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Hydrogeological ~~HYDROLOGICAL~~ INVESTIGATIONS IN THE AUSTRALIAN CAPITAL TERRITORY

by

G.M. Burton

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(Paper prepared for submission to Hydrology Sub-Committee, Institute of Engineers of Australia, for Cooma Meeting, May 1961).

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SUMMARY

Water bores are commonly used for supplying water to farms in the Australian Capital Territory and the adjoining areas of New South Wales. Most of the underground water comes from fractured and weathered zones of crystalline rock.

Geologists of the Bureau of Mineral Resources frequently site bores for local graziers and investigate groundwater drainage problems. In the course of this work they have systematically investigated the occurrence of underground water and the natural environment which controls it. They have paid particular attention to the genesis of the crystalline-rock aquifers.

This paper sets out the information gathered so far on the occurrence of underground water, and outlines the quantitative studies being undertaken into the properties of the aquifers and the quality of the water.

INTRODUCTION

General

Geologists of the Canberra Engineering Geology Group of the Bureau of Mineral Resources have ~~been~~ investigated systematically for the past seven years the occurrence of underground water in the Australian Capital Territory (other than the Jervis Bay area). This inland part of the Territory covers 880 square miles of the tableland and alps of south-eastern Australia.

A maximum of 2 geologists have been engaged part-time on this work which falls into three categories:

1. The location of groundwater supplies for farms and small settlements in the A.C.T., or in the immediately adjoining parts of N.S.W. under agreement with the New South Wales Geological Survey;

2. Studies of underground water as it affects engineering structures or gives rise to drainage problems;

3. Research into all aspects of the occurrence of water in crystalline rock.

The development of farm supplies is the most important and has received the greatest attention. Nearly all the bores for farm water supplies tap the crystalline-rock type of aquifer; this paper deals with the history of investigation, and the problems of development and assessment of these aquifers in the Territory and environs.

Crystalline rock aquifers and their importance

A crystalline-rock is defined for the purpose of this paper as one whose component grains have crystallized, recrystallized or compacted to give a dense fabric which possesses no significant intergranular porosity. Included under this definition are plutonic, hypabyssal and volcanic igneous rocks, marmorised limestones and metamorphosed or strongly recemented sediments in general. The aquifer properties of such rocks depend on the porosity and permeability of joints and fractures, modified in many cases by solution and weathering. Such aquifers are commonly less regular in extent and permeability than the better known aquifers provided by alluvial deposits or by sedimentary rocks.

Crystalline-rock aquifers are receiving progressively more attention for farm supplies in Australia. In the past, rural landholders have usually settled near perennial streams and springs and these, supplemented by roof-tanks, have been sufficient for their domestic, pastoral and agricultural needs.

The rural population is now spreading and exhausting the limited quantity of land with natural perennial surface supplies. At the same time farm domestic consumption of water is rising with the introduction of hot-water systems, washing machines, septic tanks, evaporative-type air-coolers, garden beautification and in some cases swimming-pools. Also, improvements in pastures and animal husbandry are requiring more and better spaced watering points; changes in farm economics are leading to diversification, most of which requires new water sources.

The main requirements for farm water-supply points in areas with an annual rainfall of more than 15 inches are that they should be economical, yield between 500 and 3,000 gallons per day and that the salt content should be less than 2,000 parts per million, and preferably less than 800 p.p.m. Such supplies must come from either bores or earth-dams.

Underground supplies of such specifications can commonly be obtained from shallow bores (80 to 250 feet) in crystalline rocks. These rocks, as defined earlier in the paper, cover considerably more than half of Australia including many areas where alluvial aquifers are scarce.

The difficulty of obtaining supplies of water within the above specifications by boring in crystalline rock becomes greater in areas of less than 15 inches rainfall, but in these areas lower specifications are often acceptable.

Table I shows the relative advantages and disadvantages of bores, as compared with wells, dams and roof-tanks, as a source of farm water supply in the A.C.T.

Literature on crystalline aquifers in Australia is scarce. Notable among the few published reports are those by officers of the New South Wales and South Australian Geological Surveys and by geologists of the Bureau of Mineral Resources working at Alice Springs and on the Barkly Tablelands of the Northern Territory. Most of the reports have dealt with large areas and it has rarely

TABLE I

RELATIVE MERITS OF A.C.T. FARM WATER SUPPLIES

	Earth-dam	Roof-tank	Bore	Well
Usual size	1500 - 2000 cub. yds. (250,000 - 350,000 gals.)	8,000 gals.	100 ft. deep	10 ft. deep
Cost: (1) Supply point	£300	£250	£400	£100
(2) Pump, motor and housing	£140	-	£320	£140
(3) Low tension electric supply per 100 yds.	£ 75	-	£ 75	£ 75
(4) Polythene piping to house etc. per foot.	2/3	-	2/3	1/9
(5) Total cost of equipment supplying to house 200 yds. from bore etc. and 100 yds. from power supply.	£590	£250	£870	£370
(6) Annual depreciation and maintenance.	£ 35	£ 15	£ 50	£ 10
(7) Pumping per 1000 gals. (a) to surface	-	-	6d ?	-
(b) to point further 100 ft. above.	3d ?	-	3d ?	3d ?
Loss of water by: (1) evaporation	High	Very low	Nil	Nil
(2) drainage	Low to very high	Nil	Nil	Nil
Effect of drought	Very serious	Serious	Noticeable but not serious	Noticeable, may be serious in very bad drought.
Supply per annum ∅	>300,000 gals.	20,000 gals.	> 300,000 gals.	50,000
Contamination: (1) Suspended matter	Strongly discoloured	Clear	Clear	Clear
(2) Animal pollution	Great	Slight to great by rodents and birds	Slight	Slight
(3) Human	Nil to great	Nil	Nil to great	Nil to great
(4) Industrial	Nil to great	Nil	Nil to great	Nil to great
(5) Mineral	Medium	Nil	Medium to great	Medium
Suitable for use by:	Stock, irrigation, septic tank	All purposes	Often all purpose; each bore should be tested before use.	Generally all purposes; each well should be tested before use.

∅ Average consumption per house: (1) Yass: 90,000 gals. per annum.

(2) Canberra: 140,000 gals. per annum.

been possible to enter the field of detailed quantitative analysis. The A.C.T. survey is of a small area wherein it will be possible for a geological staff working from a nearby well-equipped headquarters to carry out quantitative studies and detailed investigations. This paper gives a broad outline of what is being done in the hope of focusing further attention, and producing discussion, on this important type of aquifer.

History of underground water use and investigation

Underground water in the Australian Capital Territory has been exploited by both bores and shallow wells. The wells are the older form of exploitation; they number about 12 and are of little importance (yielding usually less than 150 gallons per day). In most cases it is impossible to gather any reliable information about them.

The earliest bores were sunk in 1946; the two preceding years' rainfall had yielded a total of only 31 inches instead of the usual 50 inches. The success of these bores led to many more being sunk in the succeeding years. To date 38 have been drilled and only 3 have failed to yield useful supplies of water (they yielded less than 150 gallons per hour for three-hour pumping periods). Table II gives further details of these bores, and Plate I shows their distribution in the Territory.

TABLE II

A.C.T. Water Bores to Dec. 1960

Country rock	Number of bores	Salinity range p.p.m.	Successful bores		Unsuccessful bores	
			Number	Average depth	Number	Average depth
Crystalline igneous	28	290-2240	26	95 ft.	2	69 ft.
Crystalline sedimentary	10	624-1560	9	236 ft.	1	345 ft.

Geological investigation of underground water commenced in 1944. In that year geologists of the Mineral Resources Survey (which preceded the Bureau) made several short surveys for bore sites for local graziers and government departments. In the next ten years, 19 bores were sunk in the A.C.T.; of these, 15 were sites selected by geologists of the Bureau and New South Wales Mines Department and 4 by water diviners. In the same period 11 bores were sunk in the immediately adjoining part of New South Wales on sites selected by New South Wales geologists.

The systematic study of the underground water resources in the A.C.T. started after the publication of the first detailed geological studies of the A.C.T. by Öpik (1954) and Noakes (1954) and the publication of the first comprehensive regional geological map - the Canberra 4-Mile Geological Sheet (1954). All existing bore records were collected and examined, and the sites were visited to relate them to the published geology and to the local topography. Many water samples were also collected for chemical analysis. The study of the information gathered was greatly assisted by J.W. Whiting's report (1953) on the underground water resources of the neighbouring N.S.W. Southern Tablelands.

The second stage of the investigation was the drilling by graziers of 25 sites selected by the Bureau's geologists between 1955 and December 1960; of these sites 15 were in the A.C.T. and 10 in New South Wales. These bores were logged and their yields assessed. The first of these bores showed that the bailing method of testing bores had severe limitations and as used locally often gave unreliable results. L.C. Noakes (then Supervising Geologist, Engineering Group) and the writer designed mobile pumping equipment to carry out more reliable and longer tests; this equipment was obtained in December 1957 and has been in regular use since. Recent tests have been conducted mainly by E.G. Wilson who has modified the equipment and reported on the tests to date (Wilson, 1960).

The third stage was the drilling, in December 1959, of a group of 4 experimental bores by the Bureau to obtain more reliable information on long range pumping characteristics of bores, to investigate changes in water quality and seasonal fluctuations in the piezometric surface and to study the applicability to the local crystalline-rock type aquifers of methods developed overseas for determining aquifer constants. This work, together with similar work on all local unequipped private bores, is continuing.

NATURAL ENVIRONMENT OF UNDERGROUND WATER

Geology

The Australian Capital Territory lies in a belt of Lower Palaeozoic rocks which trend northerly through south-eastern Australia. This belt is the remnant of Lower Palaeozoic sedimentation and vulcanism associated with the Tasman Geosyncline, which was the controlling structural feature in eastern Australia during Palaeozoic time. The oldest known rocks are Ordovician, but the presence of Cambrian rocks is suspected.

