UNIVERSITY OF ALBERTA

PETROLEUM HYDROGEOLOGY AND HYDROCHEMISTRY OF SOUTH-CENTRAL SASKATCHEWAN

BY
DAVID CHARLES TOOP ©

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

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THE UNDERSIGNED CERTIFY THAT THEY HAVE READ, AND RECOMMEND TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH FOR ACCEPTANCE, A THESIS ENTITLED "PETROLEUM HYDROGEOLOGY AND HYDROCHEMISTRY OF SOUTH-CENTRAL SASKATCHEWAN" SUBMITTED BY DAVID CHARLES TOOP IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN GEOLOGY.

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Date:________________

"All the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again." - Ecclesiastes 1:7 - The Bible

Abstract

Groundwater flow patterns and chemistry have been the controlling influence on the migration, accumulation and preservation of hydrocarbons of the Williston Basin in southcentral Saskatchewan. Two major competing flow regimes are active in the Paleozoic aquifers of the study area. An active, meteoric regime is entering the area along its western and southwestern boundary, driven by uplands to the southwest. It is the dominant force that determines the regional flow pattern of the region, and has a potentiometric surface that closely resembles topography. The relatively fresh waters of this regime are believed to be responsible for the removal of the Prairie Evaporite salt in central Saskatchewan.

Deep basin brines originating from the centre of the Williston Basin enter the study area along its southcentral and southeastern margins. They are part of a sluggish basin-wide flow system that appears unrelated to local topography. The brines have been instrumental in the preservation of the Prairie Evaporite in southeastern Saskatchewan and are important agents of transport and preservation of petroleum in the region.

Flow patterns within the Mesozoic are markedly different from those in the Paleozoic. The potentiometric surface is somewhat subhydrostatic and appears to be independent of topography and of the Paleozoic flow patterns. Water chemistry indicates a meteoric source. Fluid pressures in the Mesozoic have probably been reduced by the expansion of the Colorado shale, due to unloading at the surface related to glacial erosion and retreat.

Three regional fracture zones corresponding to the Missouri Coteau and the Hummingbird and Coronach Troughs, are pervasive through much of the area. They were inferred through the correlation of linear potentiometric, temperature and chemical anomalies, zones of preferential removal of evaporite salts, surface lineaments and stratigraphic features.

The distribution of the region's hydrocarbon accumulations may be explained in terms of the hydraulic theory of petroleum migration. Oil was transported from mature source beds with the formation waters toward traps in potentiometric lows. Cross-formational migration of hydrocarbons has occurred along the Hummingbird Trough. Future oil discoveries in southcentral Saskatchewan will likely be made in Paleozoic aquifers near potentiometric lows east of the Hummingbird Trough and in the area surrounding the Coronach Trough.

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1.0 Introduction

1.1 Purpose of Investigation

The Western Canada Sedimentary Basin has been extensively explored and exploited for oil and gas. In recent years, new reserves have become increasingly difficult and expensive to locate. Petroleum hydrogeology provides a number of inexpensive exploration techniques that may be incorporated into a holistic program, regionally or locally, to assess the hydrocarbon potential of an area. More importantly, an understanding of the hydrogeology of a particular area allows the identification migration pathways and location of favourable sites for accumulation. The purpose of this study is to demonstrate the applicability of hydrogeology as an exploration tool where other techniques have proved too expensive or impractical. As groundwater flow and petroleum migration are not confined to isolated sedimentary units, neither is this study. Rather, it is an attempt to delineate fluid patterns in three dimensions.

1.2 Selection of Study Area:

The study area extends from Townships 1 to 23, Ranges 15 to 30 west of the Second Meridian, including all units above the Precambrian crystalline basement. Its location is approximately between 49° to 50° N latitude and 104° to 106° W longitude in the province of Saskatchewan, Canada (Figure 1.1). The area was chosen for a number of reasons. It has been sparsely explored, making it essentially a "frontier" immediately adjacent to a prolific oil producing trend. It is a region where traditional exploration methods have proved to be expensive and difficult to apply. Drill stem tests have been run in sufficient number and are favourably distributed, both geographically and by horizon. This area has also been largely ignored by the oil companies as having poor potential or being too risky to warrant much attention.

