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SPRINGS IN THE GREAT ARTESIAN BASIN, AUSTRALIA - THEIR ORIGIN AND NATURE

by

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ABSTRACT

Springs and areas of seepage are abundant in the marginal areas of the Great Artesian Basin. About 600 spring locations, concentrated in eleven groups, are described.

Artesian springs are generally associated with (1) faults along which the water flows upwards, (2) the abutment of aquifers in the sedimentary Jurassic and Cretaceous sequence against impervious bedrock, or (3) pressure water breaking through thin confining beds near the discharge margins of the basin.

Many artesian springs have built up conical mounds by mechanical deposition of particles derived from the pressure aquifers and the confining beds, and by chemical precipitation of solids dissolved in the artesian groundwater. Artesian springs and their deposits in the Lake Eyre region show a range from topographically high springs to younger, topographically lower springs as a result of the lowering of the landsurface and spring outlet levels in Quaternary times.

Discharges from springs in the Great Artesian Basin generally are small and most springs produce much less than 10 l/s; few have larger discharges, which range up to 85 l/s. The accumulated discharge of about 600 springs is estimated at about 1500 l/s. Discharges have declined since water-well development started in the basin.

Aquifers in the eastern recharge margin produced overflow springs where the topographic surface incised into the aquifers. Many springs in the eastern marginal area are not related to aquifers of the Great Artesian Basin, but issue from capping basalt sheets. Springs in the central area of the basin issue from overlying Tertiary deposits.

INTRODUCTION

Springs are natural, concentrated outlets of groundwater at the surface. Artesian springs occur where the potentiometric surface of the aquifer from which the water issues is above the groundsurface. Seepage is less distinct groundwater discharge at the surface. Tóth (1971) has described the environmental conditions necessary for a spring to form.

Springs and their deposits can provide information about geological and hydrological events in an area. The concentrations of salts and minerals near springs are records of the characteristics of the aquifers, the groundwater, the groundwater source, and the patterns of movement.

Springs and areas of seepage are abundant in the Great Artesian Basin; springs are listed by 1:250 000 Sheet area for each of the 11 groups that have been named (Table 1). Many locations on the 1:250 000 map sheets listed represent large numbers of springs in the field, either actively flowing or extinct. Most discharge groundwater from aquifers, and are located in the marginal zones of the basin towards which regional groundwater flow is directed. Springs in the basin are generally associated with faults, along which the water flows upwards and reaches the surface. Springs are also present in areas where the aquifers crop out, or where impervious rock barriers occur and thin confining beds have been breached. Many of the artesian springs have built up conical mounds, as the upwelling pressure water has led to the mechanical and chemical precipitation of sediment particles derived from the aquifer and confining beds, and of solids dissolved in the water.

The springs, the water they provide, the accompanying vegetation, and the mounds developed by active and extinct springs, are significant features in the arid landscape of the Great Artesian Basin area. Their discovery during the second half of the nineteenth century led to the suggestion that artesian water could be found in inland Australia (Tate, 1879, 1882). The first flowing artesian wells in the Great Artesian Basin were drilled near springs in the southern (Wee Wattah Spring, Table 1 - D20; Williamson, 1966) and southwestern (near Anna Creek; Whitehouse, 1954; Habermehl, in press) marginal areas in New South Wales and South Australia.

Few studies have been published on the discharge areas and the springs, and data on spring activity, discharge rates, water temperature, and chemistry are scarce. During the hydrogeological study of the Great Artesian Basin by BMR from 1971 to 1980 (Habermehl, 1980), additional information about spring discharge rates was required. As a result of a request by BMR, the Geological Survey of South Australia carried out a systematic survey of springs in the South Australian part of the basin.

I visited springs near Barcaldine (Table 1 - A7) in 1971; some springs between Marree and Oodnadata (G), and Dalhousie (H) in 1976; the location near Cuddie Spring (C1) in 1978; near the Mulligan River (I), Elizabeth Springs, and Bulla Bulla Springs (J) in 1979; and near Yantabulla (D16, D19) and Eulo (several extinct and active springs at or near the locations of E2, E23, E24, E25, and E38) in 1980. Locations, descriptions, and data from these and other springs listed in Table 1 were also obtained from the literature and from 1:250 000 topographic and geological map sheets. This report is probably incomplete as mainly existing data from references listed have been used; no field data (spring locations and occurrences, flow rates, temperatures, and chemical analyses) were collected.

THE GREAT ARTESIAN BASIN

The Great Artesian Basin is a confined groundwater basin comprising aquifers in continental quartzose sandstone and confinining beds of partly marine mudstone and siltstone, all of Triassic, Jurassic, and Cretaceous age (Habermehl, 1980). It underlies 1.7×10^6 km^2, about 22 percent of the Australian continent, and parts of Queensland, New South Wales, South Australia, and the Northern Territory (Fig. 1). The basin is, in places, 3000 m thick, and forms a large synclinal structure, uplifted and exposed along its eastern margin and tilted southwest.

Aquifers of the multilayered confined aquifer system are hydraulically continuous across he basin. Most recharge to the aquifers occurs in the eastern marginal zone, mainly on the western slope of the Great Dividing Range, where outcrops of aquifers are present, or where aquifers subcrop under Cainozoic sandy sediments. Recharge also takes place in some parts of the western margin (Fig. 2).

Regional groundwater movement in the basin, as determined from the potentiometric surface maps of the main aquifers in the Jurassic and Cretaceous sequences (Habermehl, 1980), is shown in Figure 2. Groundwater velocities in the main aquifer in different parts of the eastern marginal areas of the basin average from about 1 to 5 m/year.

Discharge from the Great Artesian Basin takes place as natural discharge in the form of concentrated outflow from springs, and also by vertical leakage towards the regional water-table, by subsurface outflow into neighbouring basins, and as artificial discharge by means of free artesian flow and pumped abstraction from wells drilled into the aquifers.

Vertical leakage from the confined aquifers upwards through the

Fig. 1 Location and extent of the Great Artesian Basin, Australia

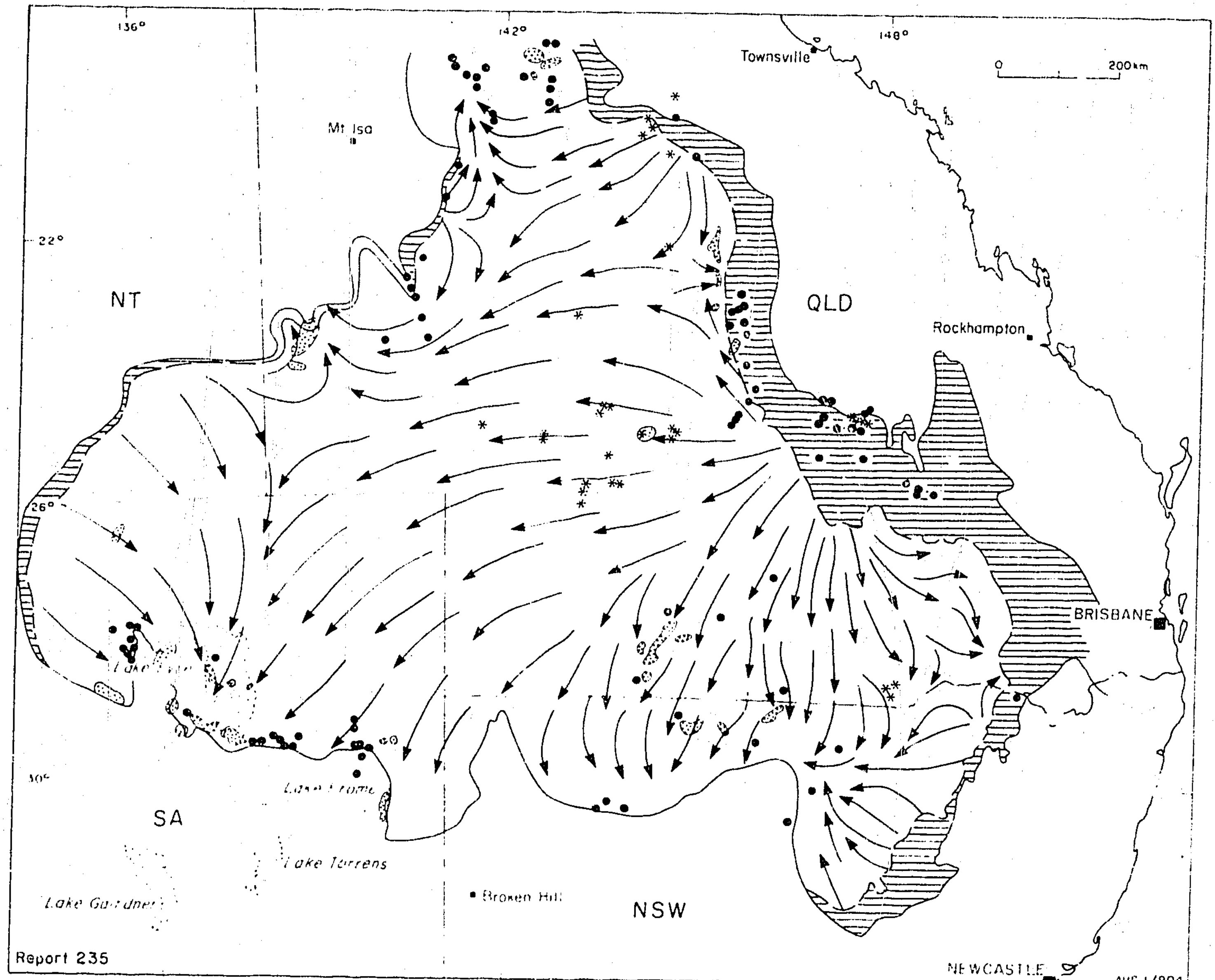
confining beds, which are considered semipervious, probably occurs over extensive areas of the basin, and, despite the low percolation rate, involves a considerable volume of water. A deep phreatic surface and high evaporation rates disguise vertical leakage.

Some of the groundwater which moves from the northern part of the Eromanga Basin into the Carpentaria Basin, and groundwater from recharge areas in the Cape York Peninsula may eventually emerge through subsea springs in the Gulf of Carpentaria.

Most groundwater from the Great Artesian Basin is exploited from flowing artesian water wells. The most important producing aquifers are in the Cadna-owie Formation, Hooray Sandstone, and Pilliga Sandstone (Fig. 3). They have yielded flows from individual wells exceeding 10 000 m^3/day (more than 100 l/s, but the majority have much smaller flows (Habermehl, 1980). The accumulated discharge rate of about 3100 of the original 4700 flowing artesian wells which obtain their water from the main producing aquifers was about $1.5 \times 10^6 m^3$/day during the 1970s; this represents a considerable lowering of the flow rate since 1918, when the maximum flow rate was about $2 \times 10^6 m^3$/day from about 1500 flowing artesian wells (Habermehl, 1980). Artesian flows are also obtained from aquifers below these, in the Hutton and Clematis Sandstones, though few flowing artesian wells tap these aquifers. Only a small number of flowing artesian wells originate from aquifers in the upper part of the Cretaceous sequence. Non-flowing artesian water wells, which generally tap aquifers in the Cretaceous Winton and Mackunda Formations, and number about 20 000, are usually windmill-operated pumped wells supplying on average 10 m^3/day.

Flowing artesian water wells occur mainly in the northern, eastern, and southern marginal areas of the basin, and in most of the south-central parts (fig. 5 in Habermehl, 1980), but are almost absent in the central part of the basin, where the main aquifers are at great depth.

The potentiometric surface of the aquifers in the Lower Cretaceous and Jurassic sequence was above the ground surface over the whole of the basin before exploitation began around 1880. Since then the regional potentiometric surface of the exploited aquifers in the Lower Cretaceous and Jurassic sequence has dropped by several tens of metres in many heavily developed areas, and the local potentiometric surface around the large number of freely or mainly freely flowing artesian wells has considerably subsided. The potentiometric surface has fallen below the ground surface in some areas near the margins and in the southeast-central part of the basin. As a result, natural flows from some artesian wells have ceased in those areas.