The oldest sediments of the sequence are mainly deep-water fine-grained slope and trough greywackes, slates and claystones which were strongly folded and faulted by the Benambran Orogeny at about the close of Ordovician time. This orogeny led to the rise of a geanticline in the vicinity of Canberra and a local change from trough to shelf sedimentation. As a result the Silurian Period is represented in the A.C.T. by shale, sandstone, limestone and volcanic rocks. The close of the Silurian Period was marked by increasing vulcanicity: igneous activity changes from some tuffs in the Lower, to more plentiful tuffs and flows in the Middle, and finally numerous flows, tuffs and intrusions in the Upper Silurian.

The Bowning Orogeny strongly fractured the Silurian and Ordovician rocks which lay at fairly shallow depths (much less than 10,000 feet). It also consolidated the Canberra Welt (Noakes, 1954) which underwent little tectonic dislocation after the close of the Silurian.

The Devonian is mainly represented by volcanic rocks which are very similar petrologically to the Silurian. There is, however, a marked difference between the rocks of the two ages in the area east of the Murrumbidgee where they may be recognised by the degree of their deformation; the Silurian rocks are strongly fractured whereas those of Devonian age are relatively unfractured because they were protected from the effects of the Tabberaberan Orogeny by the stability of the underlying welt. West of the Murrumbidgee Devonian rocks were not on the welt and Silurian and Devonian rocks differ little in structural deformation.

The post-Devonian is represented in the Territory only by some local thin gravel deposits, by Cainozoic alluvium and by widespread soils, some of which are 15 ft. thick.

Topography and physiography

The central topographic feature of the A.C.T. is the north-flowing incised Murrumbidgee River. Into it from the east flows the Molonglo River and its tributaries, the Queanbeyan River and Jerrabomberra Creek, which drain the hill and plain country (elevation 1800 to 2700 feet) around Canberra and the Gourock Highlands (2300 to 5300 feet) to the east and south of Canberra. The country to the west of the Murrumbidgee is rugged and mountainous (2000 to 6000 feet); it is drained by the Cotter, Paddy's, Gudgenby and Naas Rivers.

The physiographic evolution of this region has been discussed frequently in geological literature, but so far no completely satisfactory account has been published.

Certain broad general features which are useful for the hydro geologist can be noted, however:

1. Much of the hill and plain country around Canberra (in what Öpik (1960) calls the Canberra Rift) is essentially an old Lower Devonian mature land surface modified by long slow weathering, including Tertiary lateritisation. The surface shows fairly recent rejuvenation in the area adjoining the Murrumbidgee River. The hill and plain country was also subject to considerable periods of wasting and soil formation in Pleistocene and Recent time.

Öpik's (1960) thesis that the plains around Canberra were in the Silurian Rift and were protected from strong erosion from Devonian time onwards is accepted by ~~me~~ the writer.

2. The mountains west of the Murrumbidgee are comparatively youthful but possess puzzling areas of more mature topography, notably the Gudgenby and Paddy's River valleys and the Uriarra area.

3. The highlands east of Canberra are mature but possess fewer superficial deposits and show more rejuvenation than the Canberra plains.

4. The highlands south of Canberra appear to be a unit containing many of the mature features of the Canberra Plain and some of the more youthful features of the eastern highlands.

A better knowledge of the evolution of the physiography would be very helpful. The hydrogeologist working on crystalline rocks is primarily concerned with the upper 200 feet of the earth's crust and is interested in the nature and duration of the processes which have not only formed the topography, but also modified the underlying rocks and their ability to hold and convey water.

The problem is not easy and must await more detailed geological mapping and geomorphological work (it will be remembered that the first regional geological reconnaissance survey was completed only seven years ago). This emphasises the point that the essential basis for hydrogeology is detailed geology and geomorphology.

Climate

The Australian Capital Territory lies in a meteorological zone in which the rainfall is both reliable and evenly distributed throughout the year (Plate II). Most of the Territory receives an average rainfall of between 18 and 25 inches per year. There are mountainous areas in the west, however, which receive as much as 60 inches of precipitation (including snow) per year. Most bores lie in an area having an average of 25 inches of rainfall per year; evaporation in the same area averages 51 inches per year.

OCCURRENCE OF UNDERGROUND WATER

Water Provinces

The underground water regime of any area is dependent on:

The nature of the aquifer(s);

Discharge and recharge of the aquifer(s).

The nature of the aquifers and their discharge is governed by the geology and geomorphology . The recharge, and to a lesser extent the discharge, is governed by climate. Detailed work so far has led to division of the Territory into six provisional provinces (Plates I and Ia), each with slightly different regimes depending on combinations of climate, geology and geomorphology. These combinations are set out in Table III. Practically all bores have been sunk in the Ridge and Plain, and the West Gourock Highlands Provinces, which are the most closely farmed parts of the A.C.T. Fortunately, these are the areas where good supplies of water are easiest to find. The Ridge and Plain Province is the one in which most of the Bureau's research work has been done, and about which we now know most.

Aquifers

Underground water occurs in the following aquifers which are listed in increasing order of importance:

1. Alluvium
2. Soil and decomposed rock
3. Porous sedimentary rocks and tuffs
4. Fractured and jointed crystalline-rock.

Alluvial aquifers are confined to small areas along the main rivers. There is little need to develop these aquifers because the rivers are perennial and supply all water required.

Most of the Territory is covered by a thick mantle of soil and weathered rock which carries large quantities of water. The mantle has a rather low permeability and is not exploited directly by bores. It is considered that this mantle acts as an excellent reserve, and contributes significant quantities of water to the main deeper rock-aquifers. Most of the dozen wells in the Territory have been sunk in the soil mantle and bottomed on the surface of the decomposed rock. They usually yield about 50-200 gallons per day.

TABLE III

A.C.T. UNDERGROUND WATER PROVINCES

Province	Topography	Principal rock types	Approx. annual precipitation (inches)	Aquifers ✓ Good	Aquifers ✓ Doubtful	Aquicludes ¥	Aquifuges ✗	Depth of piezometric surface.	General salinity range. (p.p.m.)
East Gourock Highlands	Mature valleys rejuvenated in lower reaches; well defined but rounded ridges.	Strongly folded quartz greywacke, siltstone & slate.	25-27	Greywacke & siltstone	Slate, porous soils	Clay soils, weathered shale.	Shale	5-50'?	700-2000
West Gourock Highlands	Mature valleys rejuvenated in lower reaches; well defined but rounded ridges.	Volcanic and intrusive porphyries, shale and limestone.	18-24	Stressed porphyries	Unstressed porphyries, granite, limestone, porous soils.	Clay soils	Shale	5-50'	300-2,000
Canberra Ridges and Plain	Mature undulating plain country with ridges of more resistant rock. Shows rejuvenation near the Murrumbidgee River.	Sediments, volcanics and porphyry intrusions.	24	Stressed porphyries, volcanics and competent sedimentary rocks; coarse alluvium.	Unstressed volcanics, porphyries, granite, porous soils and alluvium	Clay soils, alluvial clay.	Shale	0-50'	300-2,000
Murrumbidgee Scarp	Isolated ridge with moderately deep dissection	Hornfels, siltstone, greywacke, slate and granite.	18-30	-	Hornfels, greywacke, stressed granite and scree pockets.	-	Unstressed granite?	20-100'	?
Paddy's River and Gudgenby	Rounded ridges and moderately broad valleys. Rejuvenated near Murrumbidgee River.	Gudgenby - granite. Paddy's River - Granite and volcanics.	30-35	Stressed or close jointed granite and volcanics.	Porous soils and weathered granite and volcanics.	Clay soils	Unstressed granite	0-100'	300-2,000?
Bimberi Mountain	Rugged mountainous country	Granite and highly folded greywacke, siltstone and slate.	35-60	-	Greywacke, siltstone, stressed granite, volcanics, porous soils, and scree pockets.	-	Unstressed igneous rocks?	0-150(?)	300-2,000?

✓ Aquifer: a geological formation which is capable of transmitting appreciable quantities of water under normal field conditions

¥ Aquiclude: a geological formation which may contain groundwater but is incapable of transmitting significant quantities of it.

✗ Aquifuge: a geological formation which neither contains nor transmits groundwater.

Numerous seeps or springs on hill slopes arise from certain known soil horizons and these not only commonly provide small stock watering points but give rise to bad drainage areas which can create difficulties in highway and building construction. Many earth-dams draw some of their supply from these seeps and benefit considerably from the increased rainfall run-off from the wet seep-areas. Most local earth-dams have been sunk in the past 10 years when there has been above average rainfall (Plate II), and probably a great direct and indirect contribution by these seeps. The writer considers that a short to medium drought would dry up most of these seeps. This could produce a surprisingly sharp drop in the efficiency of those earth dams that do not make use of creek flow or run-off from artificial surfaces such as roads and drains.

Porous sedimentary rocks and tuffs are of only minor importance. Little is known of their occurrence except that they are most likely to be found in the Upper Silurian Deakin Volcanics and that they will probably have a fairly low yield of about 300 gallons per hour.

The fractured and jointed rock type of aquifer supplies practically all of the underground water in the A.C.T. This is because of the wide distribution (Plate I) of competent crystalline-rocks which lay at shallow depths in the earth's crust and were stressed by two and, in some areas, three major orogenies. The joints and fractures created by these orogenies have developed and enlarged during the physiographic evolution of the region. Most of the rock aquifers have been within the influence of strong weathering and have been subjected to several major periods of glacial and peri-glacial conditions during the 300 million years since Devonian time. This has resulted in considerable opening of joints by rebound in the hilly areas and exfoliation of sheeting joints in the near-surface zone of rock over most of the unrejuvenated country.