The zone of current Mississippian production (Tp 1-6, R 15-19W2) in the southeastern corner of the study area marks the western limit of the Mississippian subcrop plays (Figure 1.1). The Jurassic and Cretaceous shoreline plays of the Swift Current Platform in southwestern Saskatchewan lie beyond Range 17W3, over 250 km to the west. In between is the central Saskatchewan barren zone. This area is characterized by scattered drilling performed mainly by early wildcatters in the 1950's, as part of incentive programs in the mid to late 1960's and in more recent years by potash exploration companies. Numerous townships have not had a single well drilled. Halabura (1987), noted the following:

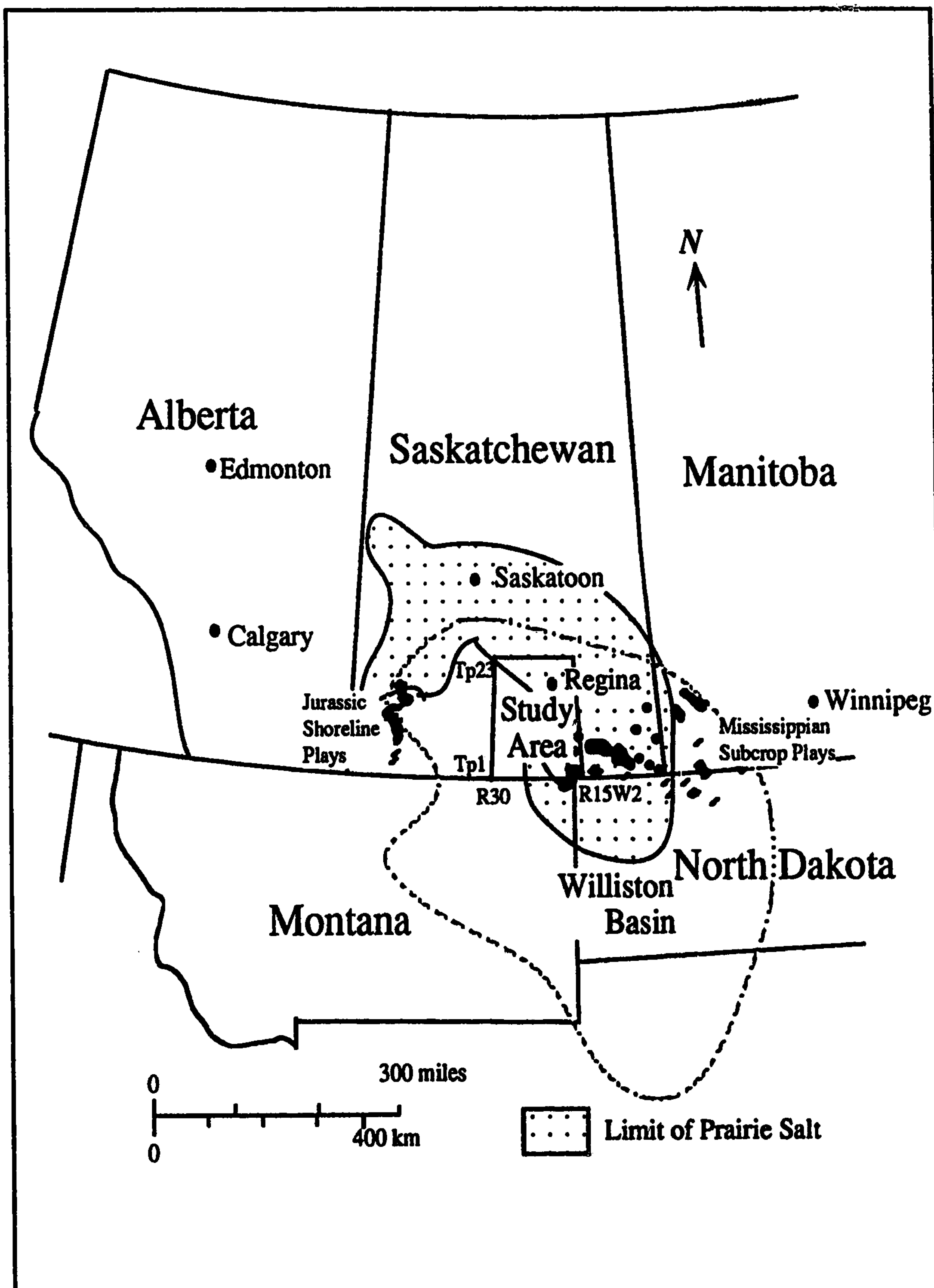


Figure 1.1 Location of Study Area within the Williston Basin (dashed outline) of western North America. The distribution of Mississippian and Jurassic oil pools (shaded black) and the Middle Devonian Prairie Evaporite Formation (solid outline and dotted fill) are also shown.

"One can make the generality that in each of the four producing regions (of Saskatchewan), the habitat of oil and natural gas is unique to that particular area. Each region has its own unique play concepts and reservoir characteristics, leading to the specialization of geologists working the Province. In the barren central portion of Saskatchewan, explorers have looked for subcrop plays, Jurassic and Cretaceous shelf trends and large tectonic structures; however, all these play concepts have met with failure. One could argue that either the area is geochemically immature and has thus never generated oils, or it has been flushed by meteoric waters moving from Montana in a northeasterly direction to the outcrop belt of eastern Saskatchewan and western Manitoba. Yet oil shows have been recorded in wells in this region, indicating that these precepts may not be entirely correct. Perhaps we are dealing with a different kind of beast in this region."