Recharge area — Direction of groundwater flow — Concentration of Great Artesian Basin springs

• Great Artesian Basin spring * Springs from Tertiary sediments and basalts

Fig.2 Recharge and natural discharge (springs) areas and directions of regional groundwater flow in the Great Artesian Basin

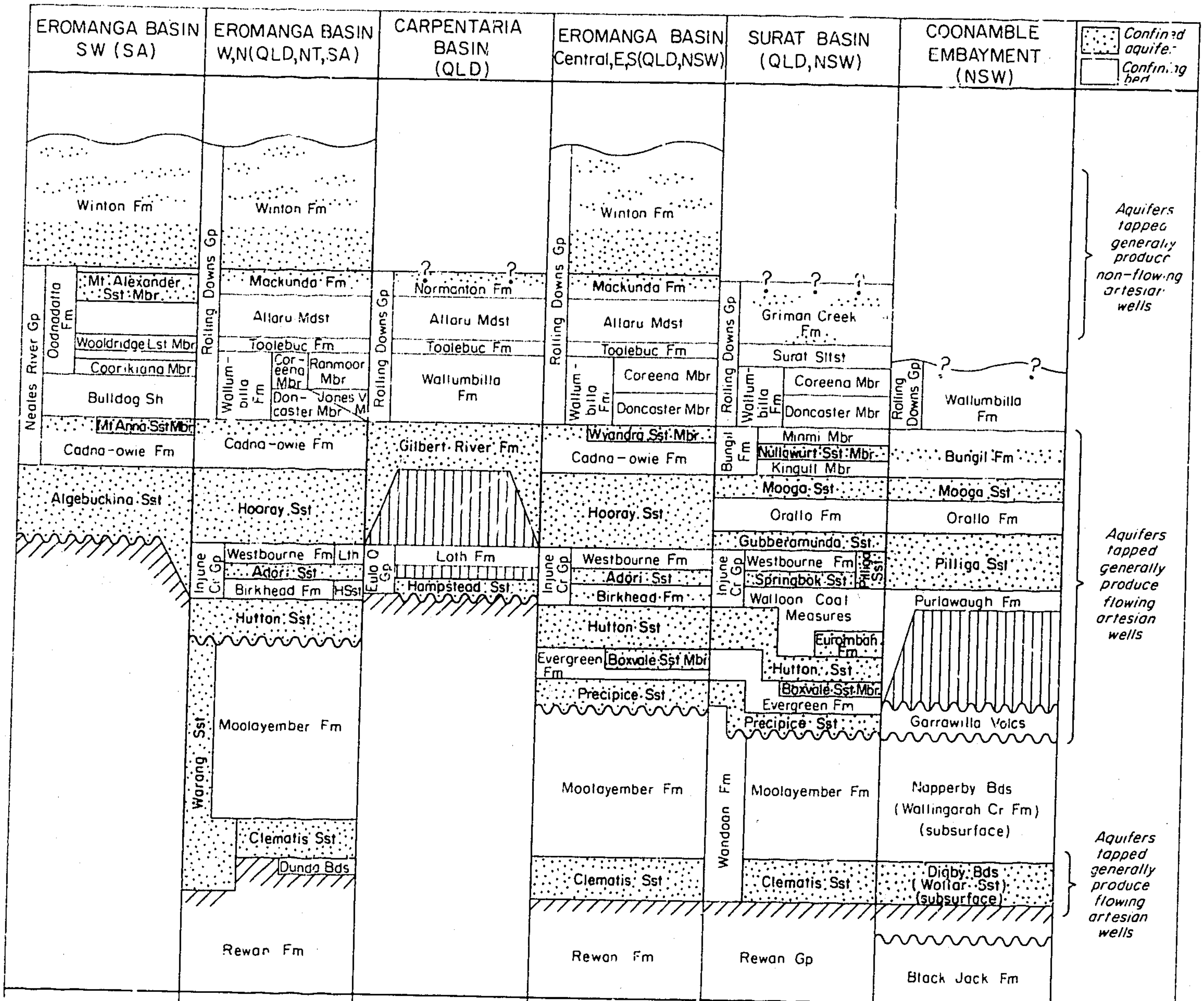


Fig.3 Correlation of hydrogeological units in the Great Artesian Basin

The potentiometric surface of aquifers in the upper part of the Cretaceous sequence has always been below the ground surface. Wells tapping these aquifers are non-flowing artesian and have to be pumped. Regional drawdown in the aquifers is much smaller than in the Lower Cretaceous and Jurassic aquifers because of the small discharges from pumped wells.

Exploitation of the basin's aquifers has caused significant changes in the rate of the various discharges in time (Habermehl & Seidel, 1979; Habermehl, 1980). Before the aquifers were exploited, the basin was in a natural steady-state condition, in which recharge and natural discharge - the latter from springs, vertical leakage, and some lateral outflow - were in equilibrium. Following development by wells, vertical leakage and spring discharge have diminished. A visible effect has been the diminution in flow from springs in the south-central, southwestern, and northwestern parts of the basin, even though abstraction by wells caused a steepening of the hydraulic gradient and allowed more recharge water to enter the system.

At present a new steady-state condition has been reached in which total recharge and discharge are approaching equilibrium again (Habermehl & Seidel, 1979; Habermehl, 1980), and consequently little change would be expected to occur in the discharge rates of springs provided that no new well development takes place.

SPRINGS

Springs of the Great Artesian Basin are the natural surface discharge points of aquifers in its sedimentary Jurassic and Cretaceous sequence. All its springs are located in marginal areas (Figs. 2 and 4) and many appear to be fault-controlled or connected with fault zones and lineaments, or with less-pronounced deformation zones in the sedimentary cover. Many springs in the south, southwest, and northwest occur where aquifers abut impervious basement rocks, and/or where only thin confining beds are present, through which the pressure water has broken and found a pathway to the ground surface. Some springs in the east owe their flows to 'overfilling' of aquifers in nearby recharge areas.

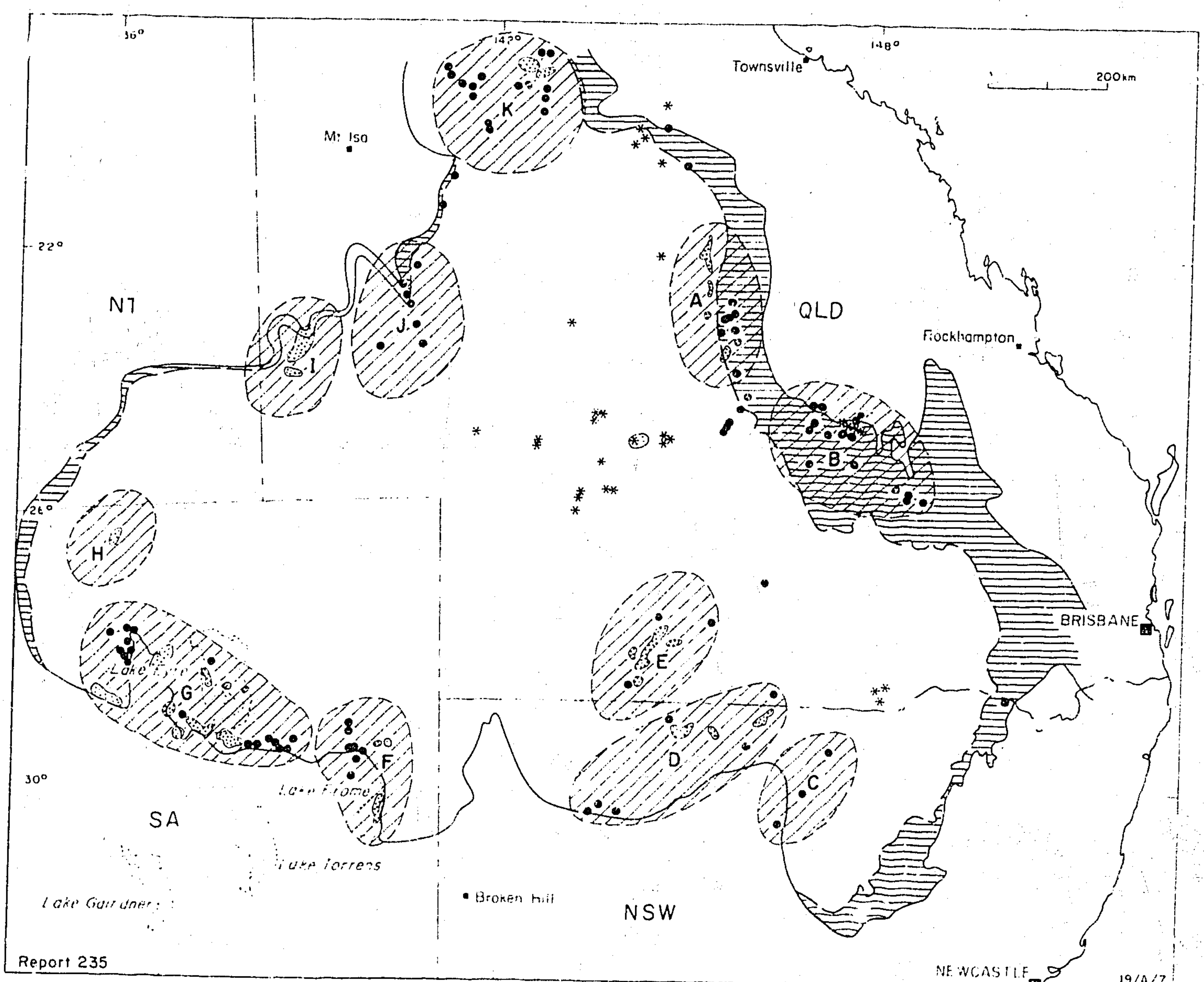
Locations of springs, and information on spring discharge rates, water temperature, and chemistry, are given in reports of Interstate Conferences on Artesian Water (1913, 1914, 1922, 1925, and 1929), during which results of investigations, descriptions, and interpretations of information on springs were presented as part of local and regional geological and hydrogeological studies. Most springs, swamps, or seeps in the arid part of the basin were discovered in the middle and latter part of the nineteenth century by early explorers of central Australia (references in Gregory, 1906; Interstate Conference on Artesian Water, 1913; Pittman, 1914; Cobb, 1975; Williams, 1979).

However, recent systematic surveys of the natural surface outlets of the Great Artesian Basin which could provide significant data on geological and hydrological events, the characteristics of aquifers and groundwater, the groundwater source, patterns of groundwater movement, transport of dissolved solids and minerals, and regional heatflow, were not carried out until the mid-1970s. At that time the Geological Survey of South Australia carried out a survey of springs in the South Australian part of the Great Artesian Basin, locating and describing them, measuring discharge rates, and sampling the water for chemical analyses. At the time of writing similar surveys have not been carried out in other parts of the basin. Overall, few earlier records are present for comparison of discharge rates; only a limited number of chemical analyses has been carried out.

Springs in the Great Artesian Basin occur in eleven groups (Table 1; Fig. 4) (mainly based on their topographical proximity) and number about 600. These locations either represent distinct discharge points, or are discharge areas where a large number of individual springs or seepages occur.

The largest concentrations of springs are in the southern, south-central, southwestern, northwestern and northern marginal parts of the basin. The area southwest and northwest of Lake Eyre contains the largest number and most active springs; these springs also produce the largest discharges. Williams (1979) stated that 95 percent of the natural discharge in South Australia occurred from the group of springs at Dalhousie, northwest of Lake Eyre (group H in Table 1; Fig. 4; Williams, 1974; Williams & Holmes, 1978). The discharge of some springs is sufficient to maintain small creeks for hundreds of metres - a few for even some kilometres - in this arid region in which evaporation and evapo-transpiration are very high. Dense vegetation surrounds many of the springs, and lines some of the streams. Around some springs, and downstream from them, are swampy areas and large, bare salt plains in which there are vertical alternations of salt and soft dark slimy mud. Other springs are surrounded by firm soil or carbonate-cemented sediments, and can be approached, even by vehicles, without danger.

Many springs have been reduced to seepages only, or have ceased flowing. In many parts of the basin spring discharges have been reported to have declined since the development of water-wells (David, 1893; Pittman & David, 1903; Jensen, 1926). Few historical records exist on springs and their discharge rates, but diminution of some spring discharges in the northwest,



Recharge area   A Spring group   Concentration of Great Artesian Basin springs

• Great Artesian Basin spring   * Springs from Tertiary sediments and basalts

Fig. 4 Location of springs and spring-groups in the Great Artesian Basin north, and east as a result of well development are documented (e.g., Elizabeth Springs - J3 - in Interstate Conference on Artesian Water, 1913; David, 1950; Queensland Government, 1954; Whitehouse, 1954; Randal, 1978).