Geological conditions for the development of crystalline-rock type aquifers could rarely be better than those found in the Canberra Plain area. This, coupled with the good rainfall recharge conditions of the area and relatively shallow piezometric surface, explains why geologists rarely select unsuccessful bore sites in this area.

Infiltration and Fluctuation of the Piezometric Surface

The question of infiltration and fluctuation of the piezometric surface in the Southern Tablelands is one which has received little attention in the past. The only known reports are Basinski's (1957) study of the hydrology of the Yass Valley and Wood's (1959) study of the urban run-off in Canberra. These, however, provide little useful data as far as hydrogeological work is concerned. The Department of Works officers have also prepared unitgraphs for the Molonglo River, but the geological complexity of its catchment makes the application of these to detailed hydrogeological work almost impossible.

Consequently, much of the Bureau's work has been directed towards direct studies of the fluctuation of groundwater level and the associated rainfall, and to compiling records such as the fluctuations of Lake George (which is a closed drainage system and hence an excellent indicator of the balance between evaporation and rainfall), and cumulative rainfall variation diagrams of local weather stations (Plate II). Plate III shows the fluctuations of water level at the Bureau's Belconnen experimental bore (C.S.I.R.O. Farm) and also the local cumulative rainfall variation from January 1959 to December 1960. Larger scale office graphs of these and other bore water-levels plotted together with their respective bi-weekly rainfall records are beginning to yield information on the rainfall threshold necessary for recharge.

C.S.I.R.O. workers are operating neutron soil-moisture logging equipment at five holes near the Bureau's Belconnen bore. Some of these holes penetrate to bedrock and their results should provide valuable supplementary information on infiltration.

The Bureau hopes to purchase in the near future a long-period continuous recording unit recently developed by C.S.I.R.O. workers (Summer, 1959) which can be fitted with a pluviometer and a bore depth - measuring unit. This rnit should be invaluable in local infiltration studies.

It is interesting to note in Plate III that for the past two years there has been no significant dry period which would provide valuable information on the decline of the piezometric surface. This gives some idea of the length of time required to build up useful records. In the absence of such records it is necessary to search for long-range records such as Lake George levels, or cumulative rainfall records of old local weather stations which will give an indication of probable fluctuation. A graph of Lake George levels (Noakes, in preparation) and Sydney and Queanbeyan rainfall variations dating back to 1820 is given in Plate II. A point of interest in connexion with the cumulative rainfall variation graph is that the rivers around Queanbeyan (which depend on groundwater flow for most of the time) dried up in 1906. Also, that some of the worst drainage problems in the A.C.T. arose in 1958 and 1959.

Siting of Bores

The siting of bores in most of the Territory is primarily a question of cost of drilling and of the nature of jointing in the immediate area.

Cost and difficulty of boring is of great importance. The fresh crystalline-rock in zones where joints are few can be so hard that drilling is expensive and in some cases impracticable: it is important for the geologist to select a site which will encounter the minimum section of the hardest rock.

The usual procedure is to consider the local recharge of the area and the topography and then to estimate from previous experience the depth to the piezometric surface (the surface has a slope of about 1 in 30 to 1 in 40 over most of the plain country). A site is then selected to encounter joints or fractures 20 to 50 feet below the piezometric surface and to have the maximum thickness above this of soil and weathered rock which is very easy to drill.

The procedure when searching for joints and fractures in the sedimentary rock such as the Ordovician is to find first a suitable sequence containing sufficient competent rock, which fractures easily, and then to locate the bore site in faulted or suitably folded and fractured areas of it.

In the igneous fractured rocks the problem, commonly, is to determine whether the exfoliation sheeting, and rebound joints are well developed and lie sufficiently far below the piezometric surface to give a good hydraulic head. If they do, they are the natural drilling target because they have the greatest permeability and generally the most direct recharge; they carry the lowest salinity water (usually 200 to 400 p.p.m.).

If the shallow joints lie above the piezometric surface it is necessary to proceed with caution and to try to find an area which contains igneous contraction joints or tectonic joints from 40 to 100 feet below the piezometric surface. This usually requires careful field work, particularly if the area is underlain by little-fractured late-Silurian intrusives or Devonian volcanics.

Plate IV illustrates three sites in typical crystalline igneous rock in hill and plain country around Canberra.

Site C is the least desirable site. It has poor local storage and poor recharge because much of the rainfall is carried away from the area by overlying, more permeable, surface-joints and weathered rock (Zone 2). Drilling will commonly be relatively easy because of the depth of weathering. The bore will not encounter the piezometric surface until it is in the zone of few tectonic or contraction joints. The piezometric surface will be subject to considerable fluctuations and the bore may fail in drought.

Site B is the most desirable site. It has the greatest thickness of soil, talus, lateritic products and decomposed rock (Zone 1). The piezometric surface is shallow and in places and at times artesian conditions occur. The bore will encounter the surface jointing and weathered permeable rock of Zone 2 at sufficient depth below the piezometric surface. The best water supply is in the open joints of the slightly weathered rock at the base of this zone. The aquifer is subject to good recharge on the hillside, has rapid water velocity and is subject to periodical flushing when surplus water escapes rapidly as springs in very high rainfall periods. It will not encounter much very hard fresh rock. It is likely that at Site B fresh surface water moves as almost a separate layer over the slower moving deeper water; heavy pumping in dry periods may produce an increase in salinity by invasion of deeper water. Assessment of yield at this site should take into consideration possible fluctuations of as much as 10 feet (on present knowledge) in the piezometric surface.

Site A is less desirable than B but more desirable than C. Zone 1 (soil and very decomposed rock) may be thin. Zone 2 (surface jointing and weathered rock) may have been partly removed by rejuvenation and the vertical joints may have been confined more in the absence of topographic relief. The bore will depend for its supply on water in the few tectonic and contraction joints of Zone 3. Water in this zone will be more stagnant and have a higher salinity. The piezometric surface is not likely to fluctuate much. The major creek is generally an effluent stream and unlikely to assist recharge or reduce salinity of most bores on the plain.

Zone 4 has not been discussed in regard to any of these sites. It is the zone, commonly deeper than 250 feet, in which joints are so few and tight that the chance of obtaining water is very low. Bores which reach this zone without encountering water should be abandoned and a fresh start made elsewhere.

Faulting must be considered carefully in Canberra where both high angle reverse faults and normal faults occur. The reverse faults may be tight and may not yield water. It is better to site the bore in the adjoining subsidiary fractures if the fault has been determined as a reverse or compressional fault or if the nature of the fault is uncertain. One of the unsuccessful bores near the A.C.T. may be entirely within a tight compressional fault zone.

Plate V shows three pumping test graphs. The first is that of a bore situated towards the top of a divide; it is not as extreme a case as Site C. The second graph is that of a bore in a similar situation to B, in near artesian conditions. The third graph is of a site in lower flat country, similar to Site A.

Water Movement between Drainage Basins

The divides between most of the major creeks and rivers in the A.C.T. have a relief of more than 300 feet. It can be seen in Plate IV that in such topography the topographic divide will coincide with an area in which the groundwater zone is divided by an elevated zone of low permeability. The underground water therefore of all surface drainage basins commonly follows the trend of surface drainage and much of it emerges in the effluent stream of its own basin; considerable quantities of the underground water, however, will pass on as underflow in the joints and fractures along the river floor.

Interesting exceptions which may give rise to strange salinity variations occur in areas such as near Kambah where one finds assymetric divides between the rejuvenated Murrumbidgee River and its nearby unrejuvenated higher tributaries. The permeability divide is less pronounced and considerable quantities of saline water are likely to cross beneath the topographic divide from the mature areas and flow underground into the more youthful Murrumbidgee River valley.

Water Quality

The nature of underground water in the Territory is best illustrated by the cation and anion triangular diagrams of Plate VI. These show the water to vary from a bicarbonate to a bicarbonate-chloride type. Calcium and magnesium are the predominant cations.

This is to be expected because the groundwater is circulating for a relatively short time at shallow depth in well-leached ground in a temperate climate.

Selected analyses of underground and surface waters from the A.C.T. and nearby N.S.W. are given below in Table IV.

TABLE IV

WATER ANALYSES

Source	Total dissolved salts (p.p.m.)	Conductivity 25° C (/u mhos/cm.)	pH	Sodium Adsorption Ratio	Radical (Milliequivalents per litre)						
					Ca	Mg	Na	K	HCO_3	SO_4	Cl
Igneous rock-good water	290	450	7.3	1.0	1.3	0.9	1.1	-	2.7	-	0.8
Igneous rock-medium water	800	1200	7.0	1.5	7.1	4.8	3.6	-	8.6	1.0	5.1
Igneous rock-worst water	4265	?	8.1	1.5	12.1	38.2	7.4	-	12.4	31.5	14.0
Ordovician sediments-medium water	734	?	8.1	1.7	7.5	5.1	4.2	-	9.0	1.0	6.5
Ordovician sediments-poor water	1560	2100	7.0	2.3	9.6	9.1	7.4	-	10.3	6.4	9.0
Lake George, N.S.W.	1286	2270	8.0	13.0	1.2	2.7	18.1	0.1	4.4	1.6	16.6
Lake Bathurst, N.S.W.	714	1310	9.3	6.9	0.8	2.5	8.7	0.5	2.8	0.4	8.8
Molonglo River, Canberra.	c. 90	220	8.3	0.9	0.5	0.5	0.6	-	0.8	-	0.7

The frequency of bore waters within the salinity range (0-2200 p.p.m.) in the A.C.T. and nearby N.S.W. is illustrated in Fig. 1. The only available analysis not shown in this diagram is the 4265 p.p.m. sample shown in Table IV which was omitted for convenience. The high frequency in the 200-400 p.p.m. range is partly explained by the fact that geologists now understand the distribution of these shallow fresh supplies and are siting more bores to cut them.

Several waters have been analysed for boron and fluorine but these have been shown to be very low.