1.3 Geological Setting

1.31 Physiography

The study area contains three zones of topographic relief (Figure 1.2). The Regina Lake Plain of the Second Prairie Level in the northeast is noted for its lack of topographic variation, typically sloping at less than 0.5m per kilometre. Its average elevation is 600 metres above sea level. The 150 metre deep Qu'Appelle Valley extends the length of the northern study area. The Missouri Coteau, marks an abrupt increase in elevation and the beginning of the Third Prairie Level. The face of the Coteau extends diagonally across the area from Tp 16, R 30W2 in the northwest to Tp 2, R 15W2 in the southeast. It

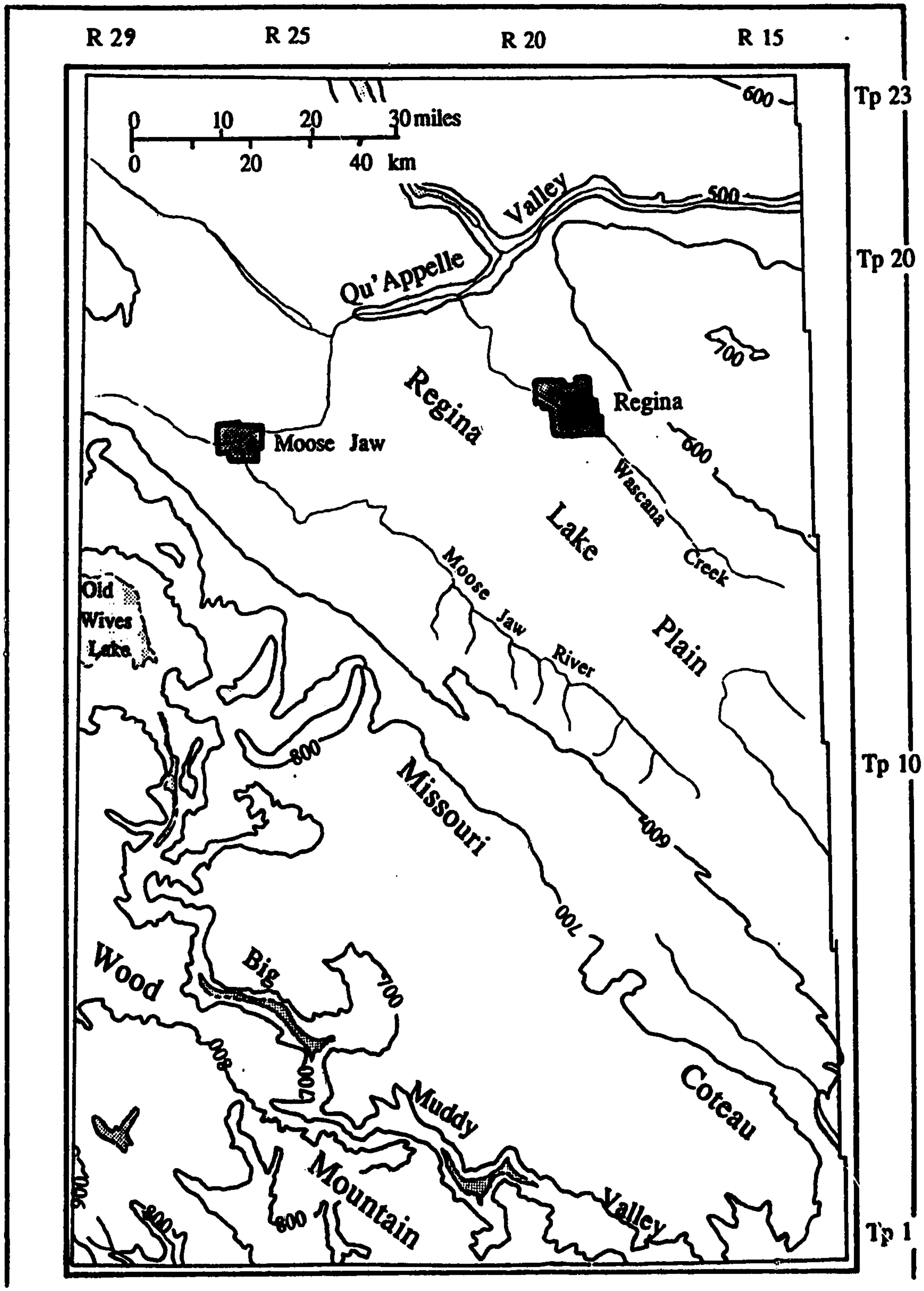


Figure 1.2 Topography of the study area.
Contour interval = 100m. Three zones of relief are illustrated:
-the Regina Lake Plain in the northeast (average elevation = 600m)
-the Missouri Coteau in central areas (average elevation = 700m)
-Wood Mountain in the southwest (average elevation = 800m)

