in White mine. There is a quarry 25ft. deep, in pale-pink feldspar and beryl (Out. 6). Northwest of this deposit there is another quarry 10ft. deep on the same claim, in pink feldspar (Out. 8).

*Little Rat Deposit*

The claim (Mineral Claim 1593) is  $\frac{1}{2}$  mile south-southeast of the Woman in White mine. Several hundredweights of beryl were obtained from a pegmatite outcrop (Out. 7).

*Viney Claim*

This claim (Mineral Claim 1903) is situated  $\frac{1}{2}$  mile northeast of the Woman in White mine. An open cut 22ft. deep yielded feldspar and  $\frac{1}{2}$  ton of beryl (Out. 9).

In three other localities (Out. 4, 5, and 12), some beryl was mined independently in shallow excavations.

*Bimbowrie Area**Maggie Mine*

This mine is 3 miles south of Teitz Dam (Mineral Lease 2785). This lease was originally pegged for andalusite mining, but a pegmatite carrying small amounts of uranium minerals and tantalite (Out. 15) was also opened up and yielded some feldspar.

*Boundary Deposit*

Situated 1 mile west-northwest of Teitz Dam. Feldspar and beryl were obtained from a 15ft. deep quarry (Out. 22). One beryl crystal from this deposit measured 5ft. long and 2ft. in diameter. This deposit has not been worked since 1949 (formerly Mineral Claim 435).

*Ameroo Deposit*

Mineral Claim 807 is located 2 miles southwest of the junction of Bimbowrie and Old Booleoomata mail roads. An open cut 30ft. deep (Out. 11) produced high-quality feldspar and some beryl. A considerable tonnage of best-grade feldspar may be observed in the northwest face.

---

Beryl was mined independently from several small excavations near Teitz Dam (Out. 16, 17 and 18), and south of Bimbowrie station (Out. 20).

*Morialpa Area**White Hope Deposit*

Mineral Claim 1193 is situated 3 miles east of Morialpa station. A few tons of feldspar have been despatched from this deposit.

**Mica**

Muscovite occurs in association with beryl in many of the pegmatite deposits described above, but the mineral usually possesses defects which render it valueless for the important use in electrical equipment. The best of the known mica deposits is situated about 8 miles north of Weckeroo station (Out. 93), and consists of a large and irregular body of pegmatite carrying scattered segregations of muscovite, a large quantity of which has been shed from the outcrop. The material available is mostly flawed, either due to impurities or "fishbone" structure, and could only be sold as scrap mica.

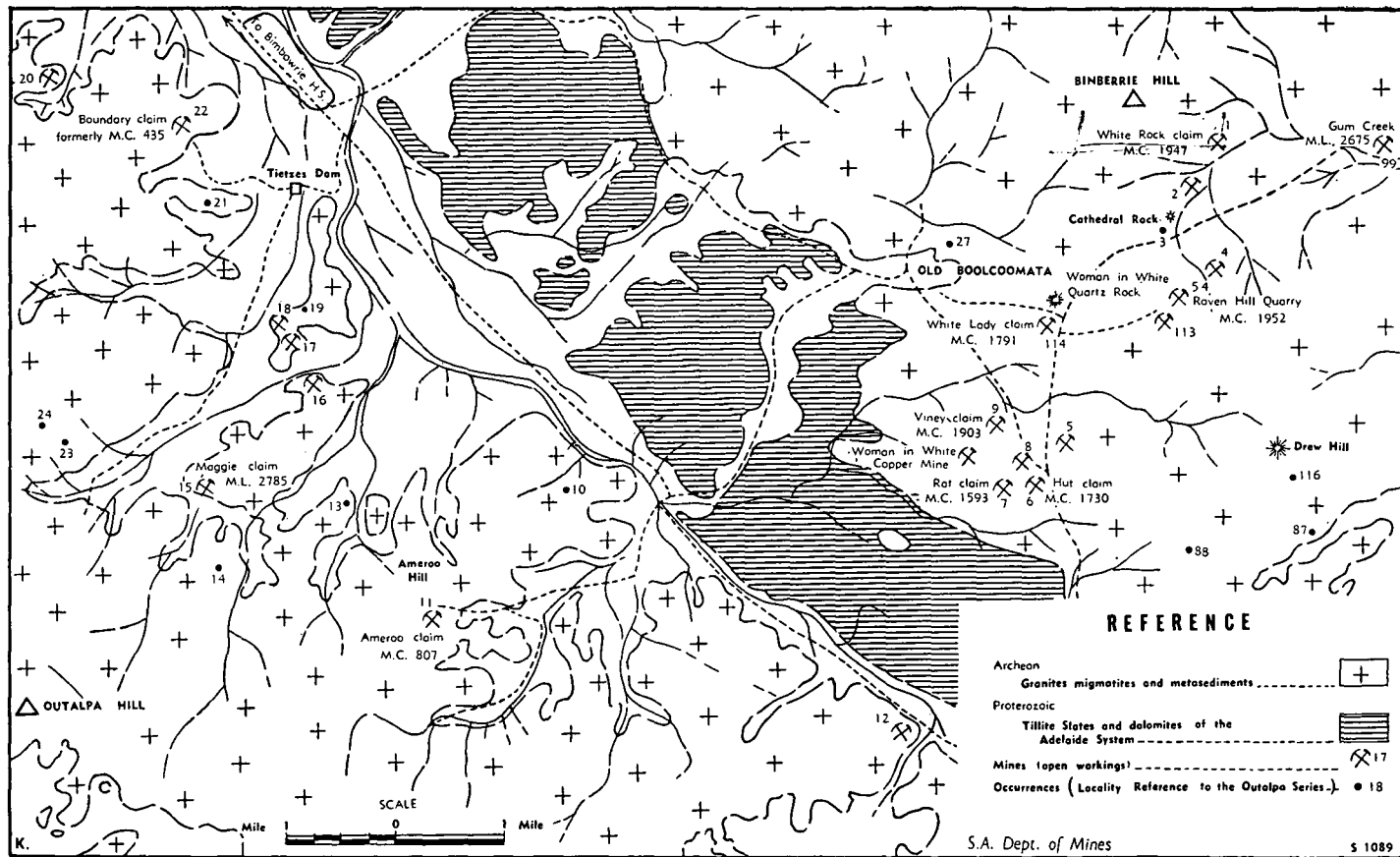


FIG. 78—PLAN OF BIMBOWRIE—OLD BOOLCOOMATA AREA  
Showing felspar-beryl deposits

TABLE IX  
CHEMICAL ANALYSES OF INDUSTRIAL MINERALS  
*Olary Province*

	FELSPAR	BERYL	BERYL	APATITE	APATITE	KYANITE	FLUORITE	CARPHO-SIDERITE
	White Rock Claim (Out. 1), Old Boolcoomata (rep. channel sample)	Maggie Claim (Out. 15), Bimbowrie (specimen)	Boundary Claim (Out. 22), Bimbowrie (chipping)	Spring Well, first grade (selected)	Old Boolcoomata, first grade (selected)	Dey Hill Prospect (specimen)	Plumbago Workings, ave. grade (rep. vein mat.)	Old Boolcoomata, average of several samples
Silica, SiO <sub>2</sub> .....	62.88	64.51	64.94	—	—	36.8	19.53	—
Alumina, Al <sub>2</sub> O <sub>3</sub> .....	20.92	18.90	18.90	0.91	1.00	60.2	0.11	—
Ferric oxide, Fe <sub>2</sub> O <sub>3</sub> .....	0.34	1.57FeO	1.50	0.88	1.10	1.0	0.55	34.38
Manganous oxide, MnO .....	—	—	—	0.27	0.30	—	—	—
Magnesia, MgO .....	0.11	0.14	—	0.38	0.21	Trace	—	—
Lime, CaO .....	0.32	0.25	—	51.20	45.44	Trace	56.40 Equiv.	1.26
Soda, Na <sub>2</sub> O .....	3.07	0.34	—	—	—	—	—	—
Potash, K <sub>2</sub> O .....	12.03	Nil*	—	—	—	—	—	—
Titanium dioxide, TiO <sub>2</sub> .....	—	Nil	—	—	—	0.1	—	—
Sulphur trioxide, SO <sub>3</sub> .....	—	—	—	0.18	0.12	—	—	23.92
Chlorine, Cl .....	—	—	—	0.10	0.16	—	—	—
Fluorine, Fl .....	—	—	—	3.65	1.98	—	38.14	—
Phosphorus pentoxide, P <sub>2</sub> O <sub>5</sub> .....	—	—	—	41.30	35.63	—	—	—
Insoluble matter .....	—	—	—	1.96	14.90	—	—	24.19
Combined water, H <sub>2</sub> O .....	0.11	0.07	—	0.36	0.08	—	—	—
Ignition loss .....	—	1.72	—	—	—	1.9	—	—
Beryllium oxide, BeO .....	—	12.74	13.86	—	—	—	—	—
Carbon dioxide, CO <sub>2</sub> .....	—	—	—	Nil	0.30	—	0.14	—
Rare earths (lanthanides)† .....	—	—	—	—	0.26	—	—	—
Analyst .....	Mines Dept.	Kleeman	Mines Dept.	Chapman	Chapman	Newbold Ref. Ltd.	Mines Dept.	Mines Dept.
Reference .....	Pearson, Min. Rev. 57	Trans. Roy. Soc. S.Aust. 68	Dickinson, Min. Rev. 76	Jack, Bull. 7	—	Dickinson, Min. Rev. 76	Pearson, Min. Rev. 57	Solomon, Min. Rev. 93

\* Rare alkalis also absent.

† Recent additional chemical assay data.

### Phosphates

The granitic rocks and pegmatites of the entire Olary Province are featured by an abnormally high content of apatite, and a wide range of rarer complex phosphate minerals.

In the two localities concentrations of coarse black apatite granules in pegmatite have attracted the attention of prospectors as a source of phosphate fertilizer (Jack, 1919<sup>(a)</sup> and 1919<sup>(b)</sup>). Tests have shown, however, that the grade and the high silica and fluorine content render the material unsuitable for fertilizer and manufacture.

#### *Old Boolcoomata Apatite Workings*

This deposit is situated 5 miles east-northeast of Old Boolcoomata homestead, and 2 miles east of Binberrie Hill.

A black apatite is segregated into sizable bodies and stringers within an irregularly pegmatized zone extending northeasterly for about 6 chains. The largest exposure of apatite rock, consisting predominantly of apatite with interstitial quartz and felspar, is a lenticular body measuring more than 30ft. long and 9ft. wide. This deposit was worked to a depth of 8ft., and the apatite continues underfoot in the now abandoned excavation.

A chemical analysis of a relatively pure sample of the apatite is contained in table IX. A recent partial assay of carefully selected apatite grains showed the presence of 0.26 per cent of rare earths.

#### *Spring Well Apatite Deposit*

Situated 5½ miles north-northeast of Old Boolcoomata homestead. This deposit is similar to the one described above but with a wider distribution of lower-grade apatite lenses. Commencing 350yds. northwest of Spring Well, dark green-black apatite forms discontinuous segregations in some of the numerous pegmatites in the locality and extends to the southwest for about 15 chains (Jack, 1919<sup>(a)</sup>).

#### *Other Occurrences*

A pale-blue translucent apatite is a minor constituent of many of the pegmatites quarried for felspar (*e.g.*, Out. 1, 9, 15, 54) and a colourless to pale-blue apatite is invariably present in the uranium-bearing pegmatites and granites of the Plumbago-Glenorchy district.

*Wagnerite* is present as coarse, pale pink-brown masses in pegmatites near Ameroo Hill (Out. 19, 24, 84) and Meningie Well (Out. 73). A dark resin-brown *triplite*, containing 27.06 per cent  $P_2O_5$ , comprises a massive aggregate 3ft. in diameter at 1 mile west of Teitz Dam, Bimbowrie (Out. 21); amber-coloured *wagnerite* with a halo of apatite occurs in the same pegmatite. Yellow *grastonite* is a minor constituent of beryl-bearing pegmatites south of Bimbowrie (Out. 18, 25), and occurs in lamellar intergrowth with dark-brown *triplite* in pegmatites at Mooleugore Hill (Out. 74), near Mount Mulga mine (Out. 56), and northwest of Ameroo Hill (Out. 13).

Minute crystals of *fremontite* are associated with apatite in joints of a pegmatite at Old Boolcoomata (Out. 6). *Collophane* and *vivianite* are found as an alteration of *grastonite* near Ameroo Hill (Out. 13), and *dufrenite* has been recognized with *florencite* at Wiperaminga Hill (Out. 28).

The widespread distribution of *zenotime* has been previously described (*see* page 57).

#### **Tantalum-Columbium Minerals**

A variety of tantalum-columbium minerals has been observed as minor constituents of pegmatites, and two distinctive types of occurrences with contrasting mineralogy and associations are recognized.

*Tantalite-Columbite*

*Tantalite-columbite* is found closely associated with beryl in the zoned pegmatites of the Bimbowrie-Old Boolcoomata district. *Tantalite* has been recorded in two occurrences of this type near Ameroo Hill (Out. 15, 17), and *columbite* is a rare mineral in pegmatite near Cathedral Rock (Out. 2) (Mawson, 1926). Detrital tantalite-columbite has been obtained from Calico Creek north of Bimbowrie and is reported to occur in pegmatites in the nearby Tonga Creek (Out. 111).

*Mixed Oxides of Titanium and Tantalum-Columbium*

These minerals, particularly *ilmenorutile*, were identified at many localities during the recent mineral survey. Ilmenorutile is usually found in close association with monazite or xenotime, but rarely with beryl. Three noteworthy occurrences were seen near Outalpa Springs (Out. 25, 41, 42), four in the Mount Victoria area (C.W. 111, 112, 123, 36) and one near Old Boolcoomata (Out. 98).

The siliceous phase of one pegmatite near Mount Victoria (C.W. 112) carried ilmenorutile (?), *cyrtolite*, and other unidentified rare-earths. Partial chemical assays of samples from this locality gave the following results:

	1 (Unidentified complex ilmenorutile (?))	2 Ilmenorutile (?)
	per cent	per cent
Manganese (Mn) . . . . .	0.10	0.06
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ) . . . . .	3.20	2.60
Titanium oxide (TiO <sub>2</sub> ) . . . . .	23.80	43.10
Tantalum-columbium oxides . . . . .	44.80	32.10
Uranium oxide (U <sub>3</sub> O <sub>8</sub> ) . . . . .	0.41	—
Thorium oxide (ThO <sub>2</sub> ) . . . . .	0.34	} 0.51
Rare earths . . . . .	1.10	

A number of complex uranium-bearing minerals found in the Crocker Well area contain appreciable amounts of tantalum-columbium. Such minerals include *samaraskite*, *polycrase*, *fergusonite*, *betafite*, and *euxenite*, and are described in an earlier section of the *Bulletin* (see pages 55, 56). Polycrase from near Crocker Well (C.W. 70) carries 17.6 per cent tantalum-columbium oxides.

**FLUORITE**

Near Plumbago station are the only productive fluorite mines in South Australia. The original workings are now abandoned, but another deposit which could profitably yield a small tonnage of fluorite has been recently found by departmental prospectors in the same area. Both are vein-type deposits in Archaean rocks.