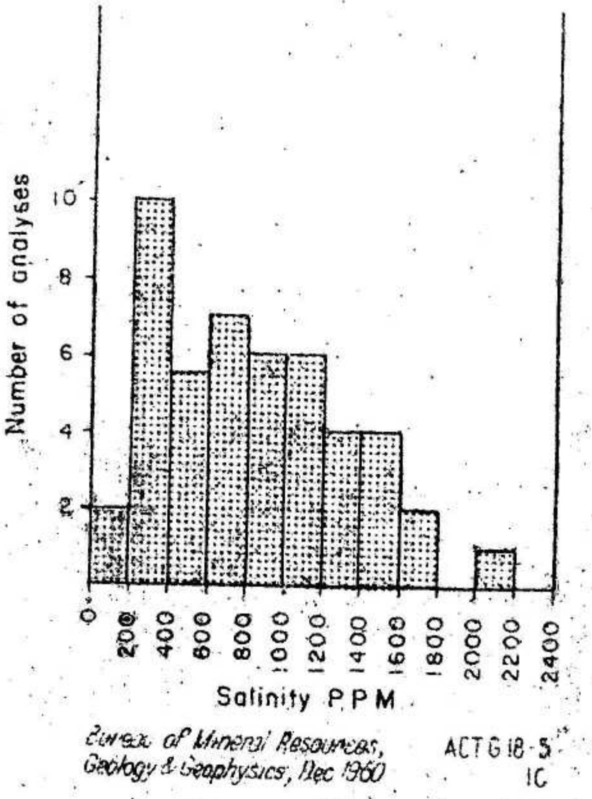
Few bores have been checked for bacteriological pollution in the past mainly because local bore water has rarely been used for human consumption. The Bureau is at present systematically sampling all bores in the Territory. It is intended to find the polluted bores and then investigate the source and path of pollution in each case. This will provide a means of studying the general question of pathogenic pollution in crystalline-rocks.

Chemical and industrial pollution has provided a bigger hazard than one would be inclined to expect in a predominantly rural region; however, the hazard is probably low. Three cases are worthy of mention as they illustrate exceptional cases of pollution which can occur. The first is the possibility of pollution of alluvial aquifers along the upper Molonglo River in N.S.W. Some years ago the retaining wall of the slimes dump at the Captain's Flat Mine collapsed and considerable quantities of lead, zinc and copper tailings were swept down over the flats near "Carwoola" 10 miles downstream. Another case is the siting of bores near sheep sheds where considerable quantities of poisonous sheep-dip are regularly discharged. The third case is one of what might be regarded as industrial bacteriological pollution - a night-soil burial ground and can-laundry was found just outside the limits of an area being investigated for underground water supplies. This depot was not shown on detailed topographical maps of the area; it lay in N.S.W. across the border from the area which was being surveyed in the A.C.T.

FIGURE I

WATER SALINITY HISTOGRAM

A.C.T. and Environs



UNDERGROUND WATER RESEARCH

Hydrogeological equipment

Field equipment of the Group falls into 3 main classes:

1. Pumping equipment
2. Depth measuring equipment and rainfall gauges
3. Field chemical equipment.

This equipment has required considerable effort in selection, design, and modification to meet difficulties encountered in local field operation. This work occupied a considerable proportion of the time of the A.C.T. water investigation geologists; they had no published reports on the construction and use of most of this equipment and had to plan it from basic items.

Pumping equipment. The group has two pumping units (Plate VIII):

1. An IBC Type A.26 variable stroke jack pump-head driving a 4-inch deep-well pump;
2. A Quirk Aquajet venturi-type pump.

Both of these units are powered by a 7-horsepower J.A.P. petrol motor mounted in a Jeep-trailer.

The IBC unit is used for most tests and is capable of pumping up to 900 g.p.h. from a depth of 240 feet. The pump has been used to pump as much as 1500 g.p.h. from a depth of 120 feet. The main difficulites with it are: (1) the need to transport and use a heavy tripod for lowering the pumping-string; and (2) the time necessary to lower the pumping-string into the bore. Some difficulty is being experienced in controlling the yield from the bore to the required accuracy needed when estimating the aquifer's transmissibility. It is planned to overcome this by plumbing fixtures capable of returning part of the yield to the bore.

The Quirk Aquajet unit is capable of pumping 900 g.p.h. from a depth of about 90 feet: it has the advantages of not requiring a lowering tripod and of taking much less time for lowering the pump and polythene pumping-string. Difficulties have been encountered in using this unit for testing purposes but it is expected that these will be overcome shortly by changing the type of foot-valve and size of jet and by fitting a non-return valve to the discharge pipe. The absence of this non-return valve has led to considerable priming difficulty when the pump motor failed during a test.

Depth measuring equipment and rainfall gauges. Three types of depth measuring instruments are used.

1. The Hydrometrische Werkstatten Model HWK AG2 (Plate VII). This unit is used for routine measurements of groundwater levels in observation bores. It is a mechanical direct-reading instrument. It consists of a float which descends down the bore at a fixed speed; when the float touches water a brake mechanism operates and the depth registers on a dial at the surface. The same instrument can be used to measure the total depth of a hole by replacing the light float with a heavy metal plumb-bob.

2. An electric depth sounding probe. The conventional twin-pole instrument is used and the position of the water level noted by movement on a micro-ammeter at the surface. This unit is used mainly for checking levels during bailing tests and checking readings of a pneumatic depth-measuring instrument.

3. The pneumatic depth measuring system consists of the usual polythene tubing, bicycle pump and surface pressure gauge. This unit is used for measuring draw-down during pumping tests. Some difficulty is being experienced in recording accurately fast recovery for theoretical calculations. It is hoped that this will be overcome by fitting an automatic pressure recording unit to the air-line. The bicycle pump may be replaced also by an air pressure-bottle which will give the tester greater freedom and speed at critical times during the test.

Rainfall is measured by either the standard 8-inch or 5-inch rainfall gauge, one of which is always set up at each observation bore. It is hoped that an automatic recording unit mentioned earlier and capable of measuring simultaneously both rainfall intensity and water-depth in bores may be available soon. This unit should give valuable information on the relationship between infiltration and rainfall intensity.

Field chemical equipment. Field equipment includes conductivity meter, Lovibond colorimetric pH meter, and a small chemical kit (Plate VII).

The conductivity meter used is the Evershold and Vignoles Dionic Tester which was described to this Committee by E.P.D. O'Driscoll (1957). It is used either with its normal glass conductivity cell or with a probe similar to that mentioned by O'Driscoll.

The Lovibond pH meter permits rapid approximate field determinations of pH by colorimetric means.

The chemical kit used is manufactured by the Hach Chemical Company (USA); it is similar to ones used by the United States Geological Survey. It is capable of measuring total hardness, alkalinity and chloride and provides a means by which the geologist can make a better field selection of samples for laboratory analysis. It yields a rough field chemical analysis in the following way:

The Dionic conductivity meter can be used to give the total milliequivalents of anions or cations.

The sum of the calcium and magnesium ions can be obtained from the total hardness found by the kit.

Substracting this sum from the total cations gives very approximately the sodium content in local waters.

The alkalinity gives the bicarbonate content.

The chloride is obtained directly by the kit.

Finally the sulphate content is obtained by subtracting the sum of the bicarbonate and chloride milliequivalents from the total anion milliequivalents.

All water samples are collected in standard laboratory polythene bottles. This overcomes the difficulty experienced earlier of breaking sample bottles in the field and prevents the contamination of the sample by sodium, as sometimes happens when ordinary glass bottles are used.

Future research programme

Now that most of the earlier teething problems in equipment have been overcome, it is planned to undertake research into the following fields:

1. Further routine studies of rainfall and piezometric surface fluctuations;
2. Pumping tests to determine bore yields and as far as possible formation constants and groundwater velocities;
3. Groundwater depletion studies of the Jerrabomberra Creek basin;
4. Chemical and bacteriological studies;
5. The use of explosives to improve the yield of bores.

The two officers and one field-assistant engaged on groundwater studies can only devote part of their time to this work so that the programme will require a further two to three years before significant results are available. The programme is being arranged so that long-range records such as fluctuations in piezometric surface which cannot be repeated are given the highest priority. Major pumping experiments and compilation of data will be confined as far as possible to the University summer vacation when the Bureau engages University students. The students will help overcome the shortage of staff and will also gain useful training in hydrogeological work which is only briefly covered in most Australian geology-courses.

The routine studies of piezometric levels and rainfall are arranged to ensure that available bores in the most important topographical locations are selected. Access is carefully considered because it is necessary to restrict this work to one long traverse by the field-assistant on one morning each week. Levels of several earth-dams near observation bores are also observed at the same time for calculation of run-off.

Pumping tests will be conducted on each bore drilled in the Territory if the owner wishes it. A 6-10 hour test will be run to obtain an approximate figure for "safe-yield"; the farmer can use this to determine the most suitable permanent pumping unit. Recovery tests on these bores will give additional estimates of the transmissibility of crystalline aquifers. If an observation bore is available near any test bore the storage coefficient will also be determined.

A group of three Bureau bores on the C.S.I.R.O. Farm will be used to determine transmissibility, storage coefficient and velocity in the aquifer by both equilibrium and non-equilibrium methods and by recovery. They will also be used for experimenting with dye, radioactive salt and tritiated water tracers.

The Jerrabomberra Creek catchment has been chosen as a suitable area for study of groundwater depletion. This catchment measures 40 square miles and its geology, topography and rainfall are typical of much of the Southern Tablelands. Access to the whole of the catchment is easy and there should be little difficulty in obtaining the co-operation of farmers in gathering rainfall readings. The Department of Works hopes to construct a new gauging-weir on the Creek as part of its flood-warning scheme for the Canberra Lakes and this gauge will provide the necessary flow records.