rises about 100 metres above the Regina Lake plain and has hummocky relief. It is separated from the lower slopes of the Wood Mountain highlands in the southwest by the Big Muddy Valley. Wood Mountain is an eastern extension of the Rocky Mountain-Cypress Hills uplift. Tertiary strata are exposed in arid elevated badlands which range from around 800 to 900 metres elevation within the area to as high as 1100 metres west of the area. Streams east of the Missouri Coteau drain into Hudson Bay. Between the Coteau and Wood Mountain surface run-off is internally directed into the Old Wives Basin, which is characterized by knob and kettle topography lacking an integrated surface drainage pattern. Shallow sodium sulphate lakes and playas, often lacking in tributaries are common. Apart from a few short tributaries entering the Big Muddy Valley on the Coteau, streams in the Wood Mountain district drain into the Gulf of Mexico.

With the exception of Wood Mountain in the southwest, Pleistocene, glaciers covered the area, depositing a thick blanket of till over north and central regions. Meltwater trapped against the glacier as it retreated formed the smooth plain of glacial Lake Regina. The U-shaped Qu'Appelle and Big Muddy Valleys were cut into till and soft bedrock by escaping waters. Preglacial fluvial erosion was the primary factor in shaping the land surface prior to glaciation. Glacial and glaciofluvial erosion caused only minor modification of the topography (Whitaker and Pearson, 1972).

1.32 Regional Geology

The study area lies along the northern flank of the Williston Basin. The 2000 to 3000 metre thick sedimentary succession in the area may be divided into three major lithological units ranging in age from Cambrian to

Quaternary and interrupted by a number of unconformities. The Paleozoic consists of a 200m thick basal clastic unit overlain by over 1000m of carbonate and evaporite strata. Mississippian carbonates and evaporites subcrop against the SubMesozoic Unconformity. Triassic-Jurassic redbeds, shale, sandstone and limestone and Cretaceous-Tertiary shale and sand capped by glacial drift make up the remaining sequence. Upper Cretaceous and Tertiary units outcrop at Wood Mountain. Major unconformities occur at the base of the Cambrian, Ordovician, Devonian, Jurassic, Cretaceous and Quaternary systems.

The strata are relatively undeformed and dip to the south and southeast toward the deepest part of the basin, which is located near Williston, North Dakota. Inclines of 5m/km are representative of the regional slope of Devonian strata in the Regina area. Some structural anomalies in the sediments reflect basement tectonic activity.

The Middle Devonian Prairie Evaporite Formation has a notable influence on the structure of the area. The southwestern edge of the evaporite has been removed by dissolution, forming a scarp-like edge in the subsurface, and resulting in localized collapse and brecciation of some overlying units and anomalous thickening and draping of others due to infilling of the subsequent depressions. Penner and Mollard (1991) and McTavish (1991) concluded that collapse structures have propagated through the geological column and are manifested in the present day topographic surface.

1.33 Stratigraphy

The sedimentary column of the northern Williston Basin ranges in age from the Cambrian to the Cenozoic (Figure 1.3). Within the area studied, its thickness increases from 2000m in the north to more than 3000m in the south and the southeast, where it approaches the thickest and deepest part of the basin in Canada. The Precambrian basement dips toward the southeast at a rate of 5m/km in the north increasing to 10m/km in the southeast.

The base of the sedimentary column is represented by a 130 to 350m thick clastic sequence of Late Cambrian to Middle Ordovician age, comprising the Deadwood and Winnipeg formations. It rests upon eroded and weathered Precambrian crystalline basement. A highly permeable regolith zone occurs at the base of the unit. The strata are composed mainly of porous, medium to coarse-grained sandstones, which become more argillaceous toward the top of the sequence. An erosional unconformity in the early Ordovician separates Deadwood and Winnipeg deposition. It represents a slight uplift on the western side of the basin, which shifted the depositional centre of the basin eastward. Waxy green claystones form an abrupt contact with the overlying carbonates. The contact is transitional in detail (30cm interval). It is believed that sources of clastic sediments were inundated as the basin expanded northeastward in the Middle Ordovician (Porter and Fuller, 1959).

The Middle Ordovician-Silurian (Bighorn) succession is composed of the lithologically similar Red River, Stony Mountain and Stonewall formations and the Interlake Group. The unit grades upward from Red River fragmental dolomitic limestone and dense dolomite to calcareous dolomite of the Stony Mountain Formation to very fine-grained dolomite and dolomitized