Traces of fluorite have also been observed in the Archaean as gangue at the Walparuta and Mount Victoria copper mines, with uranium minerals in granitic rocks at Mount Victoria (C.W. 7), Crocker Well East and near Teitz Dam, Outalpa (Out. 81) and in pegmatite near Outalpa Springs (Out. 25). It occurs as an accessory mineral in gneiss  $\frac{1}{2}$  mile north of Ameroo Hill (Out. 37), and in skarn rocks with scheelite at the carphosiderite mine, Old Boolcoomata.\*

**The Plumbago Fluorite Workings**

This deposit is located about  $\frac{3}{4}$  mile southeast of the station homestead, 35 miles west of north by a station track from Mannahill and Olary railway sidings. Here fluorite occurs, associated with quartz and traces of copper sulphides, as veins up to three feet in width along two sets of intersecting NW.-SE. and E.-W. shear zones. Each of the veins has been prospected, but the principal production came from along the most easterly of the N.W.-S.E. veins, where the workings include an underlie shaft 28ft. in depth (Pearson, 1933).

\* Fluorite is common in the Broken Hill district. A large deposit has been worked in the Mount Eltie-Mount Robe area, 23 miles northwest of Broken Hill, and other productive deposits are to be found at Thackaringa and Yancowinna.

A representative sample from the main vein assayed 78.30 per cent calcium fluoride (table IX). A high proportion of impurity consists of quartz which can be readily removed by hand sorting. A total of 581 tons of fluorite was raised during the period 1932-36 for marketing in the steel and glassware industries. Fluorite remaining underfoot cannot be profitably mined at present prices.

### Newly Discovered Fluorite Vein

This occurrence is situated on the western slopes of a low hill approximately 150yds. south of the woolshed at Plumbago station homestead, within 150yds. of existing tracks, and could be easily made accessible to 2-wheel-drive vehicles.

Fluorite mineralization follows along a narrow and well-defined shear zone directed southeasterly from the margin of Archaean outcrops for a distance of 200ft. (fig. 79). At the eastern end of the deposit, there is a width of up to 3ft. of massive fluorite, with minor off-shoots following subsidiary E.-W. shears, but towards the west the fluorite is in subordinate amounts as disseminations in schistose rock. Malachite staining is common at the western end of the shear zone.

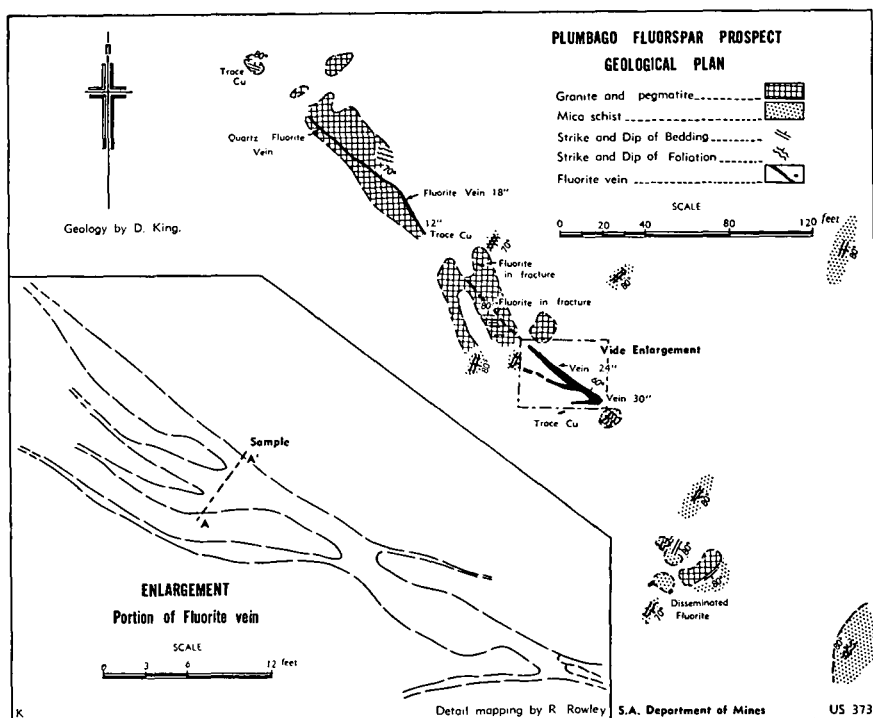


FIG. 79—FLUORITE OCCURRENCE—PLUMBAGO HEAD STATION  
Geological plan of newly discovered fluorite vein

The potentially workable fluorite is restricted to the veins of relatively pure mineral at the eastern end of the lode. This portion of the deposit extends for 40ft. at an average overall width of 2-3ft., as detailed in fig. 79, and would yield approximately 10 tons of commercial-grade ore per vertical foot of depth mined. A channel sample (A-A<sup>1</sup>) was taken across the vein as representative of the fluorite obtainable by selective mining, and was found on analysis to consist of 97.8 per cent calcium fluoride, 1.5 per cent silica, and 0.19 per cent ferric oxide.

This is an exceptionally pure fluorite which with careful hand-sorting would be suitable for special uses in glass and enamel manufacture and the chemical industry. The run-of-mine material would be satisfactory for the important use of fluorite as a flux in ore smelting, for which the market specification is a minimum of 85 per cent calcium fluoride, and a maximum of 10 per cent silica and 1 per cent ferric oxide impurities.

The prospect is thus capable of producing a small quantity of high-grade fluorite and could be worked profitably as a one- or two-man operation.\*

### ALUMINIUM SILICATE REFRACTORIES

The aluminium silicates andalusite, sillimanite (fibrolite), and kyanite, which are constantly in demand for manufacture of highly refractory porcelain products, are widely distributed in the Archaean metasediments of the Province. These minerals are of identical composition, and are converted to a similar refractory product (mullite-silica) on firing. Kyanite, however, has the disadvantage of expanding on heat treatment, and requires pre-calcining before use in mouldings, etc.

All noteworthy occurrences of the aluminium silicates lie within high-grade metamorphic zones in mica schists of the Lower Group (as defined in Part I) and are typically found in one of the following ways:

(1) Large low-grade deposits of disseminated crystals (porphyroblasts) in knotted mica schist. Kyanite and andalusite (var. chiasolite) occur most commonly in this way, and constitute between 10 and 30 per cent of the country-rock over large outcrop areas in several localities. These deposits have not been worked to date, but investigations are now being undertaken to establish whether they could be profitably upgraded by screening or flotation on a large scale—as successfully adopted in the U.S.A.

(2) Small and sporadic segregations of relatively pure aluminium silicates which are developed in proximity to pegmatites intruding mica schist. Residual blocks of sillimanite and andalusite have been gathered from the surface at numerous places and marketed at a profit, accounting for the 602 tons total recorded production from the area.†

With the possible exception of large deposits near Morialpa station (*see* page 118), the andalusite-sillimanite masses exposed in the schist bedrock are generally too small and erratic in distribution to be worth mining.

#### Andalusite

Massive pink andalusite occurs in mica schist in several localities near Ameroo Hill, and two adjoining claims have been worked intermittently on a small scale since 1936.

##### *Tommy Watty Andalusite Deposit*

This deposit is situated  $1\frac{1}{2}$  miles northwest of Ameroo Hill (Mineral Claim 1670). Lenticular masses of andalusite measuring up to 6ft. by 2ft. in cross-section are exposed in mica schist near contacts with pegmatite dykes. Numerous large boulders of residual andalusite were taken from the surface (Dickinson, 1943<sup>(a)</sup>), and more recent additional production has resulted from shallow open-cut operations (Out. 79). A similar occurrence has been noted  $\frac{1}{2}$  mile north of this locality (Out. 80).

##### *Maggie Andalusite Deposit*

Located 2 miles west-northwest of Ameroo Hill (Mineral Lease 2785). This lease adjoins the above claim to the south. A few tons of superficial andalusite have been taken from the block (Out. 107).

Small amounts of a pink andalusite have also been observed at the contact of quartz pegmatite and schist near the Walparuta mine (Out. 118).

\* This deposit is now being worked by M. vom Berg (Mineral Claim 1969) to supply an Adelaide user.

† A large body of massive sillimanite rock is being worked at Thackaringa, 20 miles west of Broken Hill and 8 miles east of Thackaringa siding on the Broken Hill-Adelaide railway. This deposit has produced many thousands of tons of high-grade sillimanite, and large reserves are available for any future open-cut operations.



FIG. 80—RADIATING BERYL PRISMS OBTAINED FROM PEGMATITE  
About 1 mile west of Outalpa Springs (Out. 25)



FIG. 81—CHIASTOLITES  
Mount Howden locality—Southwest of Kalabity station

### **Andalusite (Var. Chiastolite)**

Knotted andalusite (var. chiastolite) schists are widely developed in the Archaean metasediments of the Olary Province, and the Broken Hill district, and some occurrences described in a comprehensive paper by Mawson (1911) are famous for an abundance of well-developed chiastolite crystals showing a variety of cruciform structures in cross-section (fig. 81).

The chiastolites occur as cigar-shaped forms two to three inches in length throughout certain stratigraphic horizons of graphitic mica-schists, and well-preserved specimens are readily obtainable as residuals strewn about the surface. In the past, there has been a limited sale of cut and polished chiastolites in the semi-precious jewellery trade, mainly due to the enterprise of a local prospector, the late G. R. Howden, who also distributed specimen material to museums throughout the world.

In some places the chiastolite crystals comprise about 20 per cent of the rock and could be readily sorted mechanically for industrial use as a refractory.

The following are the most noteworthy of the numerous known deposits.

#### *Mount Howden Chiastolite Occurrence*

Situated 9 miles north of Bimbowrie station homestead, and adjacent to the Mount Howden cobalt mine. Residual chiastolites are abundant at the surface, and occur in the schistose country-rock along foliation planes. Most of the crystals show the normal cross in cut sections, but others with a more complex internal structure have become known as howdenites.

#### *Poothlaringa Chiastolite Occurrence*

This occurrence is situated near Poothlaringa Well, Kalabity station. Here the chiastolites occur as unorientated crystals associated with sillimanite in graphitic mica-schist.

#### *Alconie Hill Chiastolite-Graphite Occurrence*

Located 6 miles northwest of Bimbowrie station homestead (Out. 105). At the eastern end of Alconie Hill, a graphite-muscovite schist contains chiastolites in various stages of alteration to sillimanite or pinite pseudomorphs. This area was pegged in 1933 as a sillimanite-graphite claim (formerly Mineral Claim 13905), but no mining of any consequence was undertaken.

### **Andalusite-Sillimanite**

#### *Ameroo West Deposit*

Mixed andalusite and sillimanite parcels have been obtained from three claims west of Ameroo Hill, along a southwesterly strike continuation of the Maggie andalusite deposit. In these deposits, intergrowths of andalusite and sillimanite in a mica-schist host form lenticular and blocky masses measuring up to 8 or 9ft. in longer dimensions, at the margins of tourmaline-bearing pegmatites and quartz segregations.

Several hundreds of tons of the andalusite-sillimanite rock have been despatched to Sydney and Perth for refractory uses (spark plugs, etc.), all of which represents residual boulders taken from the surface. The marketed product consists of ovoid, relict crystals of andalusite in a matrix of fibrous to massive white sillimanite. The degree of sillimanite replacement is very variable, but the buyers accept any proportion of andalusite and sillimanite.

Mineral Claims 902 and 903 (Out. 101 and 102), 3 miles west of Ameroo Hill; sillimanite, with subordinate andalusite and some kyanite, occurs as scattered surface boulders over a wide area.

Periodic small orders are still being met by H. H. Lively of Olary.

One large cigar-shaped residual on M.C. 903, measuring 5ft. long and 2ft. maximum diameter, has an external form closely resembling that of the chiasolites from the Mount Howden locality. This specimen is internally zoned concentrically about the longer axis; the peripheral zone consists of sillimanite surrounding a zone of andalusite, partly replaced by sillimanite. The inner zone consists of quartz growing into a central cavity. The occurrence of quartz in this way suggests that it has been released during the formation of the aluminium silicates from the mica-schist country-rock, which may also account for the numerous quartz segregations which are so commonly associated with andalusite-sillimanite bodies.

Mineral Claim 1672 (Out. 78),  $3\frac{1}{2}$  miles west-northwest of Ameroo Hill; a similar deposit to the above in which the raw material consists of about equal proportions of andalusite and sillimanite. In the northern portion of the claim, a coarse muscovite is intergrown with the andalusite and sillimanite and renders it unfit for refractory uses.

### Sillimanite

#### *Morialpa Sillimanite Occurrence*

A greyish-white sillimanite occurs as lenses along the foliation of mica schist over a strike length of several miles near Morialpa station (fig. 77). The size of the lenses varies from augen 2ft. long and a few inches wide to large masses some 100ft. long and up to 8ft. wide (Ridgway and Johns, 1950<sup>(a)</sup>).

The sillimanite rock forms prominent outcrops, reduced in places by weathering to scattered boulder fragments up to several tons in weight. Pegmatites carrying tourmaline, and small quartz veins, are commonly found in close association with the sillimanite masses, and corundum has been observed with the sillimanite at one occurrence 6 miles north of Morialpa station.

No production has been recorded from these deposits which are reported to be capable of yielding at least 1,000 tons of clean sillimanite above surface level.

#### *Centralia Sillimanite Occurrence*

Situated 2 miles northwest of the Centralia copper mine and 5 miles east of Outalpa station homestead. Small sillimanite lenses occur in mica schists (Out. 103). About 50 tons of shoad rock were marketed.

### Kyanite

Several extensive low-grade deposits are known within a 3-mile radius of the Radium Hill uranium mine, where it was first reported in 1914 by the former Government Geologist, L. Keith Ward. Other similar deposits were discovered in this area and near Mutooroo during the regional geological survey of the Ballara military sheet (Sprigg, 1952<sup>(a)</sup>).

In each of the deposits the kyanite chiefly occurs as well-formed crystals from 1 to 3in. long in a matrix of mica schist, the kyanite comprising from 10 to 50 per cent of the rock. Locally there are small segregations of relatively pure kyanite adjacent to crosscutting quartz reefs. The Metallurgical Branch are at present carrying out upgrading experiments on bulk samples of the schist. At this stage of the research it is evident that coarse crushing (1in.) followed by screening can produce a 60 per cent kyanite concentrate. A marketable product for refractory purposes can be obtained by fine grinding and flotation.

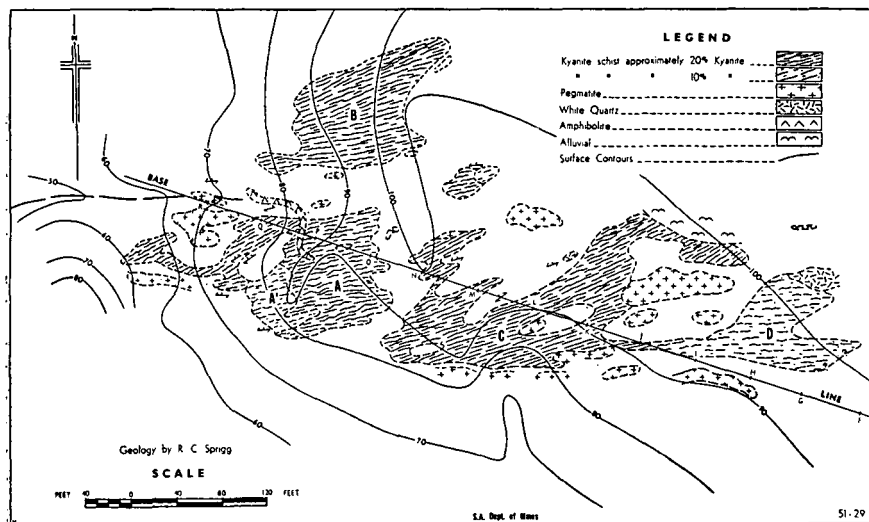
The best of the kyanite occurrences are as follows:

#### *Radium Hill Kyanite Prospect*

This deposit is situated  $2\frac{1}{2}$  miles north of Radium Hill mine. In an earlier report (Sprigg, 1952<sup>(a)</sup>), four main areas of easterly trending kyanite-mica schist are described which have a total outcrop coverage of some 4,000 sq. yds., each of the bodies being separated by relatively narrow stretches of alluvium. The southern

boundary of the deposit is defined by extensive areas of pegmatite. Small pegmatite bodies, and a sinuous amphibolite dyke, intrude the schists in some places (fig. 82).