Discharges from individual springs range up to about 85 l/s (Dalhousie group of springs). Generally springs in the Great Artesian Basin produce only small discharges: most can be classified as fifth or sixth-order springs; very few are fourth and third-order according to the classification of Meinzer (1923a, b; in Davis & De Wiest, 1966; Bouwer, 1978), which is based on the magnitude of discharge. The accumulated discharge of about 600 spring locations listed in the present report is estimated at about 1500 l/s. This estimated spring discharge represents less than one percent of the water available for recharge to the aquifers of the Great Artesian Basin, and amounts to about 5 percent of the recharge computed by the GABHYD model (Habermehl & Seidel, 1979; Habermehl, 1980). The spring discharge is small compared to the model-computed basin discharge (Habermehl & Seidel, 1979, fig. 10).

Many artesian springs which were formed when pressure water was forced upwards through fault zones or confining beds have created conical mounds which consist of sediment particles brought up from the aquifers and confining beds by the pressure water, and of chemical precipitates (mainly carbonates) derived from the groundwater. Aeolian sediments, vegetation, and material caught by vegetation, all contribute to the build-up of deposits near springs. The construction of conical mounds with water issuing from the top as a result of upwelling pressure water is a well known phenomenon. Reeves (1968) described spring mounds created by artesian water in intermontane playas, and also described spring pots and necks, features which are quite common in some spring areas in the Great Artesian Basin. Kolb (1976) described sand boils (conical mounds) formed as a result of seepage under levees of the Mississippi River. Escher (1953) proposed the term pegostylite for the conical, dome-shaped precipitation of crystalline matter from an ascending spring.

Spring mounds in the Great Artesian Basin are commonly characterised by sand and silt-size sediments and carbonate cement, and interlayers or caps of carbonate. The mounds range in height and diameter from several decimetres to tens of metres. Some of the large mounds have water-filled craters, and others have subsidiary outlets at different levels from which water flows or seeps. Large seepage areas without distinct outlets are also present in spring zones.

DESCRIPTIONS OF SPRING-GROUPS

The springs which issue from aquifers (mainly from confined aquifers in the Lower Cretaceous-Jurassic sequence) of the Great Artesian Basin have been divided into eleven groups according to their locations (Fig. 4, and below), and are listed in Table 1.

SPRING-GROUP	AREA
A - Barcaldine	Aramac/Barcaldine/Jericho/Tambo
B - Springsure	Springsure/Injune
C - Bogan	Bogan River/Carinda
D - Bourke	Yantabulla/Bourke/Weilmoringle
E - Eulo	Eulo
F - Lake Frome	Lake Frome/Lake Callabonna
G - Lake Eyre	Marree/Lake Eyre/Oodnadatta
H - Dalhousie	Dalhousie
I - Mulligan River	Mulligan River/Mt Whelan
J - Springvale	Springvale
K - Flinders River	Julia Creek/Flinders River/Saxby River

A short description of each spring-group, including references to literature on springs in the groups, follows.

A - Barcaldine Group

Springs in this group occur along the northeastern margin of the basin (Fig. 4). Springs A2-6 in the northern part of the area occupy a north-trending zone about 5 to 10 km wide and 100 km long. Other springs, A7, approximately 30 km northeast of Barcaldine, occur along the same northerly trend. Most of the springs are present within an area of Quaternary alluvium overlying the Lower Cretaceous Doncaster Member, which forms a confining bed to aquifers in the Ronlow beds - a marginal facies equivalent of the part of the sequence which includes the Hoorary Sandstone to the Hutton Sandstone (Burger & Senior, 1979) - though some permeable beds might also be present within the Doncaster Member.

The springs A7 at Coreena homestead occur at the boundary of the Doncaster Member and the Coreena Member. Mud springs are numerous; they have mounds generally several decimetres in height, and from less than one to more than several metres in diameter. Salt crusts surround some of the springs and some release gasses intermittently. These springs probably developed by water permeating from aquifers in the Ronlow beds through the confining layers in the Doncaster Member. The linear pattern of occurrence suggests the presence of a fault or fault-induced monocline.

Groups of springs A9-16 in a north-northeast-trending zone between about 75 km northeast and 50 km southeast of Barcaldine occur in Quaternary deposits overlying the Ronlow Beds. Other springs, A17-20, near Tambo, occur in Quaternary sediments overlying the Westbourne Formation and near the boundary of the Doncaster and Coreena Members. Springs A9-20 may originate either from water migrating from the aquifers in the Jurassic sequence or permeable beds in the Doncaster Member, or from outflow of water that entered the Quaternary sediments along the upper reaches of the alluvial plains.

The most southerly springs in this group are located on the western slope of the Enniskillen Range Anticline, and probably relate to Tertiary and Quaternary sediments rather than aquifers in the Great Artesian Basin (shown on map in report on Interstate Conference on Artesian Water, 1913; Jensen, 1926; not on recent maps).

B - Springsure Group

Several large discharge springs occur in this group in the headwaters of the Nogoa, Dawson, Maranoa, and Warrego Rivers. Springs B3 and 4 emerge at the base of the south-dipping Boxvale Sandstone Member at or near the contact with the underlying Precipice Sandstone in the headwaters of the Nogoa River, on the northern slope of the Great Dividing Range. The uppermost part of the Precipice Sandstone in the area is fine-grained and generally impermeable. According to Whitehouse (1954) three of the many springs in a linear north-northeast-trending zone of 5-6 km near Louisa Creek in the upper Nogoa River, each produced a flow of at least 13 l/s. Springs B1 and 2, at the base of the Moolayember Formation, 100 km west-southwest of Springsure also contribute to the north-flowing Nogoa River.

Springs B5, 6 and 7 100 km south-southwest of Springsure originate in the Precipice Sandstone and provide water to the creeks of the southerly flowing Warrego River system on the southern slope of the Great Dividing Range. On the northern slope of the Great Dividing Range springs B8 and 9 occur at the lower part of the southerly dipping Clematis Sandstone.

Ball (1918) and Jensen (1926) described mound spring B10 located about 75 km northwest of Injune near Crystalbrook homestead. The mound springs hereabouts most likely occur within an area of Hutton Sandstone, and have formed by leakage of pressure water from this formation or from the underlying Boxvale Sandstone Member. Ball also referred to a spring near Bogarella (B14).

Three springs (B11-13) about 30 km southwest of Injune occur in the headwaters of the Dawson River in the Merivale Syncline, on the eastern slope of the Great Dividing Range. The springs are shown at the base of the westerly dipping Gubberamunda Sandstone, but are also very close to the edge of Tertiary basalts overlying the Mesozoic sediments.

About 25 km east-northeast of Injune, springs B15 and 16 issue from the Precipice and Hutton Sandstones and the Boxvale Sandstone Member, and are probably related to faults (cf. Mollan & others, 1972, who described mound springs near a small fault northeast of Injune). These springs, and spring B17, farther east in the Hutton Sandstone, issue into the Injune, Hutton, and other creeks of the east and north-flowing Dawson River system. In the Injune area, the Jurassic sequence dips towards the south, the topographic surface slopes east, and creeks have incised into aquifer-bearing rocks, effectively tapping some of them.

Jensen (1926) observed that many mound springs in the area diminished in flow after water wells were drilled in the west.

Several springs occur near the watershed of the Great Dividing Range in the Buckland Tableland: Pumphole Spring (lat. 24°50'S, long. 147°52'E), Bluehole Spring (lat. 24°47'S, long. 147°50'E), Lady Spring (lat. 24°47'S, long. 147°49'E; elev. 790m), Figtree Spring (lat. 24°46'S, long. 147°41'; elev. 730m), Myall Spring (lat. 24°45'S, long. 147°42'E; elev. 730m), and an unnamed spring (at lat. 24°42'S,long. 147° 42'E) are all located in or at the edge of Tertiary basalt overlying the Mesozoic sediments, and are considered not to be part of the Great Artesian Basin, but to issue from the basalt capping. Mollan & others (1972) reported that the Merivale River and several creeks are fed from springs from the basalt along the Great Dividing Range in the area around 148° 15' and 25°10'. Jensen (1926) reported the locations of many springs in the area, and considered that many of the large springs issue from the junction of the basalt and underlying sedimentary rocks.

David (1950) reported on a group of springs betweeen Mungindi and Dirranbandi between the Balonne and Moonie Rivers; they are also shown on the map in Interstate Conference on Artesian Water (1913). These springs occur in a northeast-trending zone and are most likely related to the Tertiary capping overlying the Griman Creek Formation.

David (1950) also reported on a group of springs in the Jurassic intake beds between Yetman and the Queensland border (roughly 150°50' - 28°45'). They may be related to faults mapped in the Lower Jurassic sediments overlying Palaeozoic rocks in this marginal outcrop area of the basin.

C - Bogan River Group

Rade (1955) referred to mound springs in the western part of the Coonamble Embayment, which were shown on a map (plate 3) in the report on Interstate Conference on Artesian Water (1914). Cuddie Spring was reported by David (1950) to have 'yielded great quantities of bones of Pleistocene or early Recent vertebrates'. Cuddie and Coolabah Springs, C1 and 2, are located near the western margin of the Coonamble Embayment, where Jurassic and Cretaceous sedimentary rocks contain aquifers and confining beds and onlap onto impervious Palaeozoic rocks. The springs might be related to lineaments, and their water probably has penetrated joints or fracture zones within the thin confining Cretaceous sediments. Cumborah Spring, C3, might be related to Tertiary sediments overlying the Mesozoic sequence, and therefore not be part of the Great Artesian Basin.

D - Bourke Group

Several groups of springs are present northeast, north, northwest, and southwest of Bourke. These springs were shown on maps in the report on Interstate Conference on Artesian Water (1914, plate 3), and in Hind & Helby (1969). Rade (1954) suggested that most of these springs are located along faults or near very shallow basement rock subcrop. He considered that mound springs are especially common at the point of intersection of faults. His interpretation is substantiated by the coincidence of the spring locations and his interpreted faults with steep gradients on the basement contour map of Hind & Helby (1969), with the structural lineaments mapped by Bourke & others (1974) and Hawke & others (1975), and with the lineaments on the tectonic map of New South Wales (Scheibner, 1974). Jurassic and Cretaceous aquifers and confining beds are deformed, and pressure water escape zones probably occur along faults. Vertical upwards flow and creation of springs will occur, especially if an impervious bed blocks the aquifer on the side of the fault opposite to the prevailing direction of flow of the water, and if the fault zone is permeable.

Springs D1-7, northeast of Bourke, are probably fault-controlled, but some of the springs D8-11, north of Bourke, may be related to the thin cover of Mesozoic sediments over shallow basement and/or related to Tertiary sediments capping the Cretaceous. Springs D12-19, northwest of Bourke, probably relate to structural lineaments and thin sedimentary cover over shallow basement rocks (cf. contours of base of Mesozoic on Scheibner's Tectonic map of New South Wales), though some near Yantabulla might also be associated with Tertiary sediments. The springs southwest of Bourke occur near the southernmost margin of the Great Artesian Basin, where Mesozoic sediments abut Palaeozoic bedrock.

E - Eulo Group

In southern Queensland, several groups of springs occur in an area southwest of Eulo. Spring locations shown on the map represent many mound springs. Mounds are up to 7 m high. Mounds and mud springs generally originate from a montmorillonite clay-mud slurry which has been slowly transported to the surface by the leakage of pressure water from near-surface aquifers in the Hooray Sandstone. The water has broken through the relatively thin, fine-grained confining beds of the Wallumbilla Formation. At the surface the mud hardens usually forming flat-topped conical mounds. Whitehouse (1954) related the occurrence of mound springs to faults and thin confining beds, yet Senior & others (1978) reported that clear-water springs without mounds occur near faults and fractures where the aquifers in the Hooray sandstone are within 5 m of the ground surface. Regionally, the Jurassic and Cretaceous sedimentary sequence is thin along the Eulo Ridge, and onlaps inliers of Devonian granite and Lower Palaeozoic low-grade metamorphics; near-surface basement and inliers correspond to and are surrounded by areas of spring activity. Several linear features and faults are marked by springs E28-33. Formation of the mound springs undoubtedly is a slow process; Senior & others (1978) disagreed with Whitehouse's (1954) theory of very sudden outbursts of springs and the quick development of mounds, and the suggestion that covering blocks of granite and silcrete were brought up by the sudden surge of water when the springs broke out.