The chemical and bacteriological studies will be a continuation of the present series.

Explosives are sometimes used by local drillers in an attempt to improve unsuccessful bores. It is considered that in many cases the wrong weight and type of explosive is used and that the explosive is often laid at the wrong depth. It is planned to try suitable charges in one of the low yielding Bureau experimental bores at depths which the geologist will determine after consideration of the drilling log; the charges will be laid in zones most likely to fracture and where new fractures are likely to intersect natural fractures bearing water.

ACKNOWLEDGEMENTS

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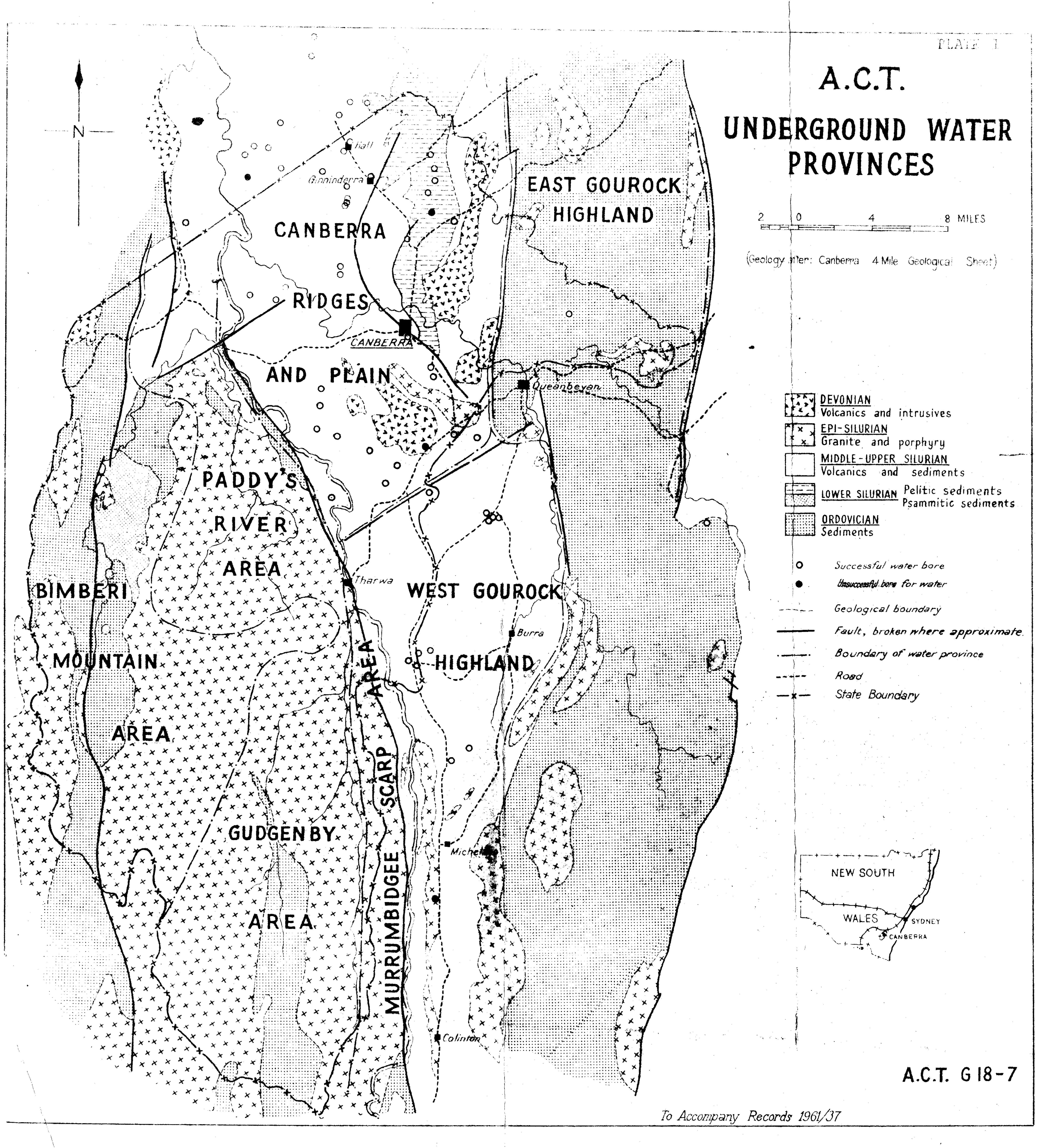
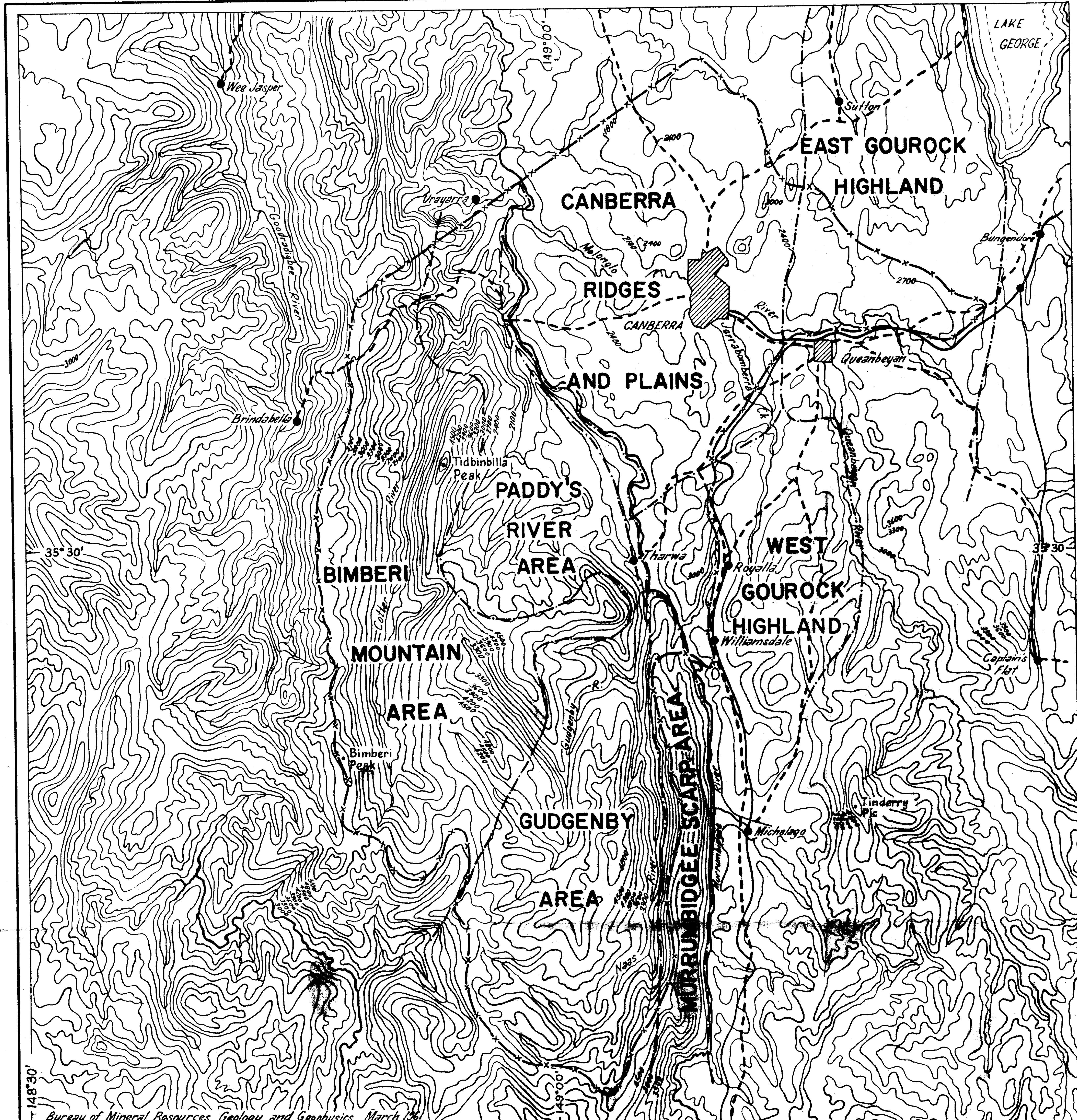


PLATE 1
A.C.T.
UNDERGROUND WATER PROVINCES
2 0 4 8 MILES
(Geology after: Canberra 4 Mile Geological Sheet)
N
CANBERRA RIDGES AND PLAIN
EAST GOUROCK HIGHLAND
PADDY'S RIVER AREA
BIMBERI MOUNTAIN AREA
GUDGENBY AREA
MURRUMBIDGEE SCARP AREA
WEST GOUROCK HIGHLAND
Hall
Ginninderra
CANBERRA
Queanbeyan
Tharwa
Burra
Colinton
DEVONIAN
Volcanics and intrusives
EPI-SILURIAN
Granite and porphyry
MIDDLE-UPPER SILURIAN
Volcanics and sediments
LOWER SILURIAN
Pelitic sediments
Psammitic sediments
ORDOVICIAN
Sediments
Successful water bore
Unsuccessful bore for water
Geological boundary
Fault, broken where approximate
Boundary of water province
Road
State Boundary
NEW SOUTH WALES
SYDNEY
CANBERRA
A.C.T. G18-7
To Accompany Records 1961/37



TOPOGRAPHIC MAP OF AUSTRALIAN CAPITAL TERRITORY SHOWING WATER PROVINCES

LEGEND

Roads

Railways

Territorial Boundary

Contours – interval 300ft. (3000)