The bulk of the schist averages about 10 to 30 per cent kyanite. On the basis of these figures, the reserves of kyanite mineral within the limits of the exposures are estimated to be approximately 300 tons per vertical foot of depth.\*



**FIG 82.—KYANITE DEPOSIT NEAR RADIIUM HILL**  
Geological plan

#### *Dey Hill Kyanite Prospect*

Situated 3 miles east of Radium Hill mine. In this locality there are widespread outcrops of contorted kyanite-mica schist cut by narrow amphibolite, pegmatite, and quartz dykes (Dickinson, 1943<sup>(b)</sup>). In one place there is a well-exposed segregation of kyanite measuring 5 by 3ft., contaminated by about five per cent of staurolite, andalusite, muscovite, and garnet.

A sample of kyanite from this deposit has been chemically analyzed, and the result is included in table IX.

#### *Bonython Hill Kyanite Prospect*

This deposit is 1 mile north of Bonython Hill and 3 miles northeast of Radium Hill mine. Another deposit of the same type as that at Dey Hill.

#### *Mutooroo Kyanite Prospect*

This is  $\frac{1}{2}$  mile west of the Mutooroo mine. Elongated segregations of kyanite up to 8in. in width hve been observed in poorly exposed mica schists near the contact with amphibolite.

### **BARITE**

Barite is found in both the Archaean crystalline basement and the overlying Adelaide System sediments.†

\* Scheelite was recently reported in a bulk sample of kyanite from the Radium Hill Prospect.

† In the Adelaide System rocks, barite is a minor constituent of metalliferous quartz veins at Teetulpa and Baratta, and occurs with purple fluorite and quartz in small disconnected (sheared) veins 5 miles south of Mutooroo station homestead (Pearce barite claims, M.Cs. 1871 and 1872.).

In the Archaean rocks, there are a number of very large but low-grade deposits of barite of the bedded replacement type which are characteristically contaminated by silica, and by a remarkably regular content of granular iron ores—comprising about six per cent of the whole. These deposits appear to follow a certain stratigraphic level within the banded iron formation as pointed out in an earlier section of this record (*see* page 93). The largest barite deposits are located at Weekeroo, Mount Mulga and Dome Rock, and are described in some detail in the following pages. Similar occurrences are also to be found near Ameroo Hill (Out. 38 and 47) and near Meningie Well (Out. 91).

Metallurgical research on bulk samples from one of these deposits (Weekeroo) has indicated that flotation methods would have to be adopted to produce a marketable product, involving high costs and a serious problem of water supply. On account of these factors and the distance from industrial areas, it seems unlikely that the low-grade barite deposits have any prospect of commercial development at the present time.

Small barite deposits of better grade are known near Old Boolcoomata homestead (Out. 71), and in the Waukaloo copper mine area.

#### **Weekeroo (Walparuta) Barite Deposit**

Mineral Claim 1775, seven miles northeast of Weekeroo station homestead. Large outcrops of low-grade barite are distributed about the periphery of an extensive siliceous mass (containing some hematite and barite) in an area of Archaean quartzites, schists, amphibolites, and intrusive granite-pegmatites (Out. 90). The barite outcrops are generally orientated parallel to the bedding of the country-rock, and in places retain the original bedding structure of sediments (Ridgway and Johns, 1949).

There are eight main bodies consisting dominantly of barite which have reasonably well-defined boundaries (fig. 83). The appearance of these outcrops is uniform, each being composed of a matrix of coarsely crystalline white barite with fine-grained silica inclusions and studded with brownish-black crystalline hematite and magnetite up to  $\frac{1}{2}$  in. in diameter.

The deposit is considered to be capable of yielding approximately 3,500 tons of ore per foot of depth by open-cut operations. The largest body contains 900 tons per foot of depth, a representative sample of which assayed 62.4 per cent barium sulphate. Metallurgical tests on the same sample, conducted by Enterprise Exploration Co. Pty. Ltd., demonstrate that a concentrate of acceptable grade cannot be obtained by gravity concentration alone; flotation is necessary (Knight, 1950<sup>(a)</sup>).

Three parcels of hand-sorted barite, aggregating 54 tons, have been obtained from the deposit during the period 1946-1954.

#### **Mount Mulga Barite Deposits**

Formerly Mineral Claims 775 and 887, three miles southeast of Old Boolcoomata station homestead. Six large and irregularly shaped bodies of massive but impure barite crop out on the crest of the Mount Mulga ridge (Out. 106). The barite outcrops are featured by faint structural lines corresponding to the bedding foliation of the quartzite country-rock which it appears to replace (Whittle, 1948). The bulk of the deposit consists of a coarsely granular white barite containing appreciable amounts of disseminated ilmenite and magnetite grains (up to about 5 per cent), in places discoloured by a pale-green copper staining, and generally becoming more siliceous at the margins.

The outcrop of the largest deposit (No. 1 lens) covers an area of approximately 15,000 sq. ft., which would represent about 1,900 tons per vertical foot of depth. The total tonnage available in the five subsidiary deposits would amount to a similar figure (Mansfield, 1949).



A. W. G. Whittle (1948) reports that smaller but better quality barite—free of granular iron ores—occurs in seams up to 3ft. wide to the north of the Mount Mulga deposit.

#### **Dome Rock Barite Deposit**

This deposit is 3 miles north of the Dome Rock copper mine. According to Dickinson (1950), the largest of several occurrences in the area is located at the pinnacle known as Dome Rock. Here a lenticular outcrop, about 200ft. long and 100ft. wide, consists of low-grade granular barite with much disseminated hematite (5-30 per cent) and quartz (10-50 per cent). The linear orientation of inclusions in the quartz grains as observed in thin section suggest that this mineral is a remnant of a former metamorphic rock that has been partly replaced by the barite. The country-rocks are hematite quartzites and schists, and a large pegmatite intrusive follows the western boundary of the deposit.

Even the best material available would not lie within the specification of first- or second-grade barite used in industry, without first undergoing treatment.

#### **Waukaloo Barite Deposit**

Situated 8 miles northeast of Kalabity station homestead. A lenticular body of white barite, about 75ft. long and 1 to 4ft. wide, has recently been found 100ft. east of the Waukaloo copper mine. The barite appears to be a reasonably high grade.

### **MISCELLANEOUS NON-METALLIC MINERALS**

The following mineral deposits which are found in the Olary Province are not being worked at present, but may provide a future source of raw materials required in industry.

#### **Carphosiderite**

An unusual deposit of carphosiderite (basic sulphate of iron) occurs interbedded with mica schists and scheelite-bearing calc-silicate rocks near Cathedral Rock, Old Boolcoomata station (*see* also page 101). The main deposit is confined to a bed about 6ft. wide, which is partly concealed by soil or limestone overburden, but probably extends over a strike length of at least 400yds., representing a minimum reserve of about 250 tons per vertical foot of depth (Solomon, 1952). The composition of the bed as established by chemical assays of several representative samples (table IX) is approximately 74 per cent carphosiderite and 24 per cent insoluble matter.

A similar but smaller deposit of carphosiderite is also known near Ameroo Hill (Out. 63).

The possible use of the carphosiderite as a pigment, or for sulphuric acid manufacture, has been investigated by chemical companies without any noteworthy economic developments.

#### **Graphite**

Finely divided (amorphous) graphite is a constituent of andalusite-mica schists which outcrop over wide areas near Kalabity and Bimbowrie stations. In at least one locality, at Alconie Hill (Out. 105), graphite comprises about 30 per cent of the schist over a very considerable width, and experiments are at present being conducted on bulk samples to establish whether a marketable product could be obtained by metallurgical treatment. (*See* page 117.)

Minor deposits of flake graphite of no commercial value are to be found in association with copper mineralization in the Ethjudna mining area (*see* page 99) and near Old Boolcoomata station homestead (Out. 119).

#### **Corundum**

Corundum occurs in small amounts as porphyroblasts in gneiss and schist near the Woman in White mine (Out. 120) and near Ameroo Hill (Out. 108).

#### **Tremolite**

Massive tremolite rock forms prominent outcrops in the Ethjudna mining area.

## Chapter 4

### POST-PROTEROZOIC VEIN DEPOSITS OF THE CRYSTALLINE BASEMENT

In the localities outlined hereunder, siliceous quartz reefs which intersect the basement rocks were mined for gold and copper. These differ markedly in structural and mineralogical features from the typically pegmatitic or pyrometasomatic deposits of the Precambrian mineragenic epochs, but are comparable in type, mineralogy, and in most cases structural orientation (fig. 65) to the epithermal veins of the Early Palaeozoic metallization. The probability that these siliceous vein deposits are in fact of Early Palaeozoic age is substantiated by the observation in numerous localities of similarly orientated quartz veins intersecting the Archaean-Proterozoic unconformity.

#### Luxemburg and Queen Bee Mining Area

The gold and copper mines of the Luxemburg and Queen Bee mining area are located along a system of parallel quartz reefs cutting granite and metamorphosed sediments on the eastern boundary of an extensive body of amphibolite. Gold was first discovered in 1887 at the Bismarek reef, and shortly afterwards the John Brown and Queen Bee reefs were pegged. In 1915, a plant was erected for crushing ore and for the recovery of gold and copper, but lack of water for the treatment plant proved to be a serious problem to the operations, and the workings were abandoned shortly afterwards.

The mining area, has been mapped in detail by Ridgway and Johns (1950<sup>(b)</sup>) and the following detail is largely extracted from their report.

#### QUEEN BEE MINE

This reef outcrops over a distance of about 800ft., with widths varying from about 1ft. to 8ft. and with a steep northerly dip. The quartz of the lode is white and massive, though often cellular along the centre. Three main shafts were sunk on the eastern end of this reef near the amphibolite-granite contact, and other small pot-holes to the eastward.

The main ladder and haulage shaft was sunk on a 3-ft. lode to a depth of 270ft. on the almost vertical underlie of the lode. There are working levels at 100ft., 160ft., and 200ft., and it is reported that the bulk of ore was won from the 160-ft. level. An 86-ft. shaft connects with the 100-ft. level at the amphibolite contact. The 63-ft. windlass shaft connects with a stope above this level.

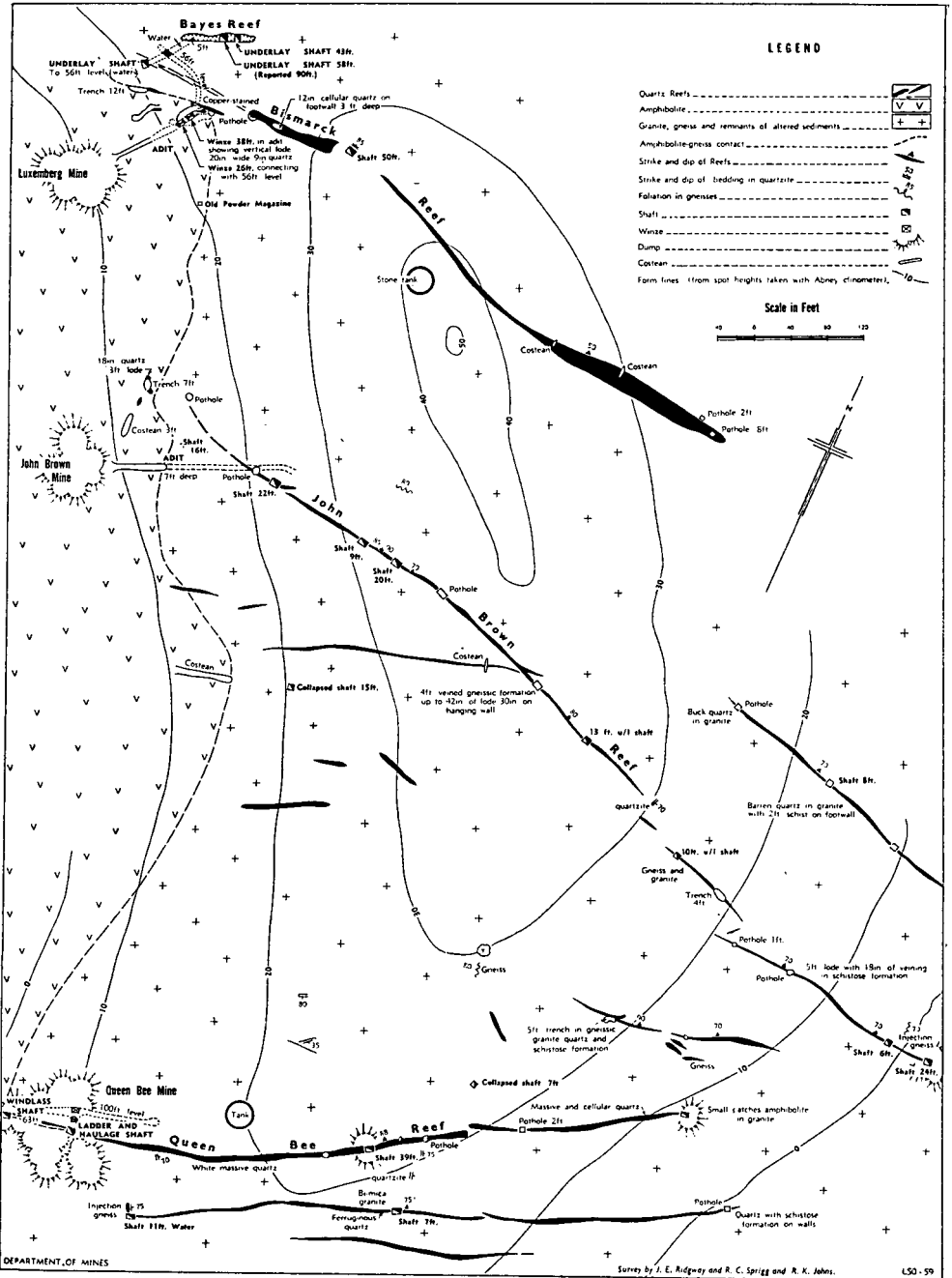
Fractures did not persist into the amphibolite which, during the shearing, acted as a competent bed. Quartz stringers up to 18in. wide, however, feather out along the cleavage planes of the schistose amphibolite for short distances.

Records show that the original workings at the main ladder and haulage shaft intersected some small rich bunches of copper carbonate, chalcocite and bornite, and free gold, and one sample assayed in bulk yielded 1oz. 10dwt. of gold per ton, 9oz. silver and 32½ per cent copper. Near the amphibolite contact the vein is richer in copper ores of chalcopyrite, tenorite, and euprite than the other reefs.