Some springs, such as E27, probably do not originate from the Great Artesian Basin but from Tertiary caprock. Other springs, for example E35-37, are located above the boundary of granite intruded in Palaeozoic sediments at the western boundary of the Nebine Ridge; this probably constitutes a deformed zone, due to compaction or movement, along which pressure water moves to the surface.

F - Lake Frome Group

Springs in the Lake Frome/Lake Callabonna area in South Australia are included in this group. Mound springs occur in a north-trending linear zone adjacent to Proterozoic rocks of the Flinders Ranges. Draper & Jensen (1976) described groups of mound springs in Lake Frome, and distinguished mounds composed of fine clastic material with a carbonate-cemented crust in the northern part of the lake from those in the south composed of carbonate. The northern mounds are up to 2 m high, are circular or elliptical in shape, and up to 15 m long and 5 m wide. The mounds in the south are about 0.5 m high, 1 to 2 m wide, and roughly circular. Water flowed from some mounds, and the volume of discharge was estimated by Draper & Jensen as a few litres per hour. Water-levels in other mounds were below their tops, but above the level of the lake floor.

Ker (1966) considered some springs along the foothills of the Flinders Ranges, including Paralana Hot Springs (F9), to be connected to fault structures. He inferred from the chemistry (analysis results are given in the report on Interstate Conference on Artesian Water, 1914) of Paralana Hot Springs that a connection with pressure water of the Great Artesian Basin existed, a suggestion which also had been made by Ward (1946) and David (1950).

Springs in Lake Frome (F1-8), Lake Callabonna (F10-11), and southwest of Lake Blanche (F15-16) are probably related to northerly and northwesterly trending faults. Other springs, F9, 12-14, occur where the thin Mesozoic cover abuts Proterozoic rocks or where faults occur in the Mesozoic sequence near the margins of the groundwater basin. Forbes (1966) related Reedy Springs, F15, to faults in an updomed area rimmed by steep monoclines. He also referred to the lineaments in and near the northern part of the Flinders Ranges and the alignment of Lake Frome, Lake Callabonna, Lake Blanche, Lake Gregory, Lake Eyre, and Lake Torrens.

G - Lake Eyre Group

Springs are most numerous in the Great Artesian Basin near its southwestern margin, south and west of Lake Eyre, in a zone about 400 km long and up to 20 km wide between Marree and Oodnadatta. More than 100 spring locations are listed; individual locations commonly represent many springs and seeps. Many springs have built up mounds consisting of sand, silt, and clay, generally cemented by carbonate, and overlain by layers of calcium carbonate. Palaeontological studies showed that the sediment particles have been brought up by the spring water from the underlying aquifers and Cretaceous cover rocks

(Forbes, 1961; Ludbrook, 1961). Distinct layers of travertine are present in the mounds, though sandy, silty and argillaceous limestone and some dolomitised rocks are more common. Quaternary fossils are abundant. The springs, and in several places their swampy surroundings or salt-crust flats overlying soft black mud, are potential traps for visitors. Many mound springs consisting of carbonate or clastic sediments can, however, be approached by vehicle. Mounds are from several metres to tens of metres in diameter and up to several metres high (fig. 13 in Habermehl, 1980). Many springs are no longer active, though the mounds remain, protected against erosion by the carbonate crusts or interbedded layers. Larger mounds may have a more or less circular water-filled crater on the top. A fine example of this is the perfect circular pool of Blanche Cup Spring, G35, situated on the crest of a mound which is about 5 m above the general ground-level and has a flat crater rim about 30 m across.

Craters of mounds are commonly breached by a single outlet, but many outlets may occur at the top or at different levels on their slopes. Large areas of carbonate rock and salt-encrusted plains surround many of the mound springs, which usually are located near the general plain level. Many mounds covered by carbonate crusts have little vegetation, though reedy grasses suggest the presence of moisture in them. Mounds built up mainly of clastic material usually sustain more vegetation, which can trap wind-blown material.

Discharges from individual springs in the Lake Eyre group are generally small, ranging from less than 1 to several litres per second (the largest being the Bubbler: 7.5 l/s; Cobb, 1975). Even so, discharges of some springs are sufficient to maintain small creeks for hundreds of metres or some kilometres; grasses, reeds and trees line the streams, although this is an arid area, where evaporation and evapotranspiration are very high. Many springs are only seepages or are no longer flowing. Flows are usually gentle and regular, though some have pulsating characteristics due to the infrequent upwelling of gas bubbles; the latter cause sediments to move in the pool of the Bubbler Spring (G37 - plate 37 in the report on Interstate Conference on Artesian Water, 1913). Total accumulated discharge from the Lake Eyre group springs is estimated at about 100-200 l/s. As the only significant water bodies in this arid area, they provide unique habitats for some endemic fauna (De Deckker, 1979).

Spring discharges probably have declined since the drilling of water wells started in the southwestern part of the Great Artesian Basin towards the end of the nineteenth century. Discharges from flowing artesian water wells in the area where the springs occur have decreased, and the potentiometric surface has been lowered. The diminution of spring discharges has not been analysed, as few historical flow records exist. Recent data on springs in the Lake Eyre region have been reported on by Cobb (1975) and Williams (1979) resulting from the BMR request to the Geological Survey of South Australia. They visited and described most of them, and measured discharges; additional work on the measurement of discharges from some mound springs is described by Holmes & others (1981). Cobb and Williams also reported on the results of recent and early chemical analyses of water. Other early results of chemical analyses of some of these springs were included in reports on Interstate Conferences on Artesian Water (1913), 1922, 1925, 1929), Jack (1915, 1923), Ward (1946), Chugg (1957), and Johns & Ludbrook (1963).

Water from springs in the eastern part of the Lake Eyre group are chemically characterised by sodium and bicarbonate components, and contain minor chloride ions. In the western part, sodium and chloride predominate over calcium and (high values of) sulphate; the bicarbonate component is small. Jack (1923) noted the difference in chemistry, which prompted him to distinguish westward and eastward-flowing groundwaters. Values of total dissolved solids for most springs range from about 2000 to 4000 ppm, which characterises the water as 'mineral water' (Richter & Lillich, 1975) - containing more than 1000 mg/l total dissolved solids. pH values range from about 7.1 to 8.1. Surface enrichment through concentration by evaporation of fluoride-bearing artesian groundwater was reported on by Forbes (1961). Near-surface samples in a drillhole on a mound spring contained up to 1900 ppm fluorine, though the fluorine (and chlorine and bromine) content rapidly decreased downward in the hole; the aquifer in this drillhole was encountered at about 17 m from the surface. Nearby artesian water wells contain about 1 mg/l fluoride. Temperature of the water in the springs shows a slight increase from east to west, from upper tens and mid-twenties (°C) to upper twenties, which places most springs in the category of 'thermal water' springs (Richter & Lillich, 1975).

Springs in this group are related to faults, to the abutment of the aquifers in the Algebuckina Sandstone and Cadna-owie Formation against the impervious basement of Proterozoic rocks at the margin of the basin, and to the breakthrough of water from the aquifers through the thin confining beds near the basin margin. Kerlatroaboorntallina Spring (lat. 28°01'S, long. 135°53'E), Edith Spring (lat. 28°28'S, long. 136°05'E), and Tarlton Springs (lat. 28°31'S, long. 136°05'E) might not originate from the Great Artesian Basin aquifers as their hydrochemistry is atypical; these springs are located on the faulted edge of basement rocks.

In this area many extinct mound springs and associated deposits still exist among the large number of active springs. Most active and extinct spring mounds rise no more than several metres above the present land surface (which is about 0 to 40 m above mean sea level), but some reach heights of more than 40 m above the surrounding area. Two such are Hamilton Hill and Beresford Hill (lat. 29°27'S, long. 136°51'E and lat. 29°16'S, long. 136°40'E), which had their beginnings as mound springs built upon or near a weathered Pleistocene land surface 10 to 50 m above the present plain (Wopfner & Twidale, 1967). The present, lower landsurface in this area resulted mainly from dissection consequent on tectonic movements, but was partly produced by deflation during a windier Quaternary arid climate (Bowler, 1976). Hamilton Hill and Beresford Hill are mesa or inselberg remnants of parts of the old land surface protected by the carbonate-cemented sediments of the ancient mound springs. Both of the hills are adjacent to active flowing springs at the present plain level.

Lowering of spring outlet levels has resulted from the combined action of step-wise lowering of the land surface by erosion and denudation, and the breakthrough of water at a lower level (Fig. 5). The latter will cause a progressive lowering of the pressure heads in the spring areas and reduced flow from higher springs (Habermehl, 1980). Clogging of the upper outlet of springs by sediments and carbonate cement, and the reslting lower-level breakthrough and discharge of water, has a similar effect on the hydraulic conditions. Phreatophytic vegetation accelerates the extinction of active mound springs by extracting water and by trapping aeolian sediments on the mound.

Lowering of the spring outlet level will cause a temporary steepening of the hydraulic gradient and increased discharge from the spring. As the hydraulic gradient adjusts, discharge will be reduced; if no further lowering of the land surface occcurs and no other springs develop at a lower level (a pre-artificial discharge stage is assumed), then the potentiometric surface will not change significantly, and the spring could exist for a long time, depositing material until it might choke itself.

Uplift of an area with springs could elevate the springs above the potentiometric surface of the aquifer in the area, causing the spring to cease flowing, or, if not lifted to such a height still reduce the hydraulic gradient and diminish the flow of the spring to the extent that the spring might become clogged with sediment and cement. Adjustment of the potentiometric surface to the higher level might eventually lead to the development of new springs at the higher level.

Rupture of the confining bed outside the area of the original spring may lead to the building of a new mound, which could even cover neighbouring

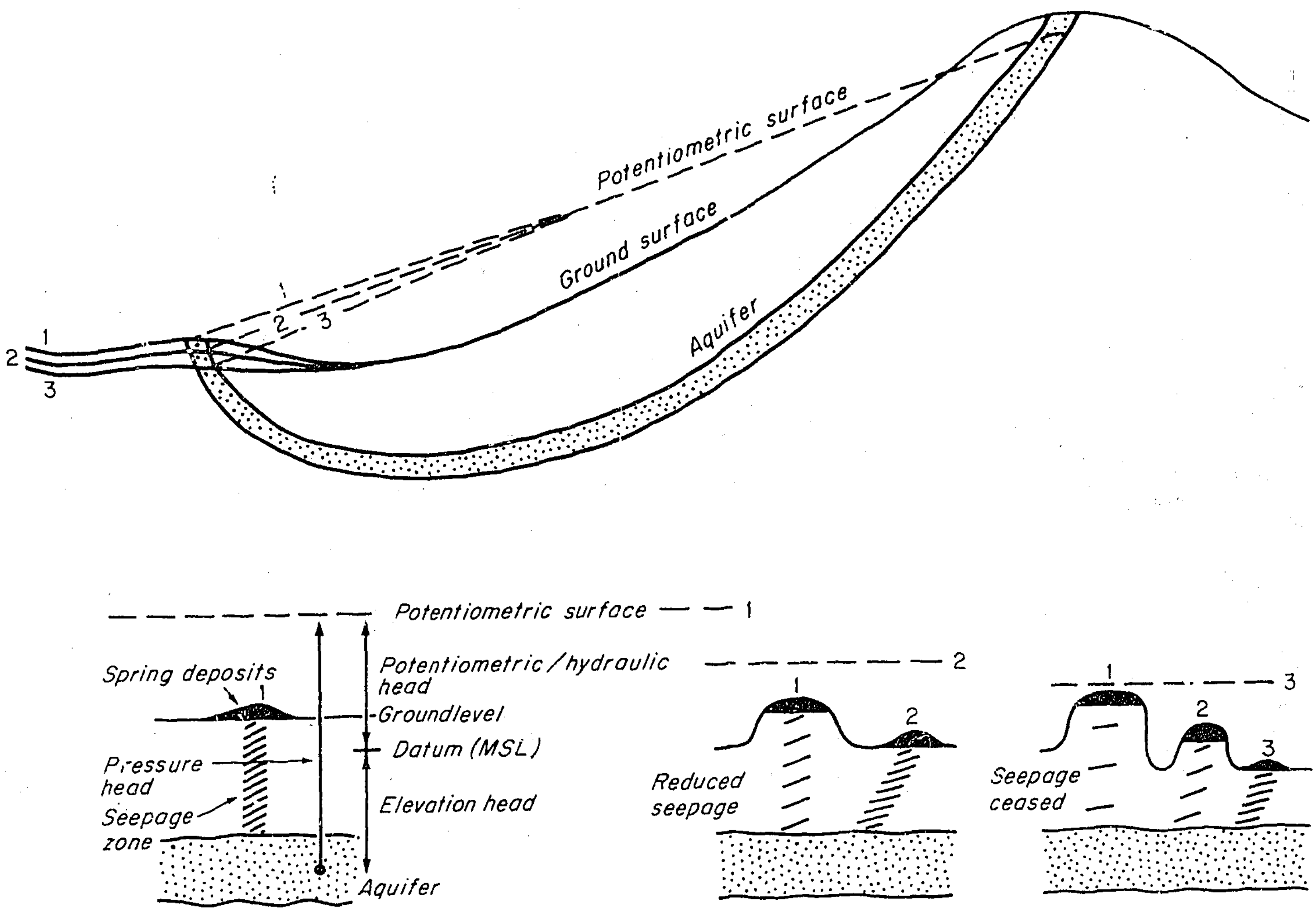


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Fig. 5 The effect on spring outlets of lowering of the potentiometric surface of an aquifer as a result of denudation of the ground surface at stages 1, 2 and 3 springs and mounds. Mounds may become prone to erosion as the landscape evolves, as in the example already given, especially if the mound has dried out and no vegetation is present; hard carbonate capped mounds, or mounds with some springflow or moisture in them, could resist erosion much better. The net result is that, in some locations, artesian springs and their deposits will range from the topographically higher and older to the topographically lower and younger.