Boundary of Water Province

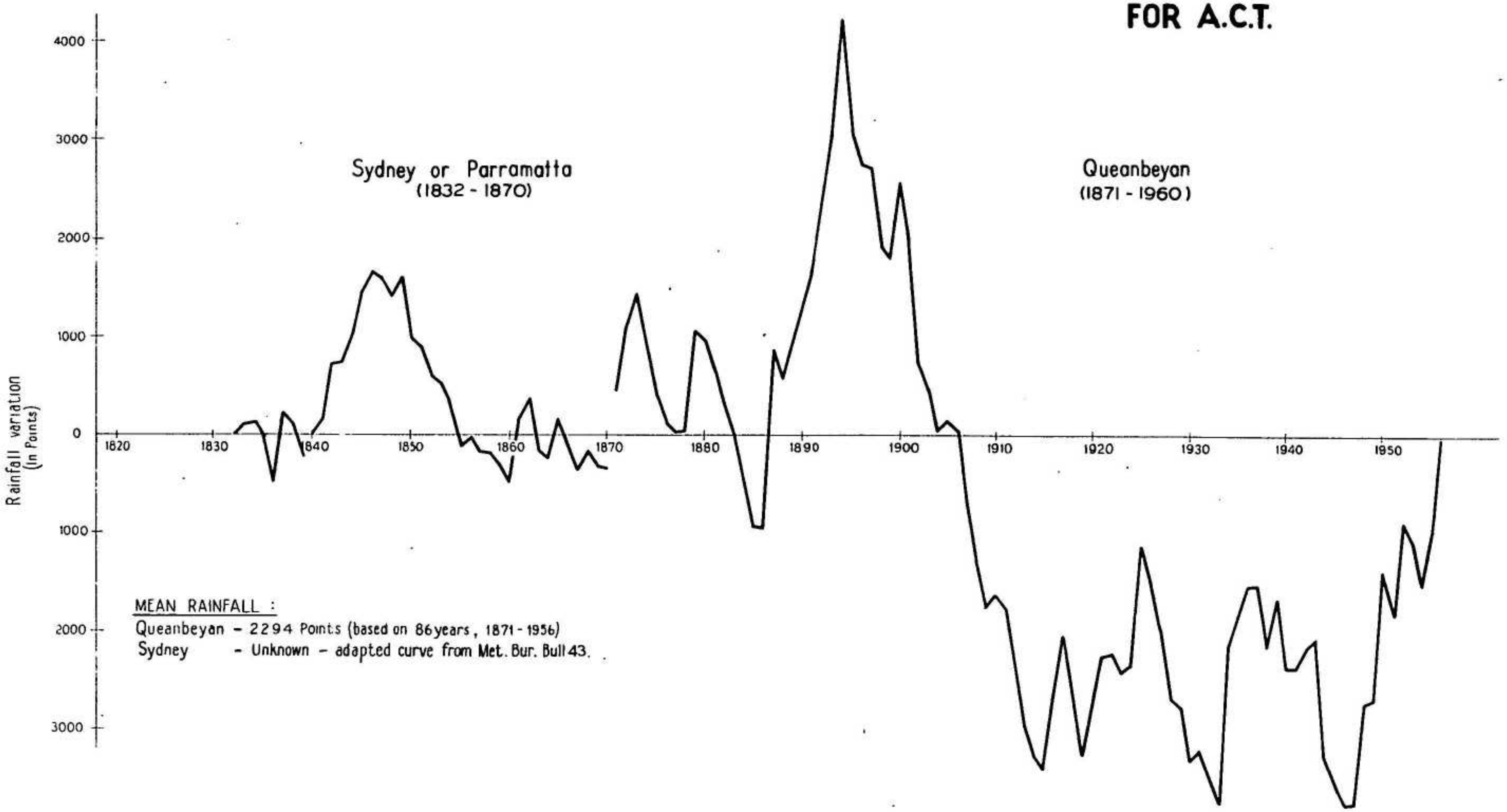
MILES 4 0 4 8 12 16 MILES

To accompany Records 1961/37 A.C.T. G18-9 P.J.B.

PLATE II

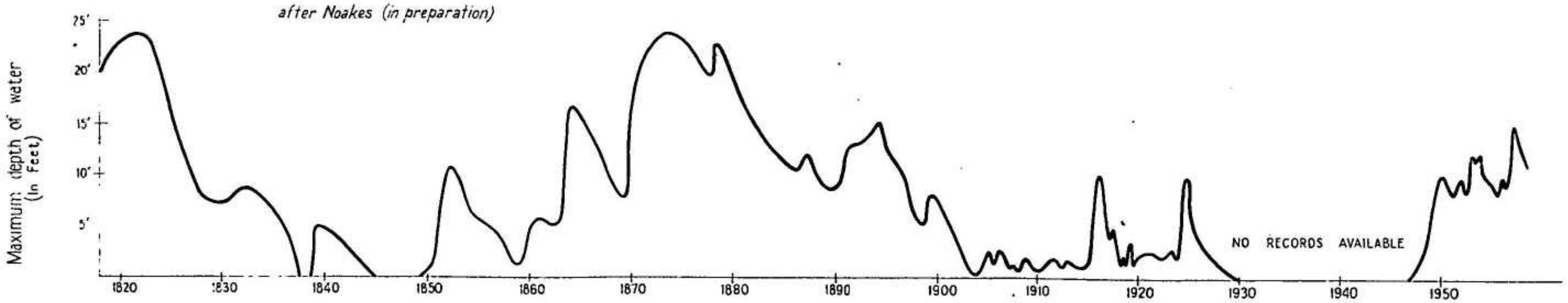
LONG RANGE RAINFALL TREND INDICATORS FOR A.C.T.

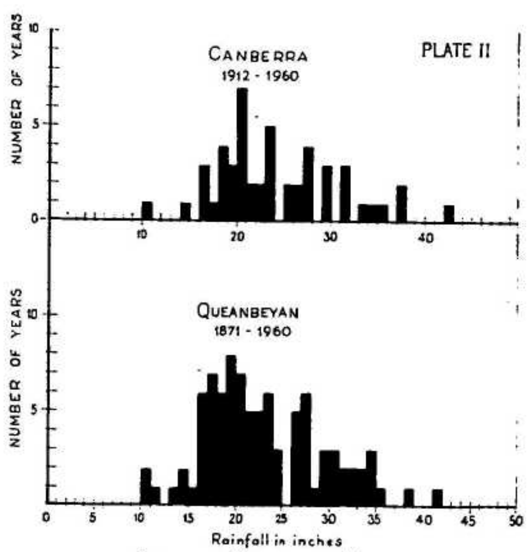
CUMULATIVE RAINFALL VARIATION



FLUCTUATIONS IN WATER LEVEL - LAKE GEORGE (1818 - 1960)

after Noakes (in preparation)





ANNUAL RAINFALL HISTOGRAMS

MEAN RAINFALL AND EVAPORATION (CANBERRA)

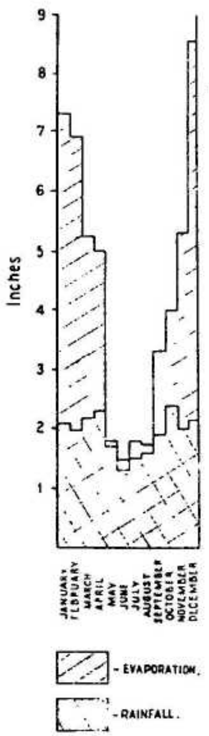
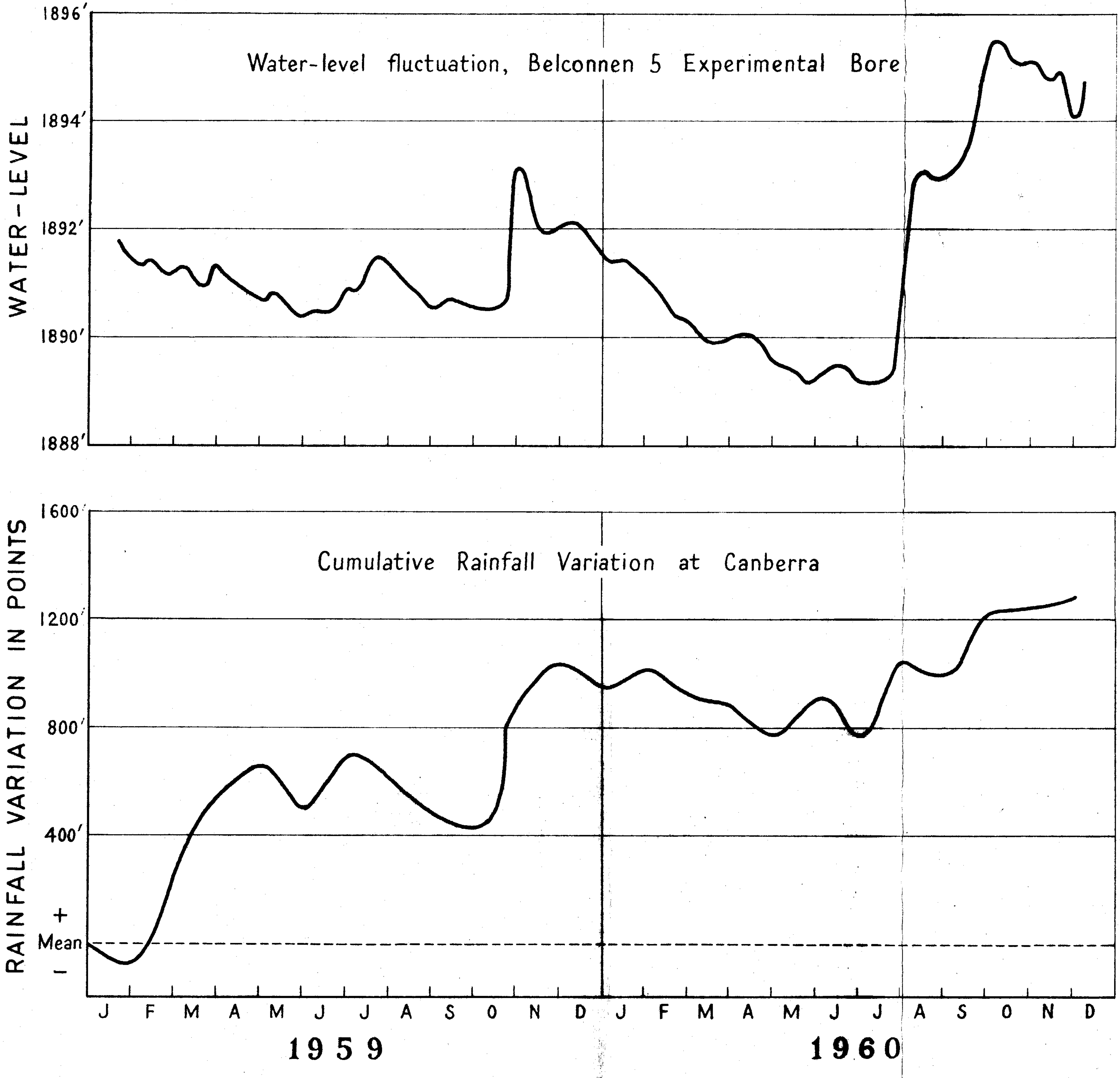


PLATE III

RELATIONSHIP OF PIEZOMETRIC SURFACE TO RAINFALL VARIATION

BELCONNEN A.C.T.