#### LUXEMBURG MINE

The Luxemburg mine comprises workings along the auriferous Bismarek and Bayes reefs.

The Bismarek reef strikes approximately east-west and dips at 45° to 85°N. The width of the vein varies from 1ft. to 20ft. On the western end near the contact with the amphibolite the reef splits into at least three veins which have been opened up by means of an underlie shaft and a level at a depth of 56ft. Workings below this level are inaccessible. The most southerly branch has been worked by means of an adit and winzes which connect through to the 56-ft. level. It has been stoped out for a length of 30ft. from the 56-ft. level to the adit.



**FIG. 84—LUXEMBURG AND QUEEN BEE MINING AREA**  
Surface geological plan

The Bayes reef, which appears to be a branch of the Bismarek, has been opened up by means of two underlie shafts, 43ft. and 58ft. deep, respectively, and an open stope 80ft. long and 30ft. deep for a width of 7 feet.

The reported production from these mines amounts to 259 tons, from which 153oz. of gold were recovered.

#### JOHN BROWN WORKINGS

The John Brown line of reef, between the Luxemburg and Queen Bee, outcrops for over 1,000ft. in length, its maximum width being 4ft. The quartz reef strikes ESE. and dips NNE. at angles between 50 deg. and vertical. It has been opened up by means of an adit, shallow shafts, and trenches at intervals over its entire length. Most of the outcrop is barren, or almost barren, quartz. There are three other barren-quartz reefs south of the Queen Bee within the map area.

#### GENERAL APPRAISAL

The total recorded production for the whole field amounts to 304 tons for 171oz. of gold bullion, and thus could not have covered cost of development. Records show the Luxemburg mine as being the major producer, but the Queen Bee is the most developed reef on the field and appears to have been the most important. It is evident from the survey (Ridgway and Johns, 1950<sup>(b)</sup>) that the ore forwarded from the mines probably represented hand-picked stone from small, richer patches along almost barren reefs, and it is unlikely that the deposits will offer any future scope for profitable operations.

#### Other Mines

##### BIMBA MINE

Situated 10 miles north of Bimbowrie station.

A shaft and numerous open cuts are sunk on cupriferous quartz veins introduced along a line of faulting which extends NNE. in schists for a distance of approximately 2 miles. A pale-coloured pyrite is the only sulphide now present on the dumps. Nickel is reported to be present (Mawson, 1911).

##### CUTANA MINE

Situated 5 miles south of Cutana railway siding.

A limited amount of copper ore was obtained from a well-defined quartz-ironstone reef 3ft. wide trending in a NE.-SW. direction for a length of over 60ft. Malachite and chalcocite, carrying up to 4oz. of silver to the ton, and some gold, were met in small but rich shoots.

##### CENTRALIA MINE

Three miles northwest of King Bluff, near Olary. A quartz lode, averaging 5ft. wide and carrying sparse pyrite and chalcopyrite, trends southeasterly across the strike of laminated metaquartzite country-rock. A quantity of secondary copper ore was raised from near the surface, but at depth only narrow and sporadic veinlets of sulphides were encountered. The main shaft is reported to be 200ft. deep.

#### OTHER DEPOSITS

Feeble copper mineralization is associated with quartz veins in schist at the *Billeroo*, *Lady Louise*, and *Copper Hill (Booleoomata)* mines, and with gold in an east-west vein cutting gneiss at the *MacDonald Hill* mine.

## Chapter 5

### POST-PROTEROZOIC EPITHERMAL VEINS IN THE ADELAIDE SYSTEM

The Adelaide System sediments flanking the crystalline basement are featured by widely distributed low-temperature metalliferous vein deposits occurring in siliceous, ferruginous, or carbonate gangue. Of special interest are the auriferous quartz veins which were formerly mined in numerous northeast localities and which contributed largely to the gold production of the State during the latter part of the nineteenth century. Lead and copper sulphides are found less commonly in a similar environment, and traces of bismuth, tungsten, and cobalt have been identified in association with the other metals.

#### Auriferous Quartz Reefs

In each of seven main mining centres, the gold occurs sporadically in narrow siliceous reefs trending parallel to the bedding or structural lines in quartzite or slate country-rock. At the *King Bluff* and *Nillinghoo* areas, auriferous quartz forms a stockwork in irregularly fissured quartzite over a strike length of several hundred yards. In other fields, where the bedrock is predominantly slate, vein swarms follow bedding (or cleavage) in the trailing limbs or axes of broad fold structures, and reefs averaging 1ft. in width may persist along the strike for considerable distances, sometimes exceeding a mile in length.

Two stages of vein development have been recognized, the earliest of which is widely represented by barren milky quartz. Later gold-bearing quartz-calcite-siderite veins, which are coarsely crystalline and sometimes banded, follow or crosscut the barren quartz, as well shown at Wadnaminga. In other places they occur as separate reefs. Pyrite is consistently present in the auriferous veins, and in fact contains most of the gold, although free gold is common in the weathered outcrops where pyrite has decomposed to limonite. Minor amounts of hematite, galena, and chalcopyrite were common to most of the auriferous deposits. Barite has been identified in the reefs at *Teetulpa*, and erythrite at *Mannahill* (Klondyke Reef). Bismuth is associated with the gold in both these localities.

Greatest gold-mining activity was centred about the Teetulpa area where it is reported that several thousand prospectors operated on alluvial and reef deposits, from which gold to the value of £300,000 was raised. In the reef deposits here, and throughout the whole district generally, it was found that the gold values are extremely irregular. Extensive selective mining to depths of up to 1,200ft. at *Waukaringa* yielded large tonnages with an average battery return of 17dwt. of gold per ton during the period 1872-1889.

A serious problem which handicapped thorough prospecting and development of these deposits and which contributed to the early abandoning of the mines about 1900, was the general lack of water supplies.

#### Silver-Lead

Numerous small and relatively unimportant showings of silver-lead minerals are known in the Adelaide System rocks of the Olary region, occurring in either of the following ways:

(1) As described in the preceding section, sparse grains of galena are characteristic of the hydrothermal quartz veins of the gold mining areas, and the *Trinkaleena* mine, east of Mannahill. Galena is particularly widespread at the Wadnaminga field, where cerussite, pyromorphite, and crocoite are also found in the weathered zone. The nearby South Australian Broken Hill mine yielded cerussite assaying 42oz. of silver to the ton.

(2) Narrow and discontinuous seams of galena are found associated with iron oxides and gold in bedding plane fissures in dolomitic slates which immediately overlie the basal grit formation. Small open-cut workings are operating at the present time in deposits of this type at the *Baratta* field, west of Waukaringa, and at *Vranes Prospect*, near Outalpa. Similar deposits were worked but later abandoned at the *Lady Elizabeth*, *Uncle Tom* and *Winkler* mines. The lead tungstate, stolzite, has been identified in samples from the latter workings (Mawson, 1907).

### **Copper**

Copper sulphides are found as sparse grains in the quartz reefs of the goldfield areas, and small parcels of copper ore were produced in the past from shallow workings at several other places in the Upper Proterozoic rocks. These include the *Mildaltie* mine near Radium Hill, where copper and silver-lead minerals occur as weak disseminations in highly cleaved slates, the *Marjorie* mine at Outalpa station, *Mitchell Prospect* on Weekeroo, and the *Nil Desperandum* near Olary.

---

## Chapter 6

### IRON ORE OCCURRENCES

The geological setting and distribution of sedimentary iron deposits in both the Archaean crystalline basement and overlying Adelaide System (Proterozoic) sediments is outlined in Part I of this *Bulletin*. Both are exposed in numerous outcrops which, although of no immediate economic interest, constitute a reserve of potential iron ore resources of the following categories:

- (a) Most important strategically are very large reserves of low- to medium-grade hematite sandstones which comprise a succession of relatively narrow but persistent beds in the Proterozoic sediments.
- (b) Isolated small bodies of medium- to high-grade iron ore in the crystalline basement.

A number of the more conspicuous iron ore outcrops of both types have been known from the earliest mining period. Some have been worked, notably those at Cutana and Booleoomata, to provide iron oxide flux for Broken Hill smelting operations. More recently, other extensive and probably more important low-grade deposits of type (a) have been disclosed by the systematic geological mapping and aero-magnetic surveys.

Brief details of the most important iron ore outcrops given below are mainly extracted from reports by Jack (1922), Sprigg (1951), and Miles (1951). The outcrops described all recorded appreciable anomalies during a recent air magnetometric survey conducted by the Bureau of Mineral Resources, Geology and Geophysics (fig. 31).

#### Proterozoic (Braemar, Bimbowrie) Iron Ore Deposits

The sequence of ferruginous sediments known alternatively as the Bimbowrie or Braemar iron formation are interbedded with the basal tillite (Adelaide System) through the greater Olary district, and extend beyond to near Orroroo in the south, and easterly into New South Wales (Hawson's Knob—Thomson, 1952). It is probably best developed at Braemar station, 45 miles south of Yunta.

In this horizon, the iron usually occurs in several narrow bands, each of a few feet thickness, which consist predominantly of medium- to fine-grained hematite. The hematite beds are finely laminated and rather porous and friable, but locally are dense, or superficially weathered to limonite in outcrop.

#### MALDORKY AREA

Located 2 to 3 miles northeast of Maldorky Hill and 6 miles southwest of Radium Hill. (Magnetic anomaly No. 7.) The hematite-rich beds are exposed here in high hills over a strike length of several miles. The average width of the horizon is 50 to 60ft., but the amount of interbedded slate varies considerably. Chip samples taken at random across the outcrops in several localities showed an iron content (Fe) ranging from 19.5 to 52.0 per cent (Sprigg, 1951).

#### CUTANA AREA

This is situated 7 to 8 miles northeast of Radium Hill and 10 miles south of Mingary railway siding. (Magnetic anomalies Nos. 8, 9, 10, and 11.) Numerous small quarries and pits are developed over a wide area in pisolitic and earthy limonite deposits which form a capping to low rises composed of flat-dipping hematite sandstones. These deposits were worked late in the last century as a source of iron-oxide fluxes for smelting of refractory ores at Broken Hill, being transported from the main workings at Grant quarries by rail *via* a former spur line. Grab samples from several of the quarries assayed 36.6 to 59.8 per cent iron (Fe).

**OLARY AREA**

Situated 7 miles north-northeast of Olary. (Area of generally high magnetic background). A laminated hematite-sandstone bed measuring about 8ft. wide is exposed for several hundred yards in low undulating hills (Out. 104).

**BIMBOWRIE AREA**

Located 1½ miles east of Bimbowrie station homestead. Intermittent outcrops of bedded hematite have been observed over a length of several miles (Out. 112).

**Archaean (Koolka-Billeroo) Iron Ore Deposits**

A banded ferruginous formation is a persistent stratigraphic marker occurring along with epidote-actinolite-quartzites in the Upper Group of the basement rocks. (See Part I, Chapter 2.) This formation is typically composed of laminae or disseminations of hematite-magnetite in arenaceous sediments, but in a number of places is locally represented by massive lenticular segregations of medium- to high-grade iron ore which may measure up to 20,000 sq. ft. in cross-sectional area. As a rule these iron-rich segregations form prominent pinnacle-shaped hills above the general level of the surrounding terrain, and several have been considered as a possible source of iron oxides for industrial use, at least locally (Broken Hill). The relatively small size of the scattered occurrences, however, seriously curtails the value which can be attached to these deposits.

The largest outcrops of the medium- to high-grade iron ore are as follows\*:

**KOOLKA AREA**

Situated 6 miles north of Bimbowrie station homestead. (Magnetic anomaly No. 31.) Two isolated pinnacles of iron ore (magnetite-hematite), ½ mile apart, are capable of yielding about 70,000 tons of 66 per cent iron (Fe) above plain level.

**BILLEROO AREA**

Located 12 miles north-northeast of Plumbago station homestead. (Magnetic anomaly No. 36.) Three ridges of banded magnetite-hematite rock in this locality could provide some 50,000 tons of ore assaying 50 per cent metallic iron above plain level.

**OTHER DEPOSITS**

Other similar ironstone bodies are known in less accessible places at *Mount Bull* (Pimpena Hill), and near *Doughboy Well* and *Outalpa Station*.

---

\* For further information refer to *Geol. Survey S. Aust. Bull.* 9 (R. L. Jack), 1922.

## ACKNOWLEDGMENTS

A work of this magnitude, involving detailed regional investigations and geological mapping of over 3,000 sq. miles in one of the more remote parts of the State could hardly have been carried out without the close co-operation of authorities, numerous scientific and technical personnel, and local pastoralists.

The writers are particularly indebted to Mr. S. B. Dickinson, Director of Mines, for his invaluable scientific and administrative support. Mr. L. W. Parkin, Chief Geologist, supervised the investigations and was consulted on a variety of problems, particularly on the recent Radium Hill development. He also assisted the writers in the final compilation of the manuscript.

The departmental prospectors, who operated under the guidance of the writers, are credited with most of the new mineral discoveries described herein, which periodically revived the enthusiasm of the field parties. Mr. H. E. Campana was responsible for the finding in October, 1953, of the Crocker Well East, Windamerta, and Mindamereeka uranium prospects. Messrs. J. E. Johnson and H. E. Campana located the Mount Victoria uranium deposit in March, 1954. Mr. T. Amtmanis found other mineral occurrences in the area. Mr. Johnson also collaborated with the writers as a technical assistant and identified many of the rare minerals described. His wide knowledge of field mineralogy was drawn upon during the compilation of reports and maps.

Messrs. R. B. Wilson, I. R. Campbell, and K. W. A. Summers (Assistant Geologists) participated for short periods of regional mapping. Messrs. M. L. Reyner, R. K. Pitman and W. R. Peterson, Geologists of the U.S. Atomic Energy Commission, assisted in the economic appraisal of the uranium deposits. Mr. Peterson has continued this activity during 1955.

Mr. A. W. G. Whittle (Chief Mineralogist) performed mineragraphic and petrographic determinations on numerous mineral and rock specimens submitted by the field parties, and the results are partially incorporated and acknowledged in the text.

The writers were also able to consult, in the course of field works, radiometric and magnetometric surveys carried out by the Geophysical Sections of the South Australian Department of Mines and of the Bureau of Mineral Resources, Geology and Geophysics in Canberra. Specific geophysical data which have been used in the compilation of the manuscript are acknowledged in the text.

Field excursions and stimulating discussions with the exploration staff of the Broken Hill mining companies (Messrs. M. A. Mawby, H. F. King, B. Thomson, T. Henderson, and E. S. O'Driscoll) enabled the writers to draw an invaluable comparison and possible stratigraphic correlation between the mineralized terrains of the Olary Province and the Broken Hill area.

The co-operation and friendly relations with the pastoralists at Bimbowrie, Plumbago, Glenorchy, Mount Victoria, Bindara, and Eringa stations were appreciated by the field parties.

## REFERENCES

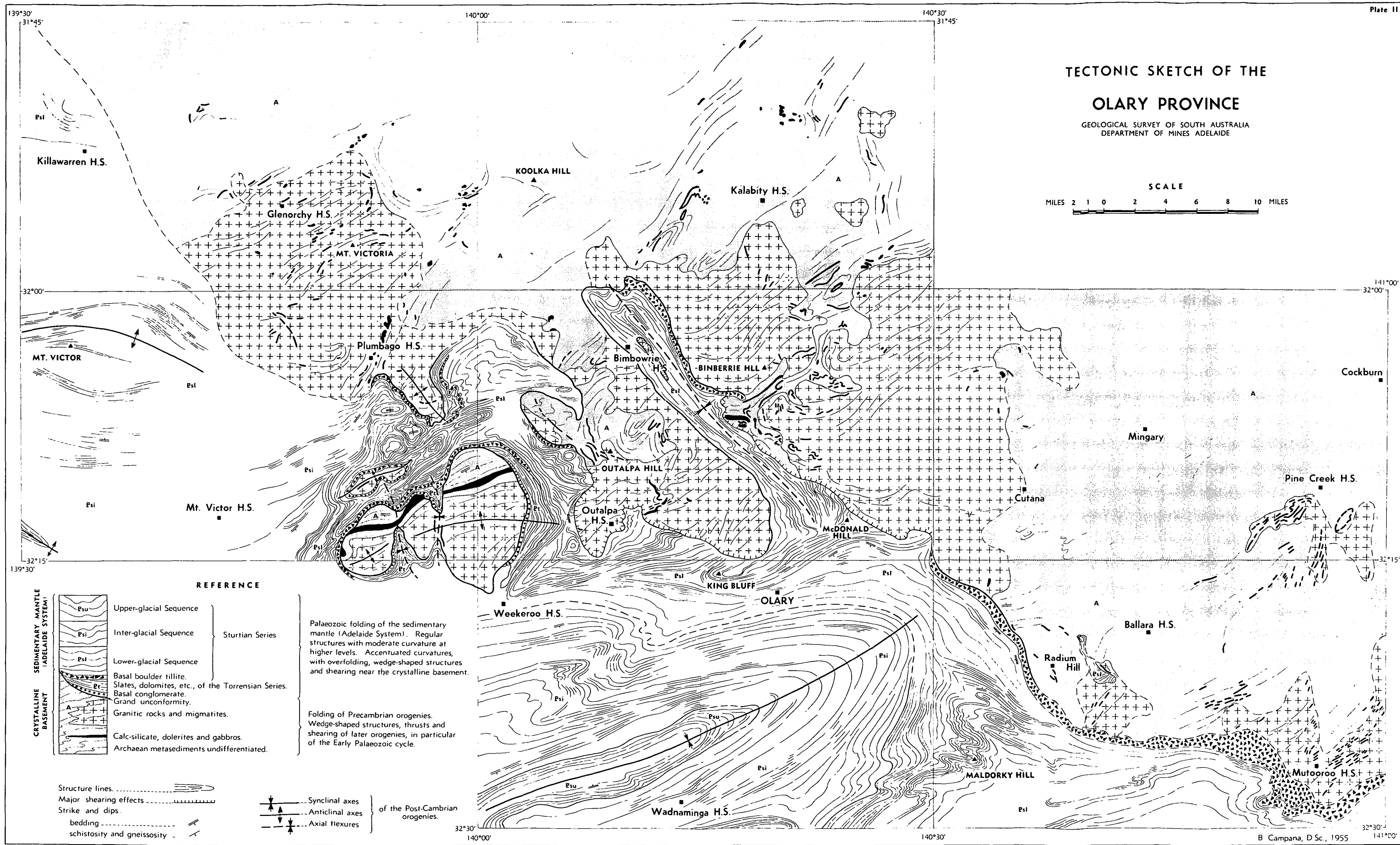
- Campana, B., 1953 (a)—“Mineralization Controls in the Olary-Cockburn Kalabity-Plumbago Military Sheet Areas with reference to the discovery of new radioactive deposits near Plumbago H.S. and easterly of Crockers Well.” Dept. of Mines report—unpublished.
- Campana, B., 1953 (b)—“Geological Report on the discovery of new uranium occurrences at Windamerta Hill between Mount Victoria Hut and Glenorchy Station, with further notes on Glenorchy-Plumbago Areas.” Dept. of Mines report No. RB219—unpublished.
- Campana, B., 1954—“Absolute Age of the Uraniferous Granite and Pre-Cambrian Tillite in the Crockers Well Area (Olary District).” *Aust. Jour. Sci.*, 16 (6), pp. 240-241.
- Campana, B., 1955 (a)—“The Structure of the Eastern South Australian Ranges—The Mt. Lofty-Olary Arc.” *Jour. Geol. Soc. Aust.* 2, pp. 47-61.
- Campana, B., 1955 (b)—“Tillites and Related Glacial Topography of South Australia.” *Ecologiae Geol. Helvetiae*, 48 (1).
- Campana, B., 1955 (c)—“The Stratigraphy of the Northern Flinders Ranges, and the alleged granitization of Tillite in the Mount Fitton Area.” *Aust. Jour. Sci.*, 18 (3), pp. 75-77.
- Campana, B., and Wilson, R. B., 1955—“The Geology of the Jervis and Yankalilla Military Sheets.” *Geol. Survey S. Aust. Rep. of Inv.* 3.
- Corbin, P., and Oulianoff, N., 1932—“*Carte geologique du Massif du Mont-Blanc, Feuille Argentiere, avec Notice Explicative.*” Imp. J. Dufrenoy, Paris.
- Corbin, P., and Oulianoff, N., 1935—“*Carte geologique du Massif du Mont-Blanc, Feuille Talefre, avec Notice Explicative.*” Imp. J. Dufrenoy, Paris.
- Dickinson, S. B., 1942—“The Dome Rock Copper Mine” *Geol. Survey S. Aust. Bull.* 20, pp. 40-49.
- Dickinson, S. B., 1943 (a)—“Andalusite Occurrence, North of Olary.” *Mining Rev.* 76, p. 81.
- Dickinson, S. B., 1943 (b)—“Kyanite occurrence near Radium Hill.” *Mining Rev.* 76, pp. 81-82.
- Dickinson, S. B., 1943 (c)—“Beryl Occurrences, North of Olary.” *Mining Rev.* 76, pp. 80-81.
- Dickinson, S. B., 1950—“Barytes Deposits near Dome Rock.” *Mining Rev.* 89, pp. 100-102.
- Dickinson, S. B., and Sprigg, R. C., 1953—“Geological Structure of South Australia in Relation to Mineralization.” *Symposium on Geology of Australian Ore Deposits*, I, A.I.M.M. Melbourne, pp. 426-448.
- Glaessner, M. F., 1953—“Some Problems of Tertiary Geology in South Australia.” *Jour. and Proc. Roy. Soc. N.S.W.* LXXXVII (2), pp. 31-45.
- Gross, W. H., 1953—“Airborne Scintillometer Reconnaissance Survey of the Radium Hill Area, South Australia.” *Mining Rev.* 94, pp. 15-19.
- Gustafson, J. K., 1954—“Geology of Australian Ore Deposits—Broken Hill.” *Economic Geology*, 49 (7), pp. 783-786.
- Holmes, A., 1947—“The Age of the Earth.” *Endeavour* (July).
- Holmes, A., and Cahen, L., 1955—“African Geochronology.” *Colonial Geol. & Min. Resources*, 5 (1), pp. 3-39.
- Jack, R. L., 1919 (a)—“Apatite at Boolcoomata Springs.” *Geol. Survey S. Aust. Bull.* 7, pp. 130-133.
- Jack, R. L., 1919 (b)—“A second discovery of apatite near Old Boolcoomata Station.” *Geol. Survey S. Aust. Bull.* 7, pp. 133-136.
- Jack, R. L., 1922—“The Iron Ore Resources of South Australia.” *Geol. Survey S. Aust. Bull.* 9, pp. 58-69.
- King, D., 1953—“North East Uranium Investigations. Summary. Report on Investigations of Airborne Scintillometer Anomalies and other Uranium Prospects.” Dept. of Mines report No. 35-8—unpublished.
- King, D., 1954 (a)—“Geology of the Crockers Well Uranium Deposit.” *Geol. Survey S. Aust. Bull.* 30, pp. 70-83.
- King, D., 1954 (b)—“Examination of Rare-Earth Pegmatite Near Wiperaminga Hill, Old Boolcoomata Station.” *Mining Rev.* 97, pp. 93-94.

- King, D., 1954 (c)—“Preliminary Report on the Spring Hill Davidite Prospect.” Dept. of Mines report No. RB42—unpublished.
- King, D., 1954 (d)—“North-East Uranium Exploration, Explanatory Notes to Accompany Mineral Map of the Crocker Well Uranium Field.” Dept. of Mines report No. RB5—unpublished.
- King, D., and Webb, J. E., 1954—“Report on Progress of Grade Evaluation Investigations.” Dept. of Mines report No. RB305—unpublished.
- King, H. F., and Thomson, B. P., 1953—“The Geology of the Broken Hill District.” *Symposium on Geology of Australian Ore Deposits*, A.I.M.M., Melbourne, pp. 533-577.
- Kleeman, A. W., 1944—“On the Analysis of Beryl from Boolcoomata, South Australia.” *Trans. Roy. Soc. S. Aust.* LXVIII (1) pp. 122-124.
- Knight, C. L., 1950 (a)—“Weekeroo Barytes, South Australia.” Report to Enterprise Exploration Co. Pty. Ltd.—unpublished.
- Knight, C. L., 1950 (b)—“Mutooroo Copper Mine, South Australia.” Report to Enterprise Exploration Co. Pty. Ltd.—unpublished.
- Leslie, R. B., and White, A. J. R., 1952—“Geology of Portion of the Grand Unconformity North of Broken Hill, New South Wales.” Unpublished thesis. University of Adelaide.
- Mansfield, L. L., 1949—“Barytes Deposit, Boolcoomata.” *Mining Rev.* 87, pp. 205-207.
- Mansfield, L. L., 1956—“Walparuta Mine (Mount Hecla or Bilcooper).” *Mining Rev.* 99, pp. 210-212.
- Mawson, D., 1906—“On Certain Mineral Species Associated with Carnotite in the Radioactive Ore Body near Olary.” *Trans. Roy. Soc. S. Aust.* XXX, pp. 188-193.
- Mawson, D., 1907—“Mineral Notes—Stolzite.” *Trans. Roy. Soc. S. Aust.* XXXI, p. 123.
- Mawson, D., 1911—“Chiastolites from Bimbowrie, South Australia.” *Mem. Roy. Soc. S. Aust.*, II (3).
- Mawson, D., 1912—“Geological Investigations in the Broken Hill Area.” *Mem. Roy. Soc. S. Aust.*, II (4).
- Mawson, D., 1916—“Mineral Notes—Davidite.” *Trans. Roy. Soc. S. Aust.* XL, pp. 265-266.
- Mawson, D., 1923—“The Dome Rock Copper Mine.” Unpublished report to Dome Rock Copper Mining Company N.L.
- Mawson, D., 1926—“Additions to the South Australian Mineral Record.” *Trans. Roy. Soc. S. Aust.*, L, pp. 25-28.
- Mawson, D., 1944—“The Nature and Occurrence of Uraniferous Mineral Deposits in South Australia.” *Trans. Roy. Soc. S. Aust.* LXVIII (2), pp. 334-357.
- Miles, K. R., 1951—“Inspection of Iron Ore near Radium Hill.” Dept. of Mines report—unpublished.
- Oulianoff, N., and Parejas, E., et al 1951—“*Atlas geologique de la Suisse* 1:25000, *Feuille Finhaut*.” Wasserman S.A., Etablissement Graphique, Basle.
- Parkin, L. W., 1953—“Mutooroo Copper Mine.” *Mining Rev.* 94, pp. 21-29.
- Parkin, L. W., and Glasson, K. R., 1954—“The Geology of the Radium Hill Uranium Mine, South Australia.” *Economic Geology* 49 (8), pp. 815-825.
- Pearson, J. L., 1933—“Fluorspar on Mineral Claim No. 13749, Plumbago Station.” *Mining Rev.* 57, pp. 80-81.
- Peterson, W. R., 1955—“A New Scheelite Occurrence on Old Boolcoomata Station, Olary, South Australia.” Dept. of Mines report No. 39/58—unpublished.
- Pitman, R. K., 1954 (a)—“Preliminary Report on the Victoria Hut (Mount Victoria) Davidite Prospect.” Dept. of Mines report No. RB40—unpublished.
- Pitman, R. K., 1954 (b)—“Report on the Billeroo Davidite Prospect.” Dept. of Mines report No. 37/89—unpublished.
- Raguin, E., 1946—*Geologie du Granite*. Masson & Cie, Editeur, Paris.
- Read, H. H., 1954—“Granitization and Mineral Deposits.” *Geologie en Mijnbouw*. Nieuwe Serie, 4.
- Ridgway, J. E., and Johns, R. K., 1949—“Barytes Deposit—Weekeroo Station.” Dept. of Mines report No. 26/69—unpublished.

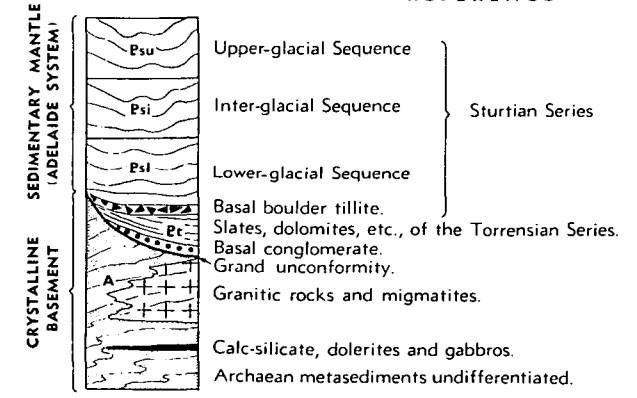
- Ridgway, J. E., and Johns, R. K., 1950 (a)—“Sillimanite Deposits—Morialpa Station.” *Mining Rev.* 90, pp. 117-119.
- Ridgway, J. E., and Johns, R. K., 1950 (b)—“Luxemburg Gold Mines.” Dept. of Mines report No. 29/8—unpublished.
- Rodgers, T. A., 1953—“Radium Hill Uranium Deposits.” *Mining Rev.* 94, pp. 165-171.
- Russell, R. D., Collins, C. B., and Farquar, R. M., 1953—“The Maximum Age of the Elements and the Age of the Earth’s Crust.” *Canadian Jour. Physics*, 31, pp. 402-418.
- Sederholm, J. J., 1926—“On Migmatites and Associated Precambrian Rocks of South-Western Finland.” *Bull. Geol. Comm. Finland*, 77.
- Smith, A. D., 1955—“Flotation of Brannerite (Absite) from Crocker Well Uranium Deposit.” Dept. of Mines Report—unpublished.
- Solomon, M., 1952—“Carphosiderite near Olary.” *Mining Rev.* 93, pp. 131-133.
- Sprigg, R. C., 1945—“Uranium Occurrence, near Ameroo Hill, North of Olary.” *Mining Rev.* 81, p. 91.
- Sprigg, R. C., 1951—“Preliminary Statement on Iron Ores near Radium Hill.” Dept. of Mines report—unpublished.
- Sprigg, R. C., 1952 (a)—“Kyanite Deposit near Radium Hill.” *Mining Rev.* 92, pp. 26-28.
- Sprigg, R. C., 1952 (b)—“Discovery of Scheelite at Old Boolcoomata.” Unpublished Memo. S.A. Dept. of Mines.
- Sprigg, R.C., 1954—“Geology of the Radium Hill Mining Field.” *Geol. Survey S. Aust., Bull.* 30, pp. 7-69.
- Sprigg, R. C., and Seedsman, K., 1951—“Crocker Well Uranium Occurrence.” Dept. of Mines report No. RB45—unpublished.
- Thomas, W. N., 1950—“Investigation of the Braemar Ironstone Deposit.” Rep. Bk. No. 27/99.
- Thomson, B. P., 1952—“The Sentinel Area, Broken Hill District, New South Wales.” Unpublished report, Zinc Corp. Ltd., Broken Hill.
- Wegmann, E., 1935—“Zur Deutung der Migmatite.” *Geol. Rundschau*, 26.
- Whittle, A. W. G., 1948—“The Geology of the Boolcoomata Granite.” *Trans. Roy. Soc. S. Aust.* LXXII (2), pp. 228-243.
- Whittle, A. W. G., 1954 (a)—“Absite—A New Mineral related to Brannerite.” *Mining Rev.* 97, pp. 99-106.
- Whittle, A. W. G., 1954 (b)—“Petrology of Crockers Well Uranium Deposit.” *Geol. Survey S. Aust., Bull.* 30, pp. 79-83.
- Whittle, A. W. G., 1954 (c)—“Radioactive Minerals in South Australia.” *Geol. Survey S. Aust., Bull.* 30, pp. 126-151.
- Whittle, A. W. G., 1954 (d)—“Mineragraphy and Petrology of the Radium Hill Mining Field.” *Geol. Survey S. Aust., Bull.* 30, pp. 51-69.
- Whittle, A. W. G., 1955 (a)—“Radio-active Occurrences of South Australia.” *Geol. Assoc. of Aust.* 2.
- Whittle, A. W. G., 1955 (b)—“Investigations into the Behaviour and Properties of Davidite.” A.N.Z.A.A.S. Section C—Geology (In the Press).
- Williams, R. E., 1952—“Ore Types of the Barrier Ranges.” A study thesis to the Faculty of Science, University of Adelaide—unpublished.
- Winton, L. J., 1933—“Fibrolite and Andalusite Occurrences.” *Mining Rev.* 57, pp. 75-76.
-

# TECTONIC SKETCH OF THE OLARY PROVINCE

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA  
DEPARTMENT OF MINES ADELAIDE

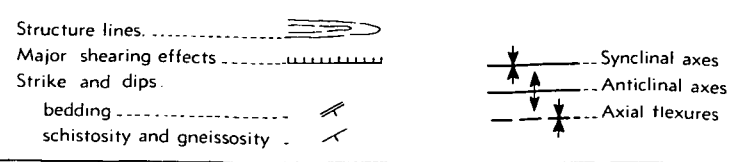


### REFERENCE

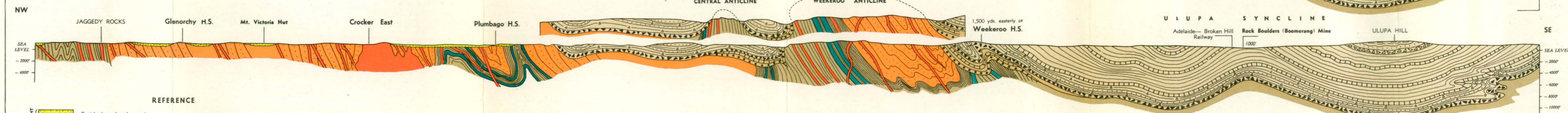
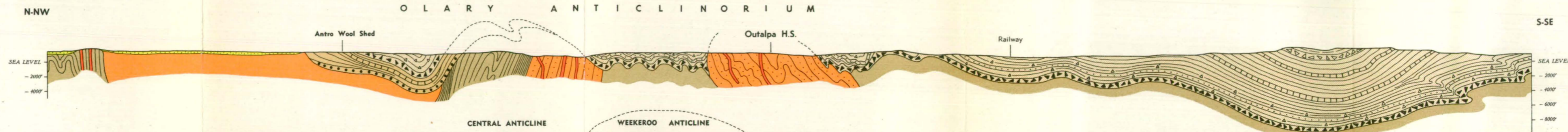
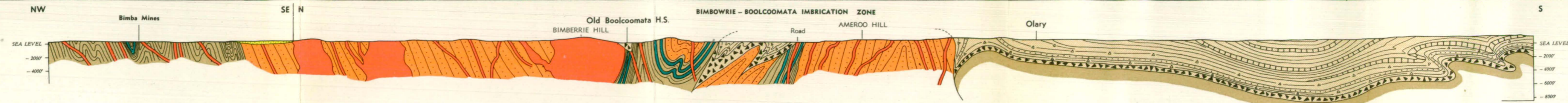


Palaeozoic folding of the sedimentary mantle (Adelaide System). Regular structures with moderate curvature at higher levels. Accentuated curvatures, with overfolding, wedge-shaped structures and shearing near the crystalline basement.

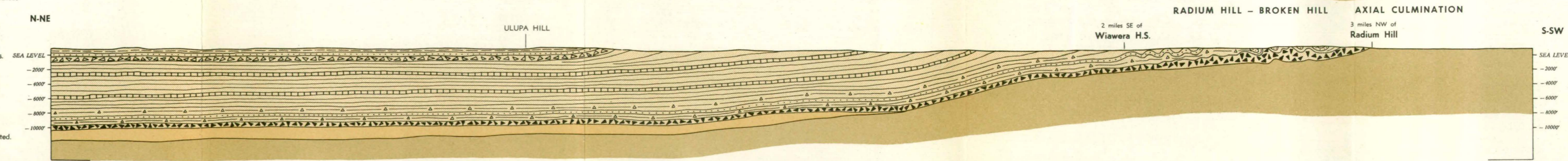
Folding of Precambrian orogenies. Wedge-shaped structures, thrusts and shearing of later orogenies, in particular of the Early Palaeozoic cycle.



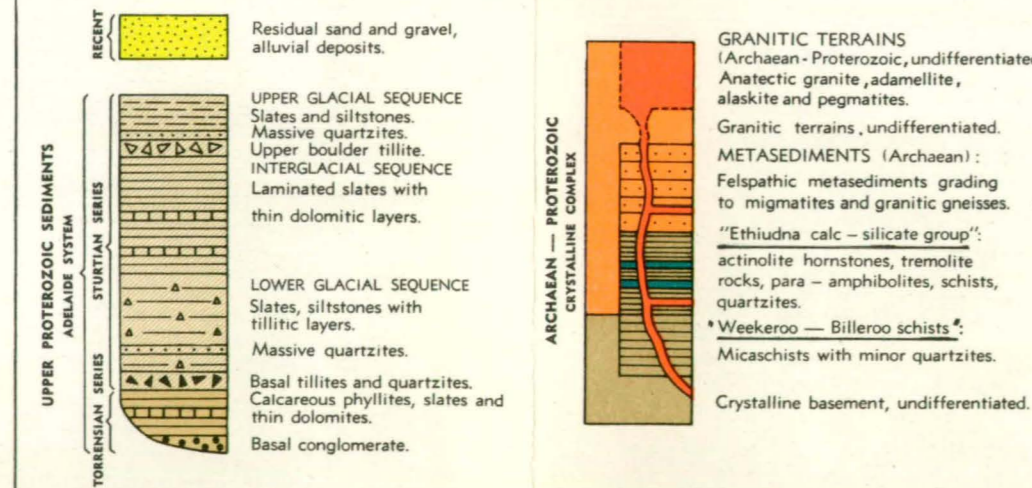
GEOLOGICAL SECTIONS  
ACROSS THE  
OLARY PROVINCE



LONGITUDINAL SECTION ALONG THE ULUPA SYNCLINE



REFERENCE





**COVERAGE BY AIRBORNE MAGNETOMETER AND SCINTILLOMETER**

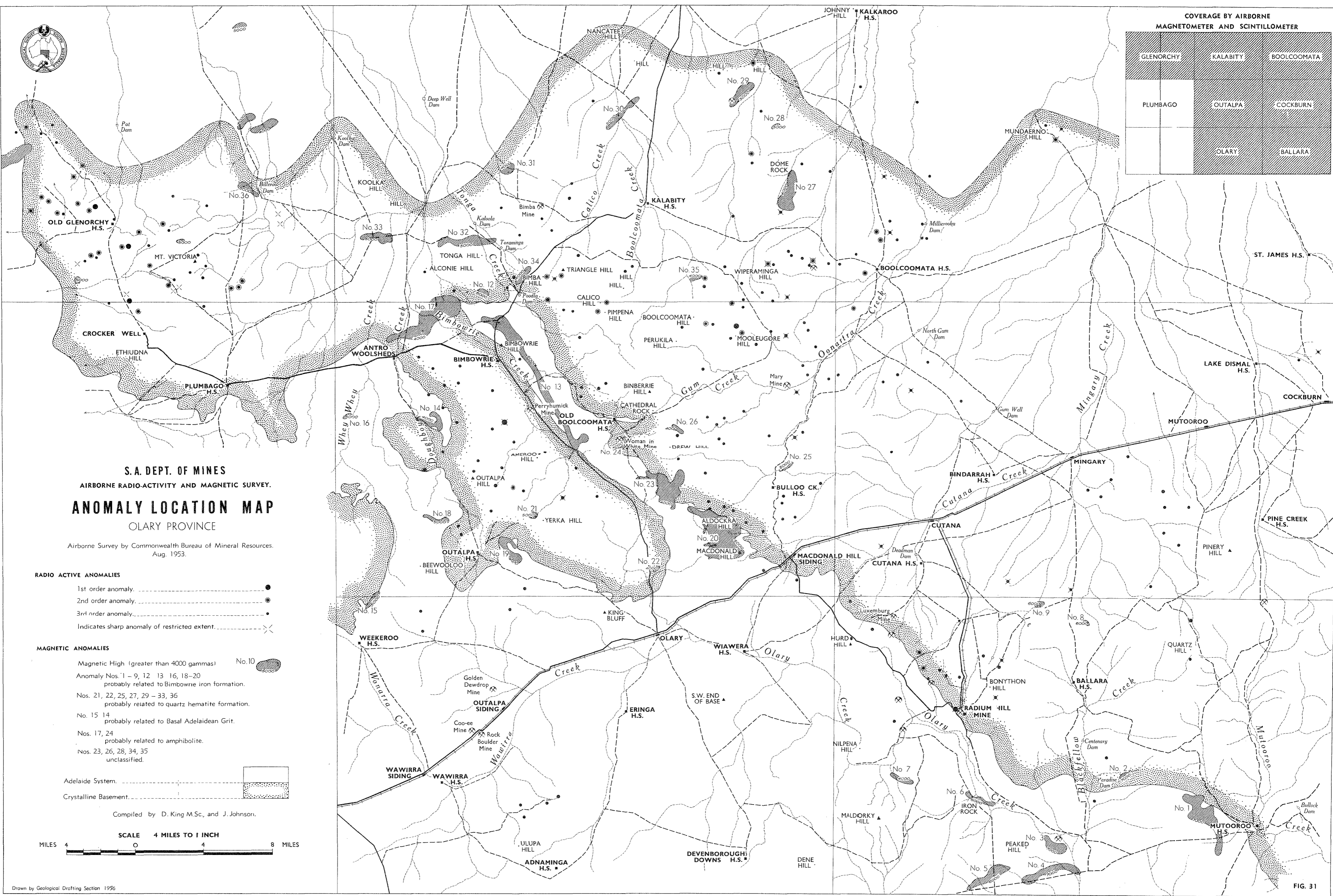
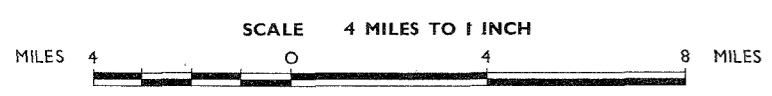
GLENORCHY	KALABITY	BOOLCOOMATA
PLUMBAGO	OUTALPA	COCKBURN
	OLARY	BALLARA

**S. A. DEPT. OF MINES**  
**AIRBORNE RADIO-ACTIVITY AND MAGNETIC SURVEY.**  
**ANOMALY LOCATION MAP**  
**OLARY PROVINCE**

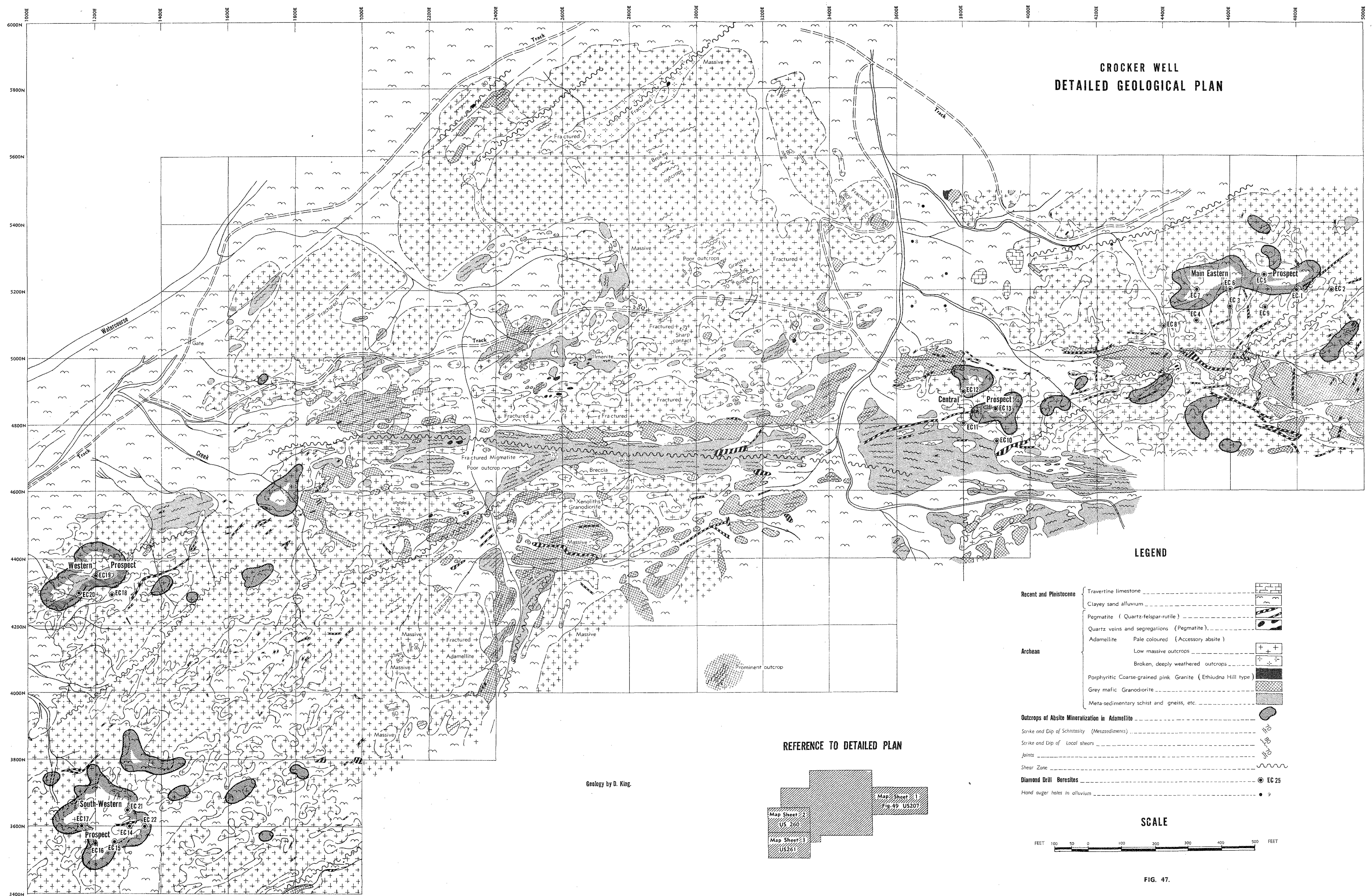
Airborne Survey by Commonwealth Bureau of Mineral Resources.  
 Aug. 1953.