The Report of the Third Interstate Conference on Artesian Water (1922), Ward (1946), and David (1950) suggested that the older, extinct and larger mound springs show features - including their heights and the distribution thicknesses of their deposits - which indicate a much larger discharge at earlier times than at present. Whitehouse (1954) regarded the high, ancient mounds as evidence that the hydraulic surface of the basin was once about 30 m higher than at present. He suggested that, with other springs breaking out, the hydraulic surface was lowered to the level of the springs active at the beginning of this century. Wopfner & Twidale (1967) suggested that the eastern rim of the Great Artesian Basin was uplifted during the Late Pleistocene, causing a marked increase in the 'piezometric' gradient of the artesian aquifers, which - together with the 'liberal charge' of the aquifers during the wetter Pleistocene - resulted in the expulsion of artesian water in springs along the west and southwest margins of Lake Eyre. They also noted that the elevation of the limestone deposited by Pleistocene artesian springs is considerably higher than the 'hydrostatic' levels of the surrounding modern mound springs. Bowler (1976) referred to the variations in flow regimes of the mound springs as an indication of climatic changes during the Quaternary.

The distribution and thickness of the limestones of the great ancient mounds are not related to a much more abundant discharge of water under a greater head, but resulted from different, and probably prolonged and steady, hydraulic conditions which were subsequently in post-Pleistocene times frequently disturbed. Changes in geological conditions caused alterations to the hydrodynamics of the southwestern marginal part of the Great Artesian Basin, and led to progressively topographically lower and, because of the short time spans of erosional activity, usually relative small deposits of the lower and younger springs. Williams & Holmes (1978) calculated that a spring with discharge of 0.055 l/s and solute concentration of 4000 mg/l (similar to some in the Lake Eyre group) would deposit 170 x 10^3 kg of calcium carbonate in 1000 years, enough to build a hemispherical mound 3 m high.

Wopfner & Twidale (1967) also stated that tectonic movements along the western lineament depressed Lake Eyre about 30 000 years ago, and uplifted areas to its west and northwest, resulting in rejuvenation of drainage and extensive dissection of the Pleistocene gypsite surface (the weathering profile associated with an extensive Pleistocene land surface) through into the Cretaceous sediments. Simultaneously with the formation of the gypsite sediments, extensive spring limestone had been deposited on the Pleistocene erosional surface southwest and west of Lake Eyre. The distribution of this limestone follows closely that of present active mound springs. However, the travertine mounds of the modern springs rest on a much younger and considerably lower erosional surface than that of the Pleistocene freshwater limestones.

H - Dalhousie Group

The Dalhousie Group of springs is a dense concentration of about 80 springs in an elongated north-northeast-trending zone roughly 15 km long by 5 km wide about 120 km north of Oodnadatta. Artesian water from aquifers in the Algebuckina Sandstone leaks along north-northeast-trending fractures in the eroded crest of the Dalhousie Anticline (Williams, 1974; Williams & Holmes, 1978; Wopfner & Twidale, 1967). The main aquifer occurs about 50 to 200 m below the ground surface in the spring area. The heights of mounds range from several metres to over ten metres above the surrounding erosion surface, which is about 5 to 25 m below a dissected limestone plateau. The latter is thought to be a remnant of an earlier phase of spring activity during the Pleistocene, and lies at about 130 m.

Springs in the Dalhousie area have built up large, mostly circular mounds up to about 100 m in diameter generally of sand and silt-size material. Dense grasses, reeds, rushes, and trees (and imported date palm trees near the ruins of Dalhousie homestead and near some northern springs) cover many of the mounds, and usually extend along the streams originating from some springs and spring-fed pools. These streams have lengths of several kilometres and many flow into Spring Creek, which drains eastwards but does not reach the sand dunes of the Simpson Desert. Some springs do not empty into the general drainage, and saline playa lakes have formed. These salt flats and some salt-encrusted areas along creeks form treacherous areas where salt crusts overlie soft dark mud. In flat areas, and along slopes without distinct spring activity or visible water, seepages are marked by moist and discoloured soils and salt deposits.

Discharge measurements and water sampling from Dalhousie Springs are reported in Williams (1974) and Williams & Holmes (1978). Earlier chemical analyses are given in the report on Interstate Conference on Artesian Water

(1914). Discharges from individual springs range from negligible flow up to about 85 l/s (Williams, 1974). Accumulated discharges* of the Dalhousie Group of springs are about 670 l/s (Williams, 1974; Williams & Holmes, 1978). Springs in the Dalhousie area provide the largest natural concentrated outflow from the Great Artesian Basin.

Temperatures of the spring water range from 29 to 44°C, the warmer springs being located in the north. Salinities range from about 650 to 2000 ppm total dissolved solids; the higher salinities are found in the southern part of the group. Values of pH range from about 7 to 8. The chemistry of the water from these springs is characterised by sodium and chloride; calcium, magnesium, and sulphate are less common. Bicarbonate is less common in the Dalhousie spring water than in water from the main (central and eastern) part of the basin. Chemically the water from the Dalhousie Group correlates with water from wells in the westernmost part of the Great Artesian Basin, which is derived from a western recharge area and flows eastwards (Habermehl, 1980, figs. 12 and 17). Jack (1923) located his 'neutral line', representing the equivalence of sulphate and carbonate ions, immediately west of Dalhousie Springs (H5), and drew the isopotentials in such a way that westward-moving water in the basin could flow towards Dalhousie Springs. Ward (1946), who reported the results obtained by Jack, included a figure (fig. 16) showing the neutral line across Dalhousie Springs, which are surrounded by eastward, southward, and westwards moving water. The potentiometric maps in Habermehl (1980) show that Dalhousie Springs derive their water from the western recharge area of the basin. Environmental isotope analysis indicate that the water issuing from the springs was recharged into the basin in relatively modern time (the water contains about 3 to 6 percent modern carbon) and that the artesian water is of meteoric origin (G.E. Calf, Australian Atomic Energy Commission, personal communication 1978).

The flow from the Dalhousie Springs (H5), which according to Williams (1979) account for 95 percent of the natural discharge from the Great Artesian Basin in South Australia and according to Williams & Holmes (1978) 10 percent of the basin recharge, is less than half of the total discharge (1500 l/s) from all springs in the basin (Habermehl, 1980). Discharge approximates 0.67 m^3/s and

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*Williams (1974) listed the total discharge of the Dalhousie Group of springs as 860 l/s, and Williams & Holmes (1978) showed the discharge as 697 l/s. However, the discharge for spring 29A (in Williams, 1974), which is shown as 230 l/s, is in error, and should be about 30-40 l/s (A.F. Williams, personal communication, 1980), changing the total discharge from the Dalhousie Group of springs after correction to about 670 l/s.

is (1) 3.94 percent of the accumulated discharge rate (about 17 m^3/s) from flowing artesian wells in the Great Artesian Basin in 1970 (Habermehl, 1980); (2) 2.58-1.91 percent of the GABHYD model computed recharge (26-35 m^3/s) to the whole basin (Habermehl & Seidel, 1979; Habermehl, 1980); and (3) 0.04 percent of the average amount of precipitation available for recharge in all intake areas of the basin, which is about 1700 m^3/s. However, little or no use has been made of the occurrence, size, and distribution of the springs and wells and their discharges in South Australia during calibration and application runs of the GABHYD model. Therefore any results and predictions for discharges and drawdowns, and particularly for potentials, produced by the model for these western and southwestern parts of the basin should be considered with caution. The imposition of the Dalhousie Group of springs and the flowing artesian wells would significantly alter the potentiometric map in the westernmost region.

Despite such changes it is clear that water from the Dalhousie Group of springs is mainly derived from the western recharge areas (Habermehl, 1980, figs. 12, 15, and 17), even though these areas are located in some of the most arid parts of Australia (evaporation in this region is about 3300 mm/year). Though recharge in the area where aquifers crop out along the western margin of the basin, is small, recharge to the aquifers probably does not occur exclusively in the aquifer outcrops. The Alberga, Hamilton, Finke, Todd, Illogwa, Plenty, Hay, and Field Rivers cross the aquifer outcrops and disappear in the sand dunes of the Simpson Desert after their long surface flow over relatively impervious Proterozoic and Palaeozoic rocks of the Amadeus Basin, Arunta Block, and Georgina Basin. These major, though ephemeral rivers parallel the dips of the sedimentary sequence in the Great Artesian Basin and probably contribute to the subcropping Jurassic and Cretaceous aquifers through leaky confining beds under the dunes. LANDSAT images show large, probably moisture - rich areas in line with the above rivers underlying the dunes of the Simpson Desert.

Recent tectonism in the western part of the basin (Wopfner & Twidale, 1967), mainly concentrated in an area surrounding the western depression (Fig. 6), contributed to the establishment of the present hydraulic regime in this area. Some of the mechanisms proposed by Burdon (1977) and Lloyd & Farag (1978) could explain the origin of the hydraulic conditions.

<u>I - Mulligan River Group</u>

Several small groups of active and extinct springs occur near the Mulligan River, along the northwestern margin of the basin. Those in the southwestern part of this group - e.g., Bepperry, Bookerra, Alnagata, Mirrica, and Ethabuka Springs - are related to the Toomba Fault and smaller cross-faults west of this structure.