A.C.T. G18-6

Bureau of Mineral Resoures, Geology & Geophysics. January, 1961. *To Accompany Records 1961/37*

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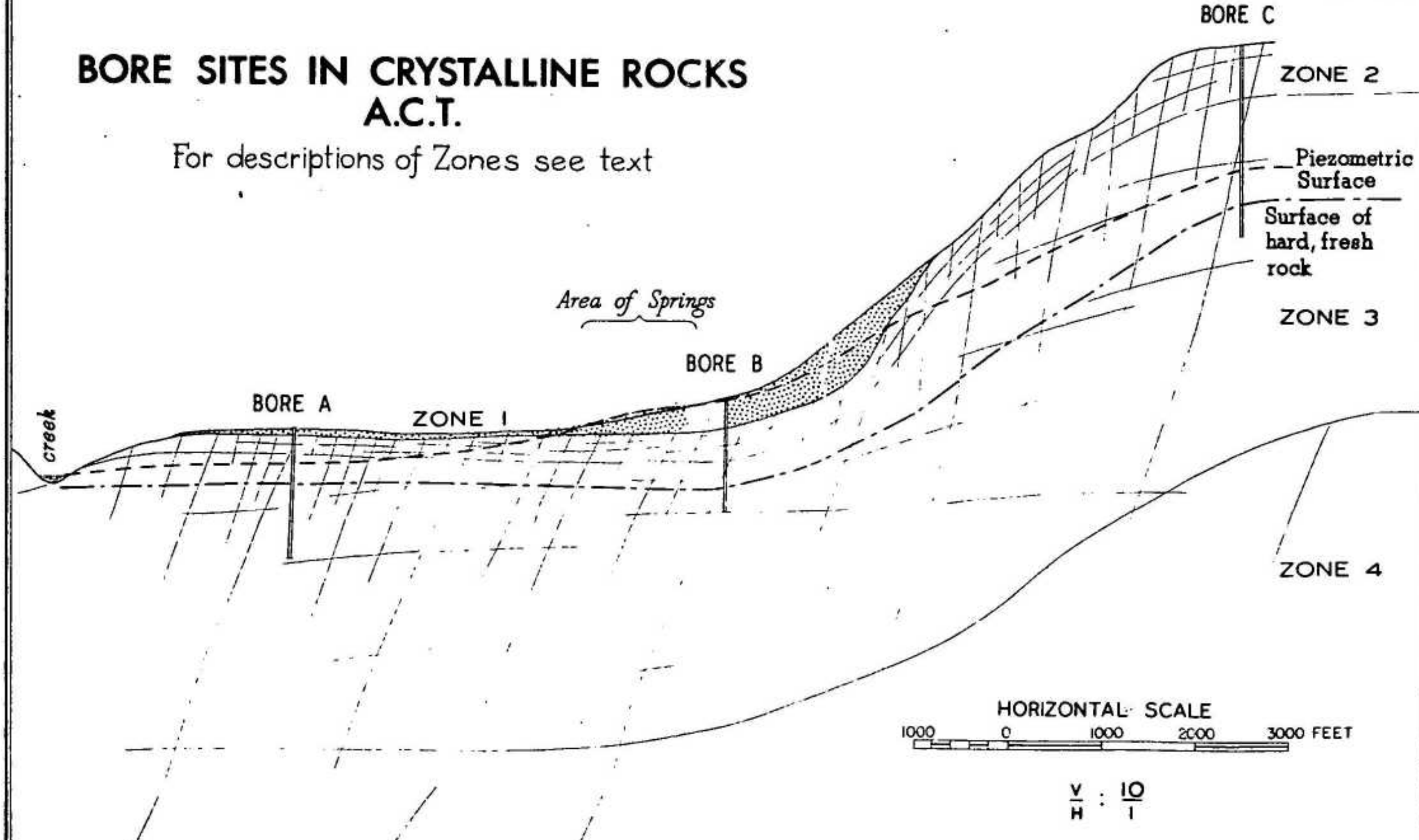
Plate IV

BORE SITES IN CRYSTALLINE ROCKS A.C.T.

For descriptions of Zones see text



Bureau of Mineral Resources, Geology & Geophysics, Dec. 1960

To Accompany Records 1961/37

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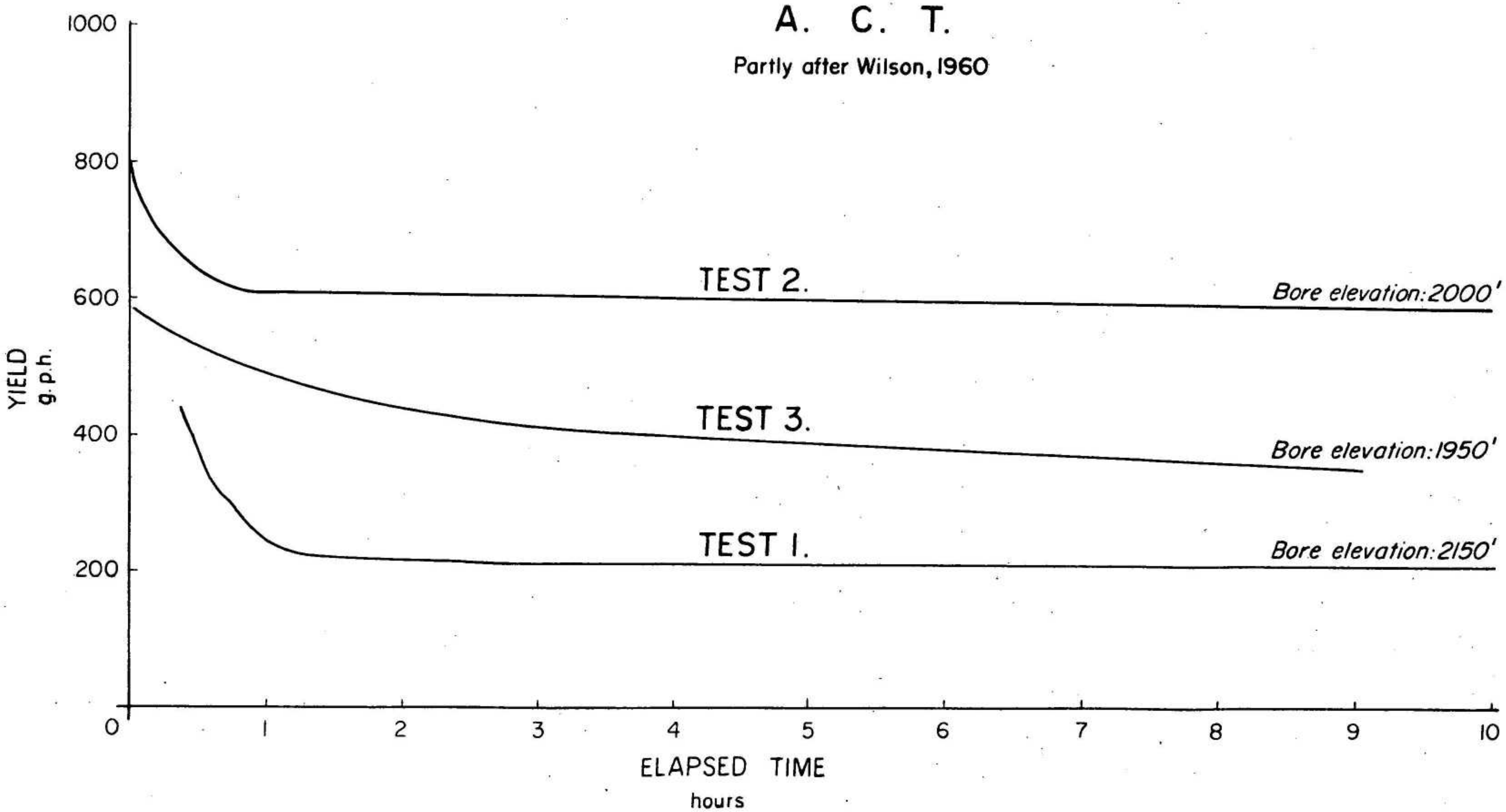
Plate V

PUMPING GRAPHS

BORES IN RIDGE AND PLAIN PROVINCE

A. C. T.

Partly after Wilson, 1960



Bureau of Mineral Resoures Geology and Geophysics. January, 1961.