- RADIO ACTIVE ANOMALIES**
- 1st order anomaly. ●
  - 2nd order anomaly. ○
  - 3rd order anomaly. ◐
  - Indicates sharp anomaly of restricted extent. ✕
- MAGNETIC ANOMALIES**
- Magnetic High (greater than 4000 gammas) No. 10
  - Anomaly Nos. 1 - 9, 12, 13, 16, 18-20 probably related to Bimbowrie iron formation.
  - Nos. 21, 22, 25, 27, 29 - 33, 36 probably related to quartz hematite formation.
  - No. 15, 14 probably related to Basal Adelaidean Grit.
  - Nos. 17, 24 probably related to amphibolite.
  - Nos. 23, 26, 28, 34, 35 unclassified.
- Adelaide System. ---
- Crystalline Basement. ---

Compiled by D. King M.Sc., and J. Johnson.



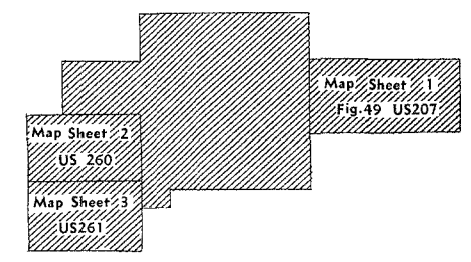
# CROCKER WELL DETAILED GEOLOGICAL PLAN



## LEGEND

<b>Recent and Pleistocene</b>	Travertine limestone	
	Clayey sand alluvium	
	Pegmatite ( Quartz-felspar-rutile )	
	Quartz veins and segregations (Pegmatite)	
	Adamellite Pale coloured (Accessory absite)	
<b>Archean</b>	Low massive outcrops	
	Broken, deeply weathered outcrops	
	Porphyritic Coarse-grained pink Granite (Ethiudna Hill type)	
	Grey mafic Granodiorite	
	Meta-sedimentary schist and gneiss, etc.	
<b>Outcrops of Absite Mineralization in Adamellite</b>	Strike and Dip of Schistosity (Metasediments)	
	Strike and Dip of Local shears	
	Joints	
	Shear Zone	
<b>Diamond Drill Boreholes</b>	Diamond Drill Boreholes	
	Hand auger holes in alluvium	

## REFERENCE TO DETAILED PLAN



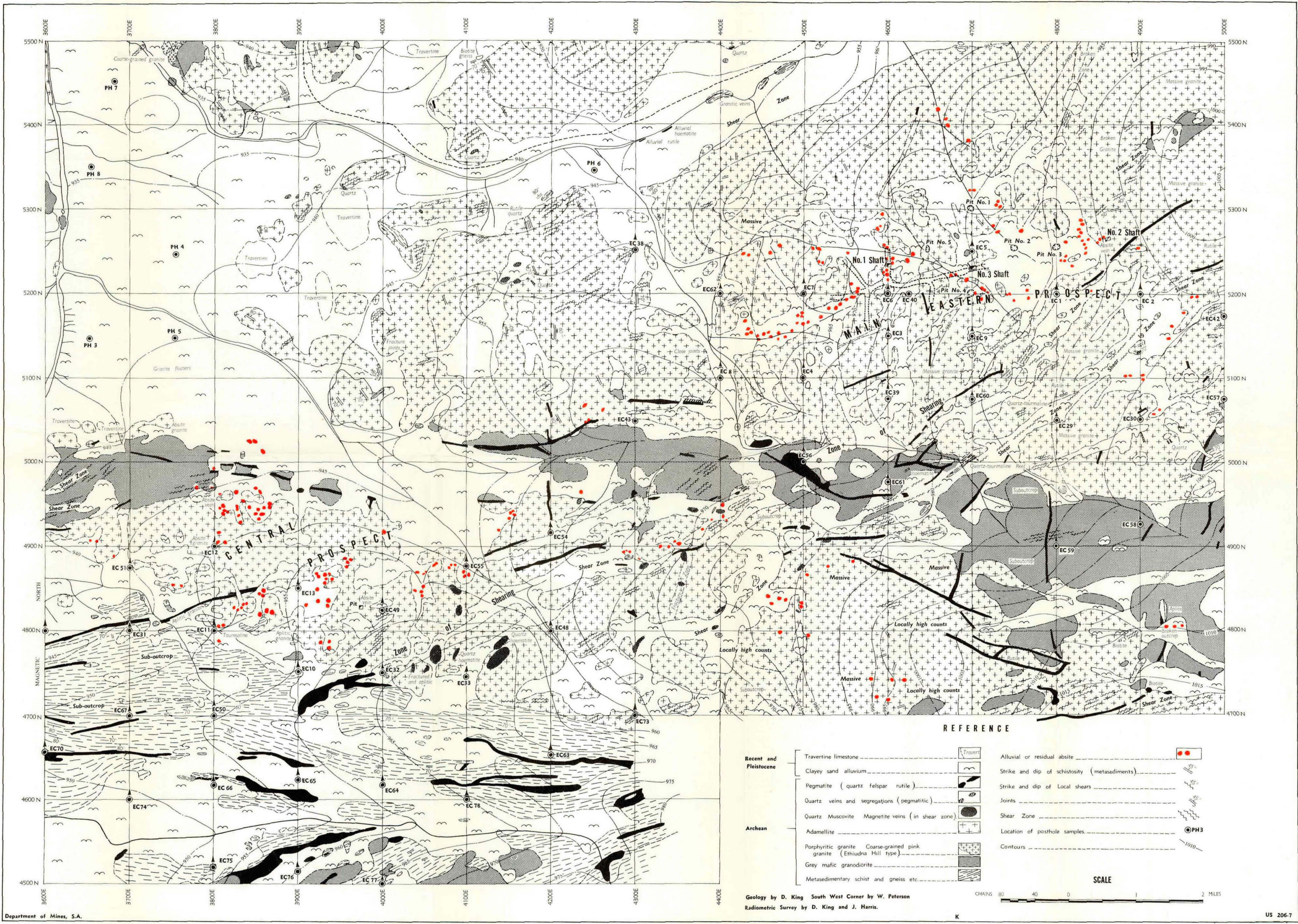
Geology by D. King.

## SCALE



FIG. 47.





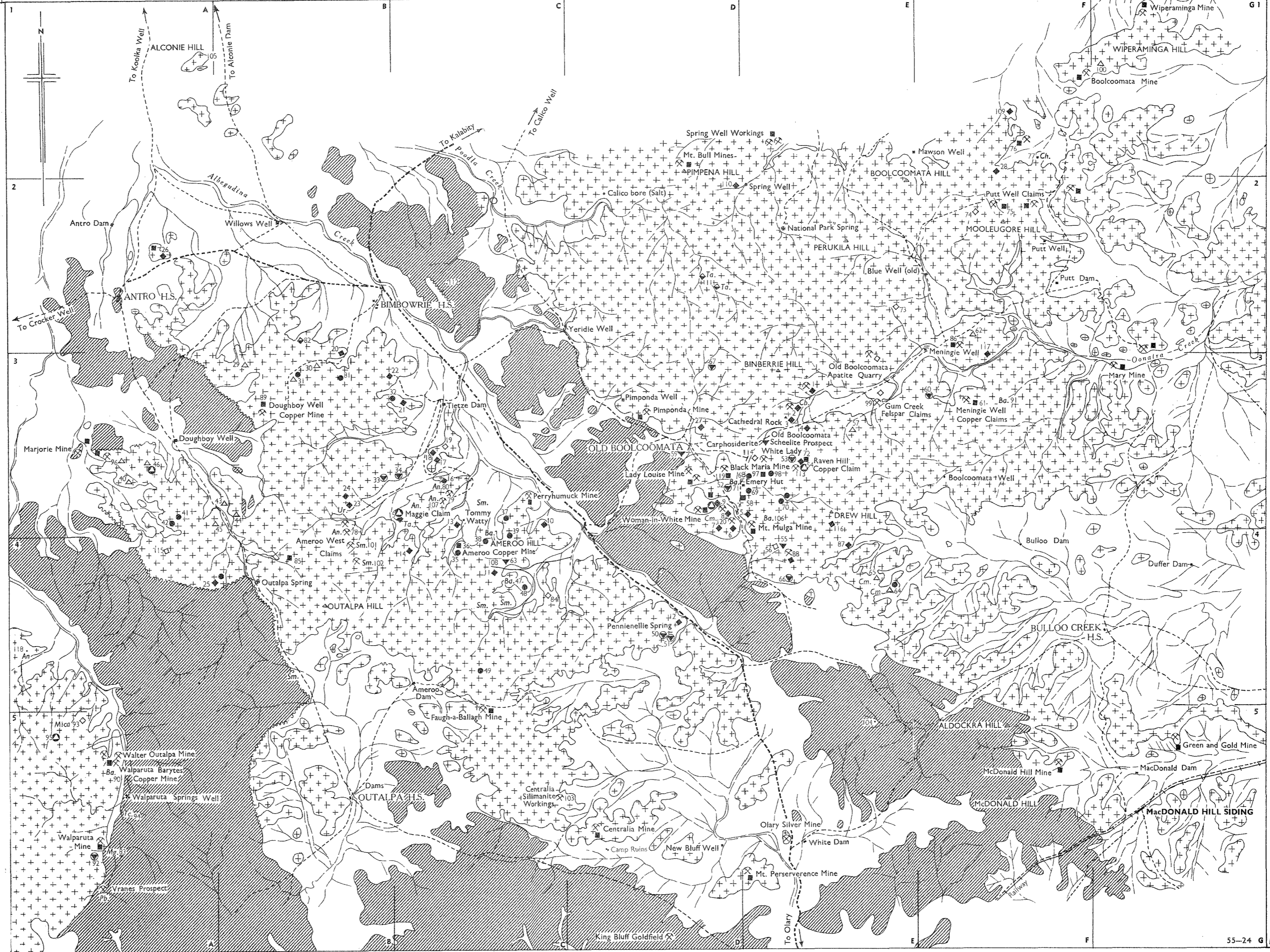
Department of Mines, S.A. K

**FIG. 49. CROCKER WELL MAIN EASTERN & CENTRAL PROSPECTS — SURFACE GEOLOGICAL PLAN**

H. J. WALL, GOVERNMENT PHOTOLITHOGRAPHER, ADELAIDE

BRIEF DETAILS OF MINERAL OCCURRENCES IN THE OUTALPA-BIMBOWRIE-OLD BOOLCOOMATA DISTRICT

Grid Reference	Location No. Outalpa Series	Description	Grid Reference	Location No. Outalpa Series	Description
E3	1	Quarry on feldspar pegmatite with beryl, grafonite and blue apatite.	D3	59	Scheelite grains in coarse garnet-actinolite skarn.
E3	2	Small quarry on feldspar pegmatite with beryl and columbite.	F3	60	Pegmatite with uranophane and ilmenite cutting epidote quartzite.
E3	3	Pegmatite with few small beryls.	F3	61	Shafts on copper-bearing shear with weakly radioactive jasper.
E3	4	Pegmatite with few coarse beryls.	F2	62	Davidite clots in quartz in granitised quartzite.
E3	5	Pegmatite with few small beryls.	F4	63	Detrital scheelite grains in garnet-actinolite skarn area.
D4	6	Quarry in feldspar pegmatite with beryl and rare fremontite.	E4	64	Davidite clots in quartz veins in epidote quartzite, near corundum gneiss.
D4	7	Pegmatite containing few coarse beryls.	E4	65	Davidite clots in quartz veins in epidote quartzite, near corundum gneiss.
D3	8	Quarry in feldspar pegmatite with few small beryls.	E4	66	Uranophane in biotite streak in hybrid gneiss.
D3	9	Quarry in feldspar pegmatite with beryl, samarskite and blue apatite.	D3	67	Uranophane in brecciated migmatite.
C3	10	Pegmatite with few loose beryls.	E3	68	Well formed xenotime prisms in small pegmatite in gneiss.
C4	11	Quarry in feldspar pegmatite with beryl, pyrite and turquoise.	E3	69	Coarse orthite and rutile in aplite band.
D4	12	Coarse pegmatite with beryl and green apatite.	E3	70	Coarse orthite with magnetite in quartz pegmatite.
C3	13	Pegmatite with small beryls, garnet and triplite intergrown with grafonite.	D3	71	Malachite stained beryls in pegmatites.
C4	14	Pegmatite with small radial beryl clusters.	E3	72	Malachite vein in epidote quartzite.
C3	15	Quarry in pegmatite with broeggerite, autunite, beryl and tantalite.	E2	73	Wagnerite in quartz pegmatite.
C3	16	Quartz pegmatite with few coarse loose beryls.	F2	74	Triplite and grafonite in pegmatite.
C3	17	Pegmatite with few small beryls and grains of tantalite.	F2	75	Malachite stains in epidote quartzite.
C3	18	Trench on pegmatite containing beryl and grafonite.	F1	76	Malachite in joints in granitised quartzite.
C3	19	Pegmatite with uranophane and Wagnerite.	F1	77	Chastolites in hornfels.
B3	20	Pegmatite with few large beryls and a radioactive mineral.	B4	78	Andalusite masses in schist. (Productive).
C3	21	Pegmatite with uranophane, beryl, Wagnerite and coarse triplite.	C3	79	Andalusite masses between schist and quartz pegmatites.
B3	22	Quarry in feldspar pegmatite with large beryls.	C3	80	Andalusite masses between schists and quartz pegmatites.
B3	23	Pegmatite with coarse beryls and uranophane stains.	B3	81	Monazite and crystalite in black sand layer in granitised quartzite.
B3	24	Pegmatite with coarse beryl, uranophane and Wagnerite.	B2	82	Fine ilmenite crystals in quartz pegmatite.
A4	25	Pegmatite with coarse radiating beryl. Coarse ilmenorutile nearby.	A5	83	Magnetite layers in talc-schist.
A2	26	Pegmatite with a few small beryls and malachite stains.	C4	84	Wagnerite in quartz pegmatite.
D3	27	Pegmatite with a few small beryls.	B4	85	Chalcopyrite grains in malachite-stained shear zone in gneiss.
F1	28	Pegmatite with florencite, specks of gummitte and few beryls.	F2	86	Malachite and azurite in shear at old copper mine.
B3	29	Very coarse davidite in quartz in granitised quartzite.	E4	87	Few beryls in pegmatite.
B3	30	Pegmatite with a little davidite.	E4	88	Few beryls in small quarry on feldspar pegmatite.
B3	31	Pegmatite with monazite grains, much magnetite and uranium ochre.	B3	89	Malachite in shear zone in gneiss.
B3	32	Well crystallised xenotime weathered out of pegmatite.	A5	90	Bed of barytes-quartz-magnetite rock.
B3	33	Uranophane stains in joints cutting red granite.	F3	91	Bed of barytes-quartz-magnetite rock.
C3	34	Uranophane stains in joint cutting red granite.	A5	92	Torbernite scales in joints in gneiss.
C4	35	Pegmatite with orthite and blue oligoclase in amphibolite.	A5	93	Pegmatite with much mica.
C4	36	Copper carbonate and epidotermine in joints in amphibolite.	A5	94	Bed of talc-schist.
C3	37	Gneiss containing grains of orthite, magnetite and fluorite.	A5	95	Samarskite and ilmenorutile in pegmatite.
C4	38	Bed of banded barytes-quartz-magnetite rock.	A3	96	Davidite in quartz veins in jointed grey laminated quartzite.
C4	39	Monazite grains in biotite clots in hybrid gneiss.	E3	97	Malachite in shear zone cutting gneiss.
A3	40	Few fragments of davidite shed from quartz seams.	E3	98	Ilmenorutile in quartz pegmatite.
A3	41	Coarse pegmatite containing monazite, xenotime and ilmenorutile.	E3	99	Quarry on feldspar pegmatite.
A3	42	Fine grained pegmatite containing grains of monazite and ilmenorutile.	G1	100	Davidite found on surface.
B3	43	Clot of davidite in quartz seam in grey laminated quartzite.	B4	101	Sillimanite lenses in mica schist (productive).
B3	44	Clots of davidite in quartz seams in grey laminated quartzite.	B4	102	Sillimanite lenses in mica schist (productive).
A3	45	Clots of davidite in brecciated grey laminated quartzite.	C5	103	Sillimanite lenses in schist (formerly productive).
A3	46	Clots of davidite in quartz seams in grey laminated quartzite.	E5	104	Bedded black iron ore in Adelaide system rocks.
C4	47	Bed of barytes-quartz-magnetite with chalcopyrite grains.	A1	105	Altered Chastolites in graphitic schist.
C4	48	Monazite and magnetite in biotite streaks in hybrid gneiss.	E3	106	Barytes, 6ft. wide with Magnetite grains, near copper mine.
C4	49	Gneissic granitised sandstone with crumpled heavy sand layer.	C3	107	Andalusite in schist (formerly productive).
D4	50	Uranophane stains in red discoloured granite.	C4	108	Corundum lying on surface.
D4	51	Uranophane in pegmatite.	F1	109	Beryl in pegmatite in staurolite-tourmaline schist (formerly productive).
D3	52	Uranophane stains in pegmatite cutting epidote quartzite.	D2	110	Beryl in pegmatites.
E3	53	Uranophane stains in patches in large irregular pegmatite.	D2	111	Tantalum minerals reported in pegmatite.
E3	54	Quarry in feldspar pegmatite with bright orange gummitte and apatite.	C2	112	Iron ore in Adelaide system rocks.
E4	55	Scheelite, detrital grains, in garnet-actinolite skarn area.	E3	113	Feldspar in pegmatite (productive).
E4	56	Pegmatite carrying intergrowth of triplite and grafonite.	E3	114	Feldspar.
E3	57	Davidite clots in pegmatite cutting grey flaggy quartzite.	A4	115	Good Feldspar in pegmatite.
E3	58	Shaft on quartz reef with copper ores. Alluvial gold found nearby.	E3	116	Beryl in pegmatite.
			A5	117	Beryl in quartz-mica pegmatite.
			D3	118	Andalusite at contact of schist and quartz-pegmatite.
			D3	119	Poor grade gritty graphitic mica-schist.
			D3	120	Corundum, in biotite-plagioclase gneiss.



REFERENCE	
Archaeon	Granites, Migmatites and Metasediments
Proterozoic	Tillites and Slates of the Sturtian Series
MINERAL DEPOSITS	
URANIUM MINERALS	<ul style="list-style-type: none"> <li>Davidite</li> <li>Complex pegmatitic minerals (Broeggerite, Gummitte, Samarskite)</li> <li>Secondary Minerals (Uranophane, Autunite, Torbernite, etc.)</li> </ul>
THORIUM MINERALS	Monazite, Orthite, Xenotime and Ilmenorutile
COPPER GOLD ORES	Chalcopyrite, Chrysocolla, Cuprite and occasionally Gold
TUNGSTEN ORES	Scheelite
LEAD ORES	Galena
TANTALUM-COLUMBIUM MINERALS	Tantalite, Columbite
BERYLLIUM ORE	Beryl
FELDSPAR	Perthite, Microcline
PHOSPHATES	Apatite and lesser Wagnerite, Triplite, Grafonite and Florencite
BARYTES	with disseminated Martite
ANDALUSITE - SILLIMANITE - CHIASTOLITE - (REFRACTORIES)	
CORUNDUM	
TALC	
MAGNESITE	
Mineral locality numbers of the Outalpa Series	
Mine workings	
Geological boundaries	
Tracks	
Creeks	

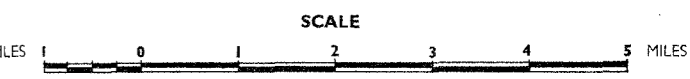
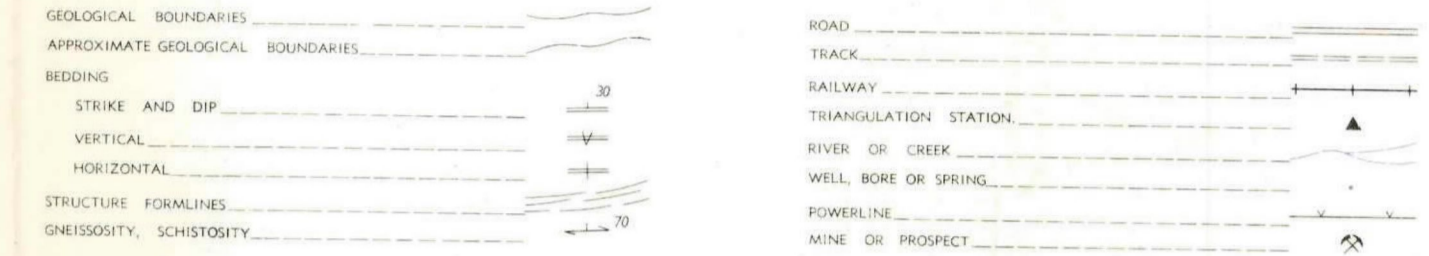


PLATE V—MINERAL MAP OF THE OUTALPA—BIMBOWRIE—OLD BOOLCOOMATA AREA

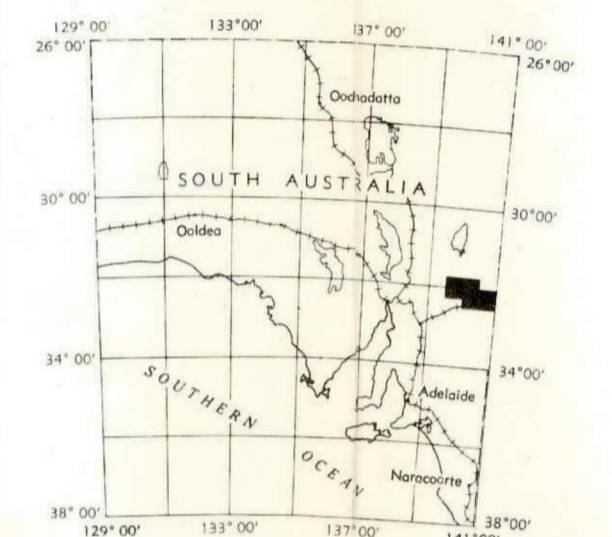
Compiled by D. King Geologist and J. Johnson Technical Assistant

# OLARY PROVINCE

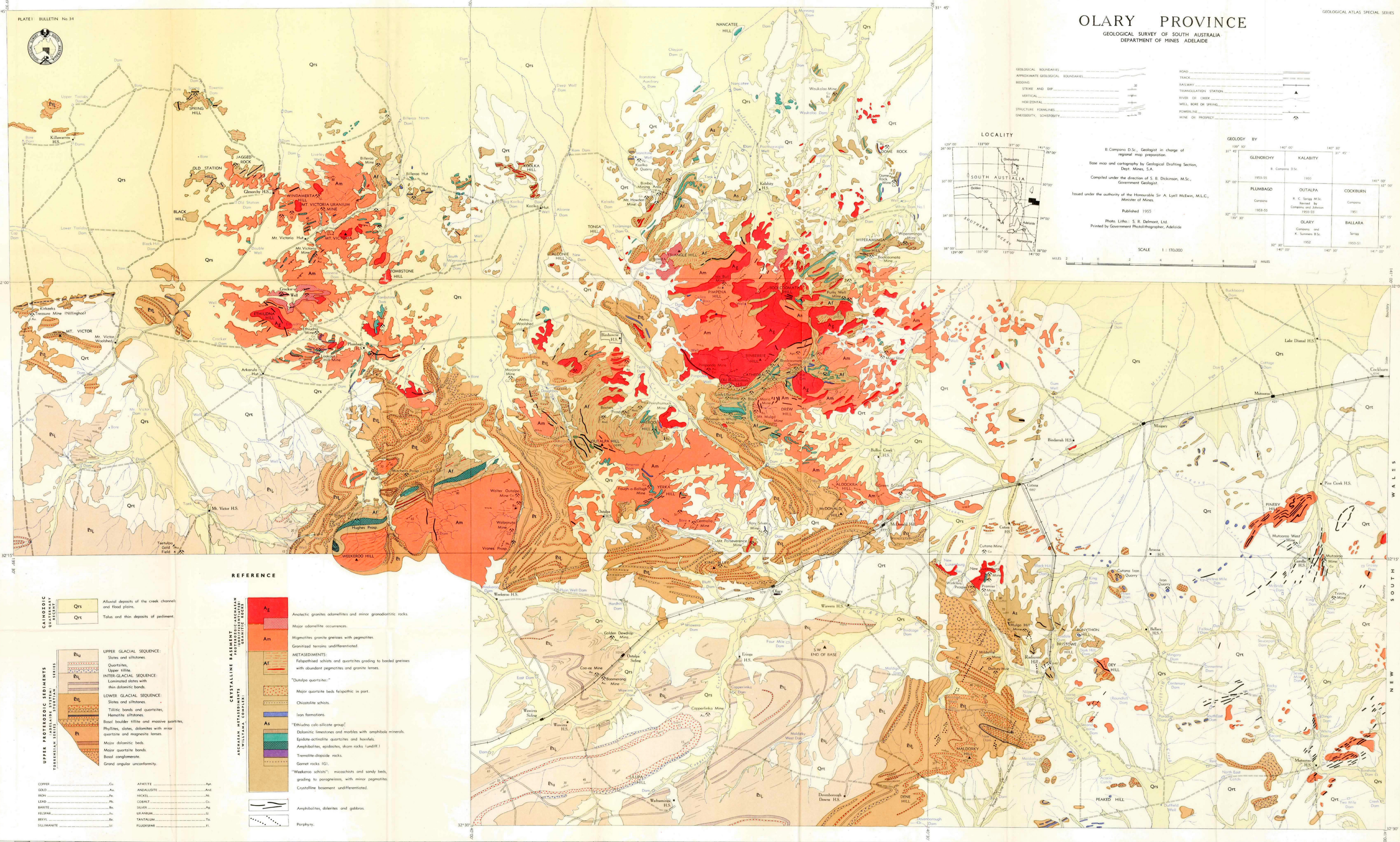
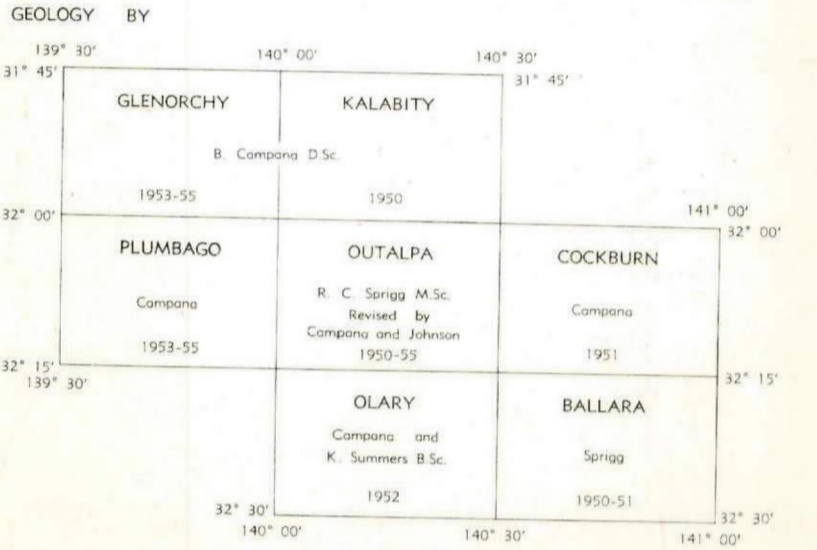
GEOLOGICAL SURVEY OF SOUTH AUSTRALIA  
DEPARTMENT OF MINES ADELAIDE



### LOCALITY



B. Campora D.Sc., Geologist in charge of regional map preparation.  
 Base map and cartography by Geological Drafting Section, Dept. Mines, S.A.  
 Compiled under the direction of S. B. Dickinson, M.Sc., Government Geologist.  
 Issued under the authority of the Honourable Sir A. Lyell McEwin, M.L.C., Minister of Mines.  
 Published 1955  
 Photo Litho: S. R. Dalton, Ltd. Printed by Government Photolithographer, Adelaide.



### REFERENCE

<b>CAINOZOIC QUATERNARY RECENT</b>	Qrs	Alluvial deposits of the creek channels and flood plains.
	Qrt	Talus and thin deposits of pediment.
<b>UPPER PROTEROZOIC SEDIMENTS</b>	Esu	UPPER GLACIAL SEQUENCE: Slates and siltstones. Quartzites, Upper tillite.
	Est	INTER-GLACIAL SEQUENCE: Laminated slates with thin dolomitic bands.
	Et	LOWER GLACIAL SEQUENCE: Slates and siltstones. Tiltitic bands and quartzites, Hematitic siltstones. Basal boulder tillite and massive quartzites. Phyllites, slates, dolomites with minor quartzite and magnetite lenses. Major dolomitic beds. Major quartzite bands. Basal conglomerate. Grand angular unconformity.
<b>ARCHAICAN METASEDIMENTS (WILLIAMA COMPLEX)</b>	A2	Anatectic granites adamellites and minor granodioritic rocks. Major adamellite occurrences.
	Am	Migmatites granite gneisses with pegmatites. Granitized terrans undifferentiated.
	Af	METASEDIMENTS: Felspathic schists and quartzites grading to banded gneisses with abundant pegmatites and granite lenses. "Outalpa quartzites". Major quartzite beds felspathic in part. Chistalite schists. Iron formations.
	As	"Ethudna calc-silicate group": Dolomitic limestones and marbles with amphibole minerals. Epidote actinolite quartzites and hornfels. Amphibolites, epibolites, skarn rocks (undiff.). Tremolite-diopside rocks. Garnet rocks (G). "Weekeroo schists": micachists and sandy beds, grading to paragneisses, with minor pegmatites. Crystalline basement undifferentiated.
		Amphibolites, dolerites and gabbros.
		Porphyry.

COPPER	Cu	AFATITE	Agr
GOLD	Au	ANDALUSITE	And
NICKEL	Ni	COBALT	Co
LEAD	Pb	SILVER	Ag
BAKITE	Ba	URANIUM	U
FELSPAR	Fs	TANTALUM	Ta
BERYL	Bc	FLUORSPAR	Fl
SILLIMANITE	Si		