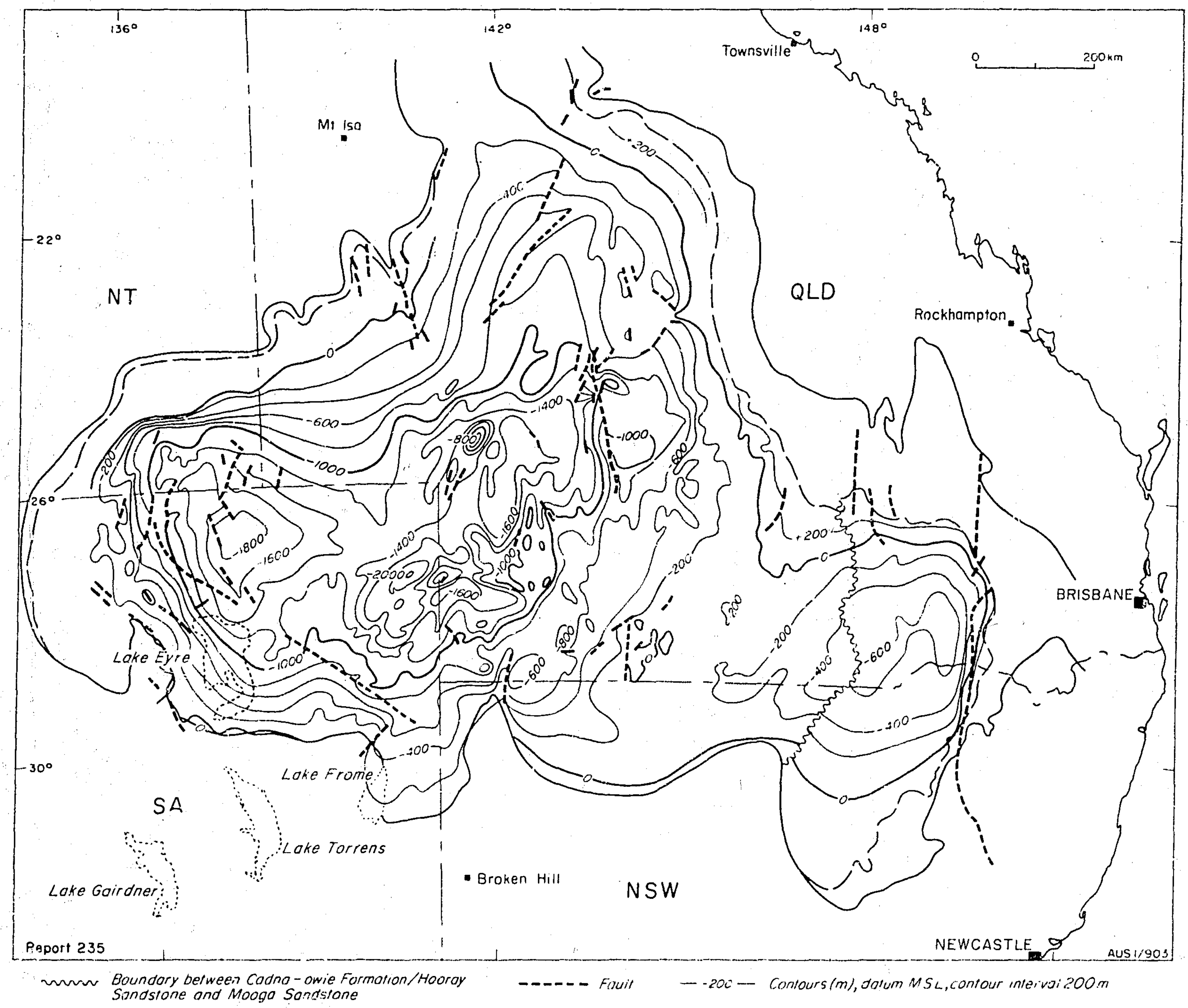

Fig. 6 Structure contour map of the base of the Rolling Downs Group and the top of the upper main aquifer producing flowing artesian wells in the Lower Cretaceous - Jurassic sequence of the Great Artesian Basin

Springs near Mount Whelan, in the northern part of this group, occur near the outcrops of the aquifer-bearing Hooray Sandstone, which abuts and overlies in the west and north the impervious Proterozoic and lower Palaeozoic rocks of the Georgina Basin. Pressure water escapes from the exposed Hooray Sandstone or has penetrated the thin beds of the overlying Wallumbilla Formation, and springs and swampy areas have formed on Cretaceous and Quaternary sediments.

Mounds consist of sand and silt-size particles; carbonate-covered hard mounds are also present. Large areas show signs of subdued seepage, and have a hummocky appearance, discoloured soils, patches of salt, and specific vegetation.

Spring discharges apparently are declining because of the drilling of wells in the area. Water discharged from these springs is mainly derived from the eastern recharge areas, though some might be derived from the northwestern and western recharge areas (according to figs. 12 and 15 in Habermehl, 1980). No hydrochemical analyses are known from these springs, but the chemistry of the water from nearby wells confirms the groundwater origin and movement as derived from potentiometric maps.

J - Springvale Group

Most springs in this group occur east and southeast of Boulia along a north-northwest-trending fault, the Burke River Structure. This fault has displaced Proterozoic and Palaeozoic rocks, and folded and faulted the overlying thin sedimentary sequence of Mesozoic rocks in the northwestern margin of the basin, affording natural outlets for aquifers in the Hooray Sandstone.

The unnamed springs J1 (shown on the SPRINGVALE SF54-14 geological map sheet as Old Spring Mounds) consists of several mounds about 2 m high; the springs, however, might not only be related to Jurassic and Cretaceous aquifers, but also to confined aquifers in Cainozoic sediments in the alluvial plain (Senior & Hughes, 1972).

Springs near the Hamilton River are listed in the report on Interstate Conference on Artesian water (1913).

Elizabeth Springs (J3), near Springvale homestead and about 80 km southeast of Boulia, are also located on the Burke River Structure and consist of a large number of mound springs in a relatively small area. Many of the mounds are about 2 to 3 m high and several metres in diameter; water flows or seeps from them and they are partly covered with grasses. Water also flows and seeps from several springs at plain level and in the bed of Spring Creek.

Water from the springs drains into Spring Creek, which contained a large body of water during my visit in August 1979. The activity of the Elizabeth Springs has diminished since well development started in the area; this is documented by figures on the spring flow in the report on Interstate Conference on Artesian Water (1913), David (1950), Whitehouse (1954), and Randal (1978).

David (1950) suggested that the original flow from springs near Springvale was probably about 105 l/s, as they used to supply a large creek flowing for about 65 km; he reported that after the drilling of nearby flowing wells the spring discharges diminished to less than 1 l/s. However, the report by the Queensland Government (1954) records that before drilling of artesian water wells took place in the area, Spring Creek was reported to run as far as the Diamantina River, about 130 km, and the original flow was about 158 l/s. The report also notes that, at the first official inspection in 1896, (Henderson , 1896) Elizabeth Springs flow was measured to be 31.6 l/s, and the creek was running for 30 km (similar figures are given in the report on Interstate Conference on Artesian Water, 1913, although it is not clear whether they were measured in 1896 or 1912); in 1914, after well drilling, spring flow was about 5.2 l/s, and in 1954 about 0.8 l/s. According to Whitehouse (1954) the creek was not flowing that year. Randal (1978) reported the flow of Elizabeth Springs to be about 29 l/s in 1896, about 5 l/s in 1914, and about 0.8 l/s in 1954. Observed flows from the Elizabeth Springs in 1979 were much larger, and amounted to at least several litres per second.

The differences in the estimates of the amounts of water flow in the creek supported by the spring at different times by different observers could be attributed perhaps to the observations having been made during different seasons, when higher or lower rates of evaporation affect the spring discharges and the creek. Contributions by precipitation shortly before measurements were made also could distort the creek flow figures.

The fact remains, however, that most springs located on the Burke River Structure, and other springs near the Hamilton River, have been significantly affected by well development, like so many other springs in the basin.

Among other springs in group J, Randal (1978) reported the Pathungra Spring to be dry; Bulla Bulla Springs are largely obliterated by the water mass of the Bulla Bulla Waterhole (1979 observation). An unnamed spring, J8, occurs close to the McKinlay River near the margin of the basin. Other springs near the McKinlay River, and probably related to the north-northeast-trending Kevin Downs Fault which displaced the Mesozoic sequence, are listed in the report on Interstate Conference on Artesian Water (1913), but are not shown on recent maps (McKINLAY 1:250 000 map sheet). Fraser (ca 1910) described active mound springs near 'McKinlay (M'Kinley) Creek'.

K - Flinders River Group

Springs and mound springs in the northern part of the Eromanga Basin and the southern part of the Carpentaria Basin are included in this group.

Springs are generally related to structural features or occur where Jurassic and Cretaceous aquifers onlap onto or are bounded by Proterozoic rocks. Water from confined aquifers in the Gilbert River Formation issues from natural outlets near the barrier formed by the impervious northwest-trending Fort Bowen Ridge, which has outcrops of Proterozoic rocks, and the associated St Elmo Structure (K1-K7); some springs are determined by the Woodstock Structure (K8-K31), Three X Structure, and other faults.

A north-northwest-trending zone of springs K32-K34, K26-K27 and K23 exists south of the Woodstock Structure and parallel to and west of the Middle Park Structure and the exposure and recharge area of the Gilbert River Formation. It suggests a zone of deformation and weakness in the Mesozoic sediments where water moves up through the Wallumbilla Formation, and is probably associated with faulting of the Euroka Arch.

Several more springs in this area were listed in the report on the Interstate Conference on Artesian Water (1913); a table of perennial springs contains the remark that Plain Spring, K12, resembles Elizabeth Springs, J3; it was listed as having a discharge of 5 l/s. About 30 springs were listed in that table for this area; most were said to have discharge rates in the range of 0.2 to 3 l/s.

Other descriptions of the springs in this area occur in Maitland (1898), Interstate Conference on Artesian Water (1913, 1914), Whitehouse (1954), and Reynolds (1960). In some of these descriptions, reference is made to the diminution or cessation of spring flows since the drilling of flowing artesian wells in the area. Some of these springs have built up mounds of clastic material and deposited calcareous layers commonly heavily vegetated by reeds and trees. Travertine deposited by spring activity is interbedded with the sediments of the late Pliocene Glendower Formation, according to Whitehouse, at Waddy Spring, K34, near Saxby Downs homestead. Levingston (1959) described a spring deposit near Saxby Downs which basically consisted of soil with carbonaceous material and sulphates of iron, calcium, magnesium, and aluminium; the carbonaceous material was probably derived from the vegetation supported by the spring.

Many other springs have sources other than the Jurassic and Cretaceous aquifers. For example, a group of five springs at roughly latitude 18°25'S, longitude 140°35'E is probably related to Tertiary weathering and duricrusting of the Normanton Formation.

In the northeastern part of the margin of the Great Artesian Basin, north of Hughenden, at least eight springs occur mostly in or at the edge of Tertiary to Quaternary basalt plateaus and plains which overlie a large part of the Mesozoic rocks in this area. Most of them (unnamed springs at lat. 20°23'S, long. 144°08'E; lat. 20°34'S, long. 144°11'E; Soda Gorge Spring at lat. 20°37'S, long. 144°05'E; Spider Creek Spring at lat. 20°17'S, long. 144°25'E; and unnamed springs at lat. 20°17'S, long. 144°26'E) probably issue from joints and fractures in the basalt and are not related to aquifers in Mesozoic rocks. Rainwater which percolates through the basalt and then recharges the aquifers of the Great Artesian Basin will display a hydrochemistry that is different from that of groundwater which entered the aquifers directly. Two of the springs north of Hughenden - Mickey Spring and an unnamed spring at latitude 20°23'S, longitude 144°37'E - might be derived from the Jurassic Blantyre beds rather than from the Tertiary basalts, and another unnamed spring, at latitude 20°56'S, longitude 144°28'E, occurs in the Tertiary Glendower Formation. Several more springs in the same area, and probably all related to the Glendower Formation, which consists of fluviatile deposits - often forming scarps and mesas - overlying the Rolling Downs Group, are listed in the report on Interstate Conference on Artesian Water (1913).

Water which flows northerly and westerly in the Jurassic and Cretaceous aquifers in the Carpentaria Basin part of the Great Artesian Basin, as shown by potentiometric maps, could emerge through subsea springs in the Gulf of Carpentaria.

SPRINGS IN TERTIARY SEDIMENTS IN THE CENTRAL GREAT ARTESIAN BASIN

In the central part of the Great Artesian Basin, springs are abundant, though none seem to derive their water from aquifers in the Great Artesian Basin. All springs are located at the edges of the Tertiary Glendower Formation, which commonly consists of quartzose sandstone, siltstone, breccia, and conglomerate overlying the Cretaceous sediments; silcrete (silicified quartz sandstone) occurs at the top of the unit.

The unnamed springs located at latitude 26°10'S, longitude 143°15'E at an elevation of 150 m occur in Quaternary sediments; they lie south of four unnamed springs (roughly at lat. 25°58'S, long. 143°15'E, at an elevation of 180 m) which are near Glendower Formation sediments overlying 900 m of Winton Formation on or near the axis of the Chandos Anticline. Two springs occur at the edge of Tertiary sediments (at lat. 25°53'S, long. 143°05'E) near northwest-trending faults west of the Canaway Fault, and one spring in the Glendower Formation is located at an elevation of 325 m at lat. 25°25'S, long. 143°45'E. Two springs, one of them Durack Spring, are present in the Glendower Formation (at lat. 25°10'S, long. 142°37'E, elevation 145 m), overlying about 650 m of Winton Formation in the axis of the Windorah Anticline; the depth to the top of the Hooray Sandstone here is about 1500 m.

About eleven unnamed springs occur in the western part of the Grey Range at the edge of the Glendower Formation which overlies the Winton Formation near Coorajah Creek (at lat. 25°05'S, long. 144°20'E, elevation 305 m). Four springs occur in the Glendower Formation where the south-flowing Bulloo River is intersected by the southeast-trending Lissoy and Gowan Anticlines (at lat. 25°05'S, long. 144°45'E, elevation 335 m).