To Accompany Records 1961/37

ACT G18-8

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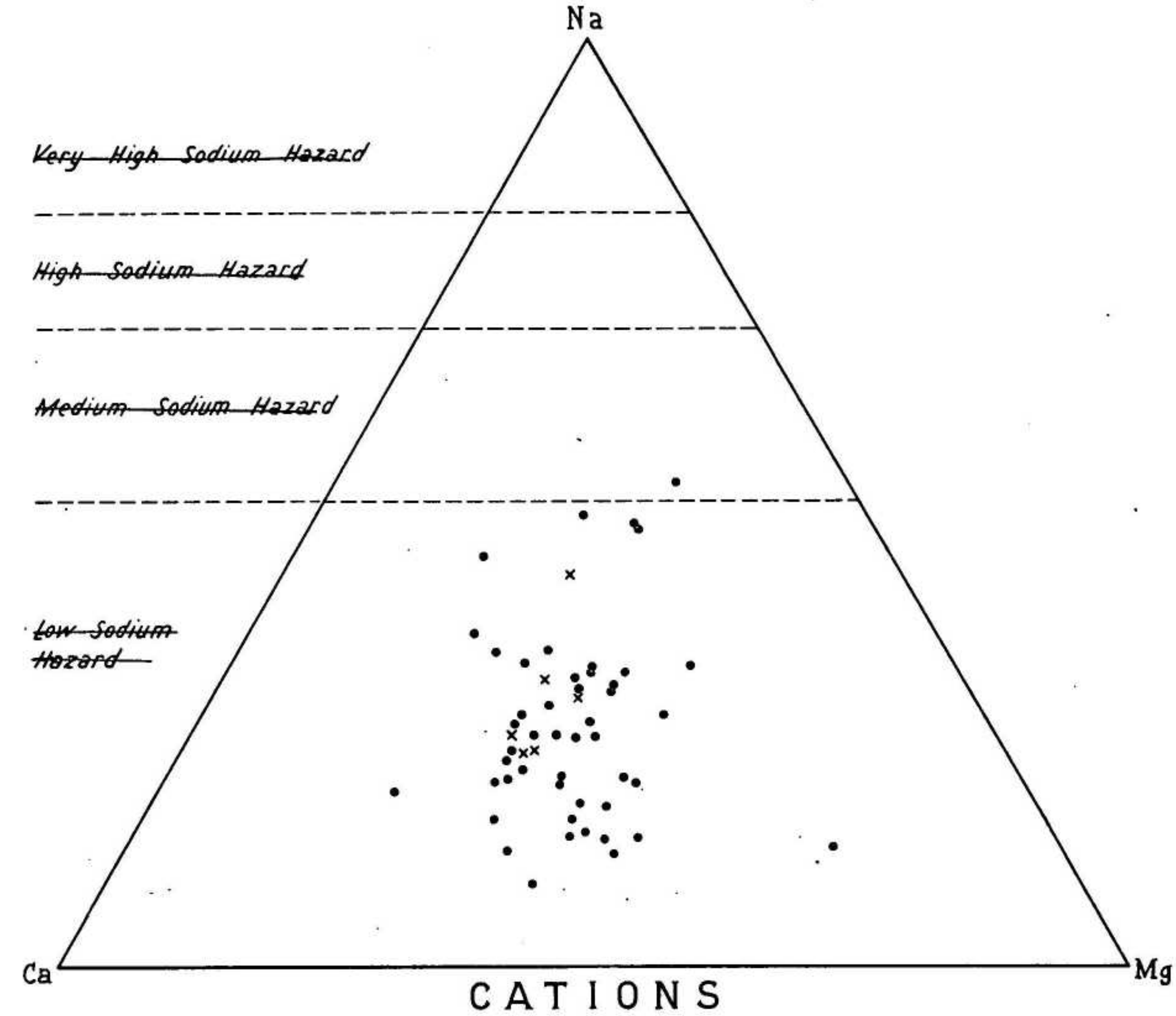
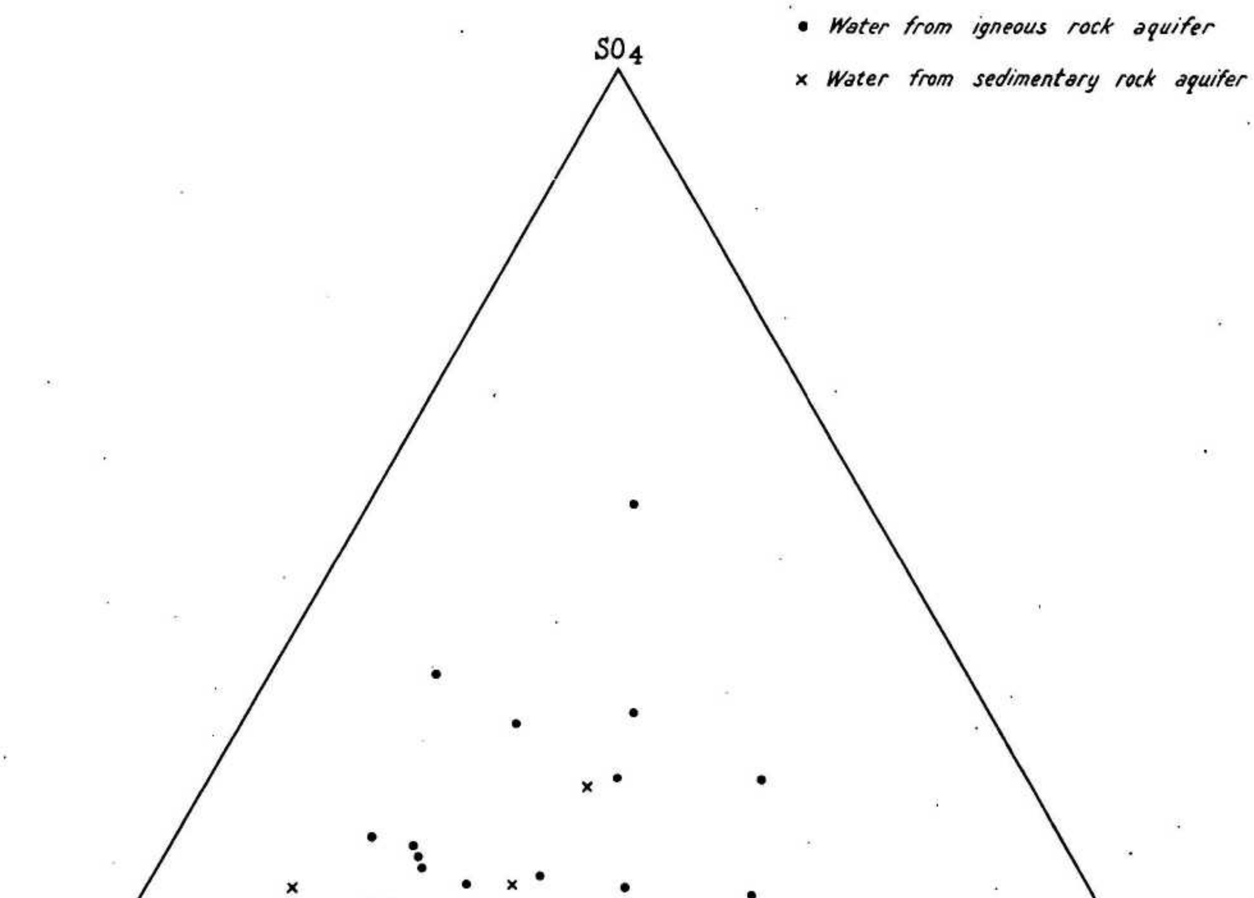
A.C.T. & ENVIRONS
BORE-WATER COMPOSITION





Bureau of Mineral Resources,
Geology & Geophysics. December, 1960.

A.C.T. G 18-3
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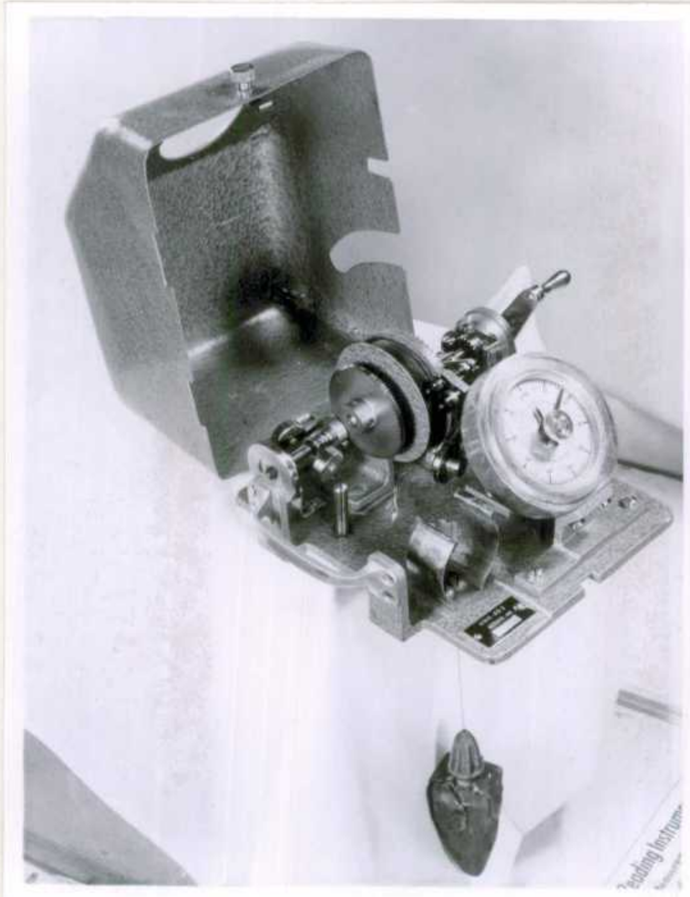
PLATE VII



1. Hydrometrische Werkstatten HWK Model AG2 Depth-Measuring Instrument

2. Field Chemical Equipment

PLATE VIII

1. Mobile Jack-Type Pump Unit

2. The Venturi-Type Pump Unit.