Teatree, Sidey, Gum and Russell Springs are situated near the edge of the Glendower Formation which overlies the Winton Formation; Gum Spring (at lat. 24°45'S, long. 143°35'E, elevation 305 m) is near a fault which is south of the Stormhill Fault, and which has displaced the entire Mesozoic sequence.

The Gerthnn Springs occur near the boundary of the Glendower and Winton Formations (at lat. 24°58'S, long. 141°37'E, elevation 135 m).

The Llanrheidal and Elderslie Springs are located at the western slope of Carters Range near Middleton Creek at the boundary of the Winton Formation and overlying duricrust (at latitude 22°29'S, longitude 141°45'E ,elevation 200 m).

An unnamed spring occurs at latitude 23°20'S, longitude 143°05'E,at an elevation of 245 m in the Winton Formation.

Springs in the central part of the Great Artesian Basin are generally related to Tertiary cappings, and not derived from aquifers lower in the stratigraphic sequence. Many faults do however, occur in the basin (Senior & Habermehl, 1980), and in many parts of the basin the regional groundwater flow is directed normal to faults. No signs of springs or pressure water seepage are present near these faults. Either these faults do not provide a pathway for upward-flowing pressure water from the confined aquifers in the Cretaceous and Jurassic sequence because the thick Cretaceous mudstone sequence sealed the faults, or pressure water from Jurassic aquifers moves upwards, but enters the Cretaceous aquifers and does not reach the ground surface. Potentials of the aquifers in the Cretaceous sequence (Winton and Mackunda Formations) are lower than potentials of aquifers in the Jurassic-Lower Cretaceous sequence (Habermehl, 1980), and upward flowing water will enter the Cretaceous aquifers instead of flowing to the surface or be absorbed in the regional groundwater-table. An example of this is given by Polak & Ramsay (1977), who suggested that, in the area of the Canaway Fault, water from the Hooray Sandstone leaked along the fault plane into the Winton Formation. Samples from water wells (Queensland Water Resources Commission - Registered Numbers 3947 and 3950) which bottom in the Winton Formation show hydrochemical characteristics of (sodium bicarbonate) water from the much deeper Hooray Sandstone, but with a much higher chloride content. The chloride is probably derived from the mixing with sodium chloride-type water, which is characteristic for the aquifers in the Winton and Mackunda Formations. Polak & Ramsay further suggested that temperatures (geothermal gradient values) in the area indicated vertical groundwater flow.

CONCLUSIONS

About 600 springs occur in the marginal areas of the Great Artesian Basin; they can be subdivided into eleven regional groups. Most springs originate from the abutment of aquifers against impervious bedrock near the discharge margins of the basin (spring groups D,E,F,G,I,J, and K), where flows occur from outcropping aquifers or where the pressure water has broken through thin confining beds and formed artesian springs. Many springs, including many near the discharge margins, are related to faults which have displaced aquifers and confining beds and created pathways to the surface for pressure water (spring groups C to K). Spring group A is probably also related to structural phenomena such as faults or monoclines, though facies changes in the aquifers and/or confining beds could also be responsible for these spring occurrences. Spring group B represents overflow from aquifers intersected by a topographic surface dipping in an opposite direction. Many springs in the area where group B is located issue not from the Great Artesian Basin, but flow out of a basalt capping. Similar springs also occur in the Hughenden area, where basalt overlies the recharge area of some Great Artesian Basin aquifers.

Springs in the central part of the Great Artesian Basin area are related to Tertiary sediments, and do not originate from aquifers in the Mesozoic sedimentary sequence which forms the Great Artesian Basin.

Discharges from the springs in the Great Artesian Basin generally are small, and most spring flows range from less than 1 l/s to several litres per second, but generally are less than 10 l/s. Few springs have flows of more than 10 l/s or several tens of litres per second; the maximum recorded flow is 851/s from a spring in the Dalhousie Group (H) of springs. The accumulated discharge of the 600 springs is estimated at about 1500 l/s. The flow from all springs represents only a small percentage of the recharge to the Great Artesian Basin.

Though few historic measurements exist, and only part of the eleven groups of springs (mainly in South Australia) have been measured in recent times, it is clear that spring discharges have declined since water-well abstraction commenced in the basin around the end of the nineteenth century.

Physical and chemical characteristics of the water issued by some springs have been studied in South Australia, and the results indicate that the water exhibits all the characteristics of the water from the main artesian aquifers in the Great Artesian Basin.

The occurrence of spring deposits at different topographic and stratigraphic levels along the southwestern margin of the Great Artesian Basin, with springs and their deposits ranging from topographically higher and older to topographically lower and younger, is the result of the lowering of the spring outlet levels caused by lowering of the land surface and the accompanying breakthrough of water at lower levels.

Table 1

SPRINGS IN THE GREAT ARTESIAN BASIN, AUSTRALIA

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
TANGORIN SF55-5					
A	1	unnamed spring	21°58'	145°24'	275
MUTTABURRA SF55-9					
A	2	unnamed springs (18)	22°10'	145°23'	245
A	3	unnamed springs (3)	22°16'	145°16'	240
A	4	unnamed springs (?)	22°18'	145°24'	260
A	5	unnamed springs (?)	22°26	145°26'	260
A	6	unnamed springs (?)	22°48	145°26'	245
LONGREACH SF55-13					
A	7	unnamed springs (3)	23°17'	145°25'	245
JERICHO SF55-14					
A	8	unnamed spring	23°00'	145°47'	370
A	9	4-mile Spring	23°08'	145°50'	365
A	10	unnamed springs (2)	23°15'	145°45'	345
A	11	unnamed spring	23°25'	145°51'	340
A	12	unnamed springs (2)	23°34'	145°55'	345
A	13	unnamed spring	23°37'	145°54'	380
A	14	unnamed springs (2)	23°44'	145°45'	320
A	15	unnamed springs (5)	23°51'	145°41'	315
A	16	unnamed springs (2)	23°54'	145°40'	320
TAMBO SG55-2					
A	17	Maryvale Spring	24°03'	145°54'	380
A	18	Cutt's Spring	24°18'	146°01'	365
A	19	Barcoo River Springs(7)	24°35	145°50'	335
A	20	Pop's and Fern Springs	24°50'	145°45'	
SPRINGSURE SG55-3					
B	1	unnamed spring	24°32'	147°15'	365
B	2	unnamed spring	24°32'	147°18'	335

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
SPRINGSURE SG55-3 (contd)					
B	3	Belinda Spring	24°50'	147°12'	440
B	4	Major Mitchell Spring	24°57'	147°11'	450
B	5	Sixteen Mile Spring	24°57'	147°29'	
B	6	Good Friday Spring	24°56'	147°44'	730
B	7	Paddy's Spring	24°56'	147°51'	790
B	8	Bulldog Springs	24°39'	147°51'	
B	9	unnamed spring	24°36'	147°57'	
EDDYSTONE SG55-7					
B	10	Crystalbrook Spring	25°30'	148°59'	525
B	11	unnamed spring	35°57'	148°16'	535
B	12	unnamed spring	25°58'	148°15'	
B	13	unnamed spring	25°59'	148°15'	
B	14	unnamed spring	25°18'	147°10'	
TAROOM SG55-8					
B	15	unnamed springs (3)	25°48'	148°46'	410
B	16	unnamed spring	25°49'	148°46'	410
B	17	unnamed spring	25°49'	149°03'	410
WALGETT SH55-11					
C	1	Cuddie Spring	30°23'	147°20'	130
BOURKE SH55-10					
C	2	Coolabah Spring	30°45'	146°58'	140
ANGLEDOOL SH55-7					
C	3	Cumborah Spring	29°45'	147°45'	150
ENNGONIA SH55-6					
D	1	Old Morton Plains Spring	29°05'	146°45'	130
D	2	Gooromere Springs	29°07'	146°40'	130

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
ENNGONIA SH55-6 (contd)					
D	3	Sandy Plains Spring	29°12'	146°40'	130
D	4	Tooloomi Spring	29°17'	146°40'	130
D	5	Bunnavinyah Spring	29°15'	146°24'	145
D	6	Gurrera Spring	29°17'	146°23'	145
D	7	Thully Spring	29°43'	146°20'	110
D	8	Yarranongany Spring	29°28'	145°45'	130
D	9	Nullyna Spring	29°30'	145°47'	140
D	10	Native Dog Spring	29°32'	145°51'	135
D	11	Lila Springs	29°32'	145°58'	140
YANTABULLA SH55-5					
D	12	Wapweela Spring	29°15'	145°28'	140
D	13	Thooro Spring	29°21'	145°21'	140
D	14	Pullamonga Spring	29°32'	145°17'	145
D	15	Coonoilly Spring	29°33'	145°16'	145
D	16	Yantabulla Spring	29°20'	145°00'	145
D	17	Cullawillalee spring	29°26'	154°07'	155
D	18	Boongunyarra Spring	29°28'	145°08'	155
D	19	Yongarinnia Spring	29°32'	145°08'	160
LOUTH SH55-9					
D	20	Wee Wattah Spring	30°45'	144°15'	80
WHITE CLIFFS SH54-12					
D	21	Peery or Peri Spring	30°45'	143°35'	120
D	22	Yantabangee Spring	30°35'	143°50'	105
EULO SH55-1					
E	1	unnamed spring	28°47'	144°15'	120
E	2	unnamed springs (2)	28°47'	144°26'	150
E	3	unnamed spring	28°45'	144°25'	175
E	4	unnamed spring	28°45'	144°24'	125
E	5	unnamed springs (2)	28°42'	144°25'	125
E	6	unnamed spring	28°43'	144°28'	140
E	7	unnamed spring	28°43'	144°30'	140

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
EULO SH55-1 (contd)					
E	8	unnamed spring	28°29'	144°29'	155
E	9	unnamed springs (2)	28°29'	144°26'	155
E	10	unnamed spring	28°29'	144°34'	170
E	11	unnamed springs (3)	28°26'	144°30'	155
E	12	unnamed springs (3)	28°18'	144°32'	215
E	13	unnamed springs (2)	28°21'	144°19'	155
E	14	unnamed spring	28°17'	144°18'	155
E	15	Wombula Springs	28°16'	144°19'	155
E	16	unnamed spring	28°16'	144°20'	150
E	17	unnamed spring	28°14'	144°21'	150
E	18	unnamed spring	28°16'	144°34'	220
E	19	unnamed spring	28°14'	144°37'	215
E	20	unnamed spring	28°12'	144°38'	215
E	21	unnamed spring	28°11'	144°43'	190
E	22	unnamed spring	28°07'	144°43'	180
E	23	unnamed spring	28°07'	144°47'	170
E	24	unnamed spring	28°07'	144°52'	150
E	25	unnamed springs (2)	28°11'	145°02'	150
E	26	unnamed springs (3)	28°07'	145°08'	165
E	38	unnamed springs (2)	28°10'	144°57'	170
CUNNAMULLA SH55-2					
E	27	unnamed springs (2)	28°51'	146°48'	130
TOOMPINE SG55-13					
E	28	unnamed spring	27°59'	144°47'	175
E	29	unnamed spring	27°57'	144°46'	160
E	30	unnamed spring	7°57'	144°48'	175
E	31	unnamed springs (2)	27°56'	144°52'	175
E	32	unnamed spring	27°54'	144°53'	180
E	33	unnamed spring	27°53'	144°54'	180
E	34	unnamed spring	27°45'	144°44'	200

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
WYANDRA SG55-14					
E	35	unnamed spring	27°12'	146°30'	260
E	36	Town Springs (2)	27°10'	146°31'	275
E	37	unnamed spring	27°08'	146°32'	275
FROME SH54-10					
F	1	unnamed spring	30°54'	139°57'	
F	2	unnamed spring	30°52'	139°57'	
F	3	unnamed spring	30°39'	139°57'	
F	4	unnamed spring	30°37'	139°59'	
F	5	unnamed spring	30°34'	140°01'	
F	6	unnamed spring	30°32'	140°01'	
F	7	unnamed spring	30°30'	140°01'	
F	8	unnamed spring	30°23'	140°00'	
COPLEY SH54-9					
F	9	Paralana Hot Springs	30°10'	139°26'	
CALLABONNA SH54-6					
F	10	unnamed springs (8)	29°55'	139°40'	105
F	11	Mulligan Springs	29°43'	139°58'	
F	12	Twelve Springs	29°50'	139°39'	80
F	13	Petermorra Spring	29°46'	139°32'	80
MARREE SH54-5					
F	14	Catt Springs	29°45'	139°28'	90
F	15	Reedy Springs	29°32'	139°26'	60
F	16	Rocky Springs	29°31'	139°25'	60
G	1	One Tree Spring	29°37'	138°27'	70
G	2	Wirringina Springs	29°44'	138°21'	75
G	3	Lignum Spring	29°46'	138°13'	65
G	4	Mundowdna Spring	29°44'	138°14'	65
G	5	Two Mile Spring	29°43'	138°15'	60

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
MARREE SH54-5 (contd)					
G	6	Four Mile Spring	29°42'	138°10'	55
G	7	Hergott Springs	29°37'	138°04'	50
G	8	Marree Springs	29°37'	138°04'	40
CURDIMURKA SH53-8					
G	9	Welcome Springs (3)	29°40'	137°49'	40
G	10	Wangianna Spring	29°40'	137°42'	50
G	11	Davenport Springs (2)	29°39'	137°35'	30
G	12	unnamed spring	29°39'	137°30'	30
G	13	unnamed spring	29°41'	137°24'	30
G	14	unnamed spring	29°41'	137°22'	30
G	15	Venable Springs (3)	29°40'	137°21'	30
G	16	unnamed spring	29°38'	137°18'	30
G	17	Beatrice Spring	29°37'	137°21'	20
G	18	Finniss Swamp	29°35'	137°24'	10
G	19	Hermit Hill (Finniss Springs-10)	29°34'	137°25'	20
G	20	Zeke (Bopeechee) Spring	29°36'	137°23'	10
G	21	unnamed springs (2)	29°33'	137°23'	0
G	22	Smith Springs (3)	29°30'	137°21'	-5
G	23	unnamed springs	29°30'	137°21'	-5
G	24	Gosse Springs (3)	29°28'	137°20'	-5
G	[illegible]	McLachlan Springs (2)	29°27'	137°19'	-5
G	[illegible]	Fred Springs (2)	29°31'	137°17'	-5
G	[illegible]	Priscilla Springs	29°34'	137°12'	0
G	[illegible]	Jacob's Spring	29°29'	137°09'	10
G	29	Emerald Springs	29°23'	137°04'	0
G	30	Walcarina Spring	29°29'	137°01'	0
G	31	Anna Springs	29°32'	136°59'	20
G	32	Horse Springs (2)	29°29'	136°55'	10
G	33	unnamed spring	29°29'	136°53'	10
G	34	unnamed spring	29°30'	136°54'	10

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
CURDIMURKA SH53-8 (contd)					
G	35	Blanche Cup	29°27'	136°51'	10
G	36	unnamed springs (5)	29°27'	136°51'	10
G	37	The Bubbler	29°26'	136°51'	10
G	38	Coward Springs (2)	29°24'	136°47'	15
G	39	Kewson Hill	29°22'	136°47'	20
G	40	unnamed springs	29°21'	136°46'	20
G	41	Elizabeth Springs(2)	29°21'	136°46'	20
G	42	Jersey Springs (3)	29°20'	136°45'	20
G	43	Warburton Springs	29°16'	136°39'	30
G	44	Beresford Spring	29°16'	136°40'	30
G	45	Strangways Spring	29°09'	136°33'	40
BILLA KALINA SH53-7					
G	46	Emily Spring	29°03'	136°24'	75
G	47	William Spring	29°02'	136°28'	
G	48	Francis Spring	29°05'	136°16'	70
G	49	Francis Swamp - unnamed springs (7)	29°06'	136°17'	75
G	50	unnamed springs (6)	29°08'	136°18'	75
G	51	unnamed springs (10)	29°10'	136°18'	75
G	52	Bishop Spring	29°08'	136°18'	75
G	53	Tom Tom Spring	29°08'	136°18'	75
G	54	Wishart Spring	29°08'	136°18'	75
G	55	Two Sister Spring	29°09'	136°19'	75
G	56	Little Depot Spring	29°11'	136°19'	75
G	57	Big Depot Spring	29°12'	136°19'	75
G	58	unnamed spring	29°12'	136°18'	75
G	59	Margaret Spring	29°13'	136°20'	75
G	60	Billa Kalina Spring	29°28'	136°29'	50
G	61	unnamed springs	29°28'	136°27'	50
G	62	unnamed spring	29°31'	136°24'	50
G	63	unnamed spring	29°03'	135°03'	110

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
LAKE EYRE SH53-4					
G	64	unnamed spring	28°53'	137°45'	-10
G	65	unnamed springs (15)	28°46'	137°19'	-10
G	66	unnamed spring	28°48'	137°00'	-10
G	67	unnamed springs (5)	28°44'	137°02'	-10
G	68	unnamed springs (24)	28°34'	137°00'	-10
WARRINA SH53-3					
G	69	Loddon (Loudon) Springs	28°35'	136°24'	50
G	70	Brinkley Springs (3)	28°30'	136°18'	50
G	71	Hawker Springs + unnamed springs (14)	28°26'	136°12'	60
G	72	Spring Hill Spring	28°25'	136°10'	60
G	73	Levi Springs	28°22'	136°09'	60
G	74	The Fountain Spring	28°21'	136°16'	40
G	75	Big Perry Springs (3)	28°20'	136°20'	30
G	76	Little Perry Springs	28°16'	136°22'	20
G	77	Fanny Springs (4)	28°19'	136°14'	40
G	78	Twelve Mile Spring	28°18'	136°15'	40
G	79	The Vaughan Spring	28°17'	136°14'	40
G	80	Outside Springs	28°16'	136°12'	40
G	81	Milne Spring	28°16'	136°04'	60
G	82	Primrose Spring	28°09'	136°22'	20
G	83	Freeling Springs (4)	28°04'	135°54'	100
G	84	unnamed spring	28°03'	135°54'	100
G	85	Allandale Spring	28°02'	135°44'	80
G	86	Peake Creek Spring	28°02'	135°44'	80
G	87	Birribirriana Spring	28°13'	135°43'	80
G	88	Nilpinna Spring	28°12'	135°41'	80
G	89	Coorandatana Springs	28°11'	135°40'	80
G	90	Cardajalburrana Springs	28°11'	135°33'	80
G	91	Cootanoorina Spring (Willow Spring)	28°12'	135°32'	80
G	92	South Well Spring	28°17'	135°34'	80

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
WARRINA SH53-3					
G	93	unnamed spring	28°17'	135°36'	90
G	94	Weedina Spring	28°23'	135°38'	100
G	95	Edadurrana Spring	28°24'	135°37'	100
G	96	Warrangarrana Spring	28°26'	135°39'	100
G	97	Widigiedona Spring	28°50'	135°32'	120
G	98	Castine Spring	28°55'	135°30'	120
G	99	Eurilyana Spring	28°55'	135°26'	120
G	100	Oolgelima Spring	28°52'	135°19'	120
G	101	unnamed springs (2)	28°52'	135°16'	120
G	102	unnamed springs (3)	28°53'	135°14'	120
G	103	Giddi-Giddina Springs (2)	28°45'	135°12'	120
G	104	unnamed springs (2)	28°48'	135°03'	120
G	105	unnamed springs (2)	28°50'	135°02'	120
G	106	unnamed springs (4)	28°43'	135°03'	120
OODNADATTA SG53-15					
G	107	unnamed spring	27°58'	135°51'	
G	108	Ockenden Spring	27°52'	135°44'	70
G	109	unnamed spring	27°53'	135°41'	90
G	110	Big Cadna-owie Spring	27°53'	135°40'	90
G	111	Little Cadna-owie Spring	27°48'	135°41'	90
G	112	unnamed spring	27°48'	135°40'	90
G	113	unnamed springs (3)	27°51'	135°38'	90
G	114	Mt Toondina Springs	27°57'	135°20'	90
DALHOUSIE SG53-11					
H	1	Mt Jessie Spring	26°30'	135°26'	130
H	2	Missionary Spring	26°30'	135°26'	130
H	3	Earwanyera Springs	26°27'	135°29'	
H	4	Dalhousie Ruins Springs	26°30'	135°28'	125
H	5	Dalhousie Springs (± 80)	135°33' and 26°30	135°26' 26°73'	100

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
BEDOURIE SG54-1					
I	1	Alnagata Spring	24°00'	138°27'	90
I	2	unnamed spring	24°00'	138°27'	90
I	3	unnamed springs (3)	24°02'	138°27'	90
I	4	Bookerra Spring	24°02'	138°30'	90
I	5	unnamed springs (3)	24°02'	138°30'	90
I	6	Beppery Spring	24°04'	138°38'	90
I	7	unnamed spring	24°04'	138°38'	90
MT WHELAN SF54-13					
I	8	Mirrica Springs (2)	23°52'	138°30'	90
I	9	Ethabuka Spring	23°45'	138°27'	90
I	10	Pitchamurra Spring	23°45'	138°38'	90
I	11	Curabinta Spring	23°41'	138°44'	100
I	12	unnamed springs (4)	23°39'	138°44'	100
I	13	unnamed springs (2)	23°38'	138°45'	100
I	14	Fairview Spring	23°37'	138°47'	105
I	15	Allawonga Springs (4)	23°34'	138°39'	120
I	16	Talaera Spring	23°30'	138°47'	110
I	17	unnamed spring	23°30'	138°47'	110
I	18	unnamed spring	23°28'	138°46'	110
I	19	Old Carlo Spring	23°27'	138°48'	120
I	20	New Carlo Spring	23°25'	138°49'	120
I	21	Peanunga Spring	23°25'	138°47'	120
I	22	Peelunga Spring	23°23'	138°48'	120
SPRINGVALE SF54-14					
J	1	unnamed springs	23°43'	139°58	110
J	2	unnamed spring	23°41'	140°42	115
J	3	Elizabeth Springs	23°20'	140°34	150
J	4	unnamed spring	23°02'	140°28	150

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
BOULIA SF54-10					
J	5	Bulla Bulla Springs	22°55'	140°27'	160
J	6	unnamed spring	22°52'	140°26'	150
J	7	Pathungra Spring	22°25'	140°34'	190
DUCHESS SF54-6					
J	8	unnamed spring	21°38'	140°58'	
JULIA CREEK SF54-3					
K	1	unnamed spring	20°26'	141°40'	110
K	2	unnamed spring	20°24'	141°39'	105
K	3	unnamed spring	20°20'	141°38'	105
MILLUNGERA SE54-15					
K	4	unnamed spring	19°33'	141°06'	72
K	5	unnamed spring	19°40'	141°09'	75
K	6	unnamed spring	19°45'	141°23'	90
K	7	unnamed spring	19°40'	141°39'	100
K	8	unnamed spring	19°47'	142°11'	150
K	9	unnamed spring	19°49'	142°21'	170
K	10	unnamed spring	19°47'	142°21'	170
K	11	unnamed spring	19°45'	142°18'	170
K	12	Plain Spring	19°34'	142°22'	180
K	13	unnamed spring	19°32'	142°18'	170
K	14	unnamed springs (3)	19°31'	142°18'	160
K	15	unnamed spring	19°30'	142°19'	160
K	16	unnamed spring	19°28'	142°17'	160
K	17	unnamed spring	19°29'	142°19'	160
K	18	unnamed spring	19°25'	142°18'	160
K	19	unnamed springs (2)	19°31'	142°22'	170
K	20	Wombat Spring	19°27'	142°24'	180
K	21	unnamed spring	19°28'	142°25'	180
K	22	unnamed spring	19°19'	142°26'	180

Group	Number	Name	Latitude (°S)	Longitude (°E)	Elevation (m)
GILBERTON SE54-16					
K	23	unnamed spring	19°28'	142°30'	200
K	24	unnamed spring	19°18'	142°32'	200
K	25	unnamed spring	19°20	142°42'	225
K	26	unnamed spring	19°33'	142°35'	225
K	27	unnamed spring	19°34'	142°34'	225
K	28	unnamed spring	19°35'	142°35'	225
K	29	unnamed spring	19°35'	142°40'	230
K	30	unnamed spring	19°34'	142°50'	280
K	31	unnamed spring	19°14'	142°59'	290
K	32	Eureka Springs	19°51'	142°41'	240
K	33	unnamed spring	19°56'	142°40'	220
RICHMOND SF54-4					
K	34	Waddy Spring	20°05'	142°40'	215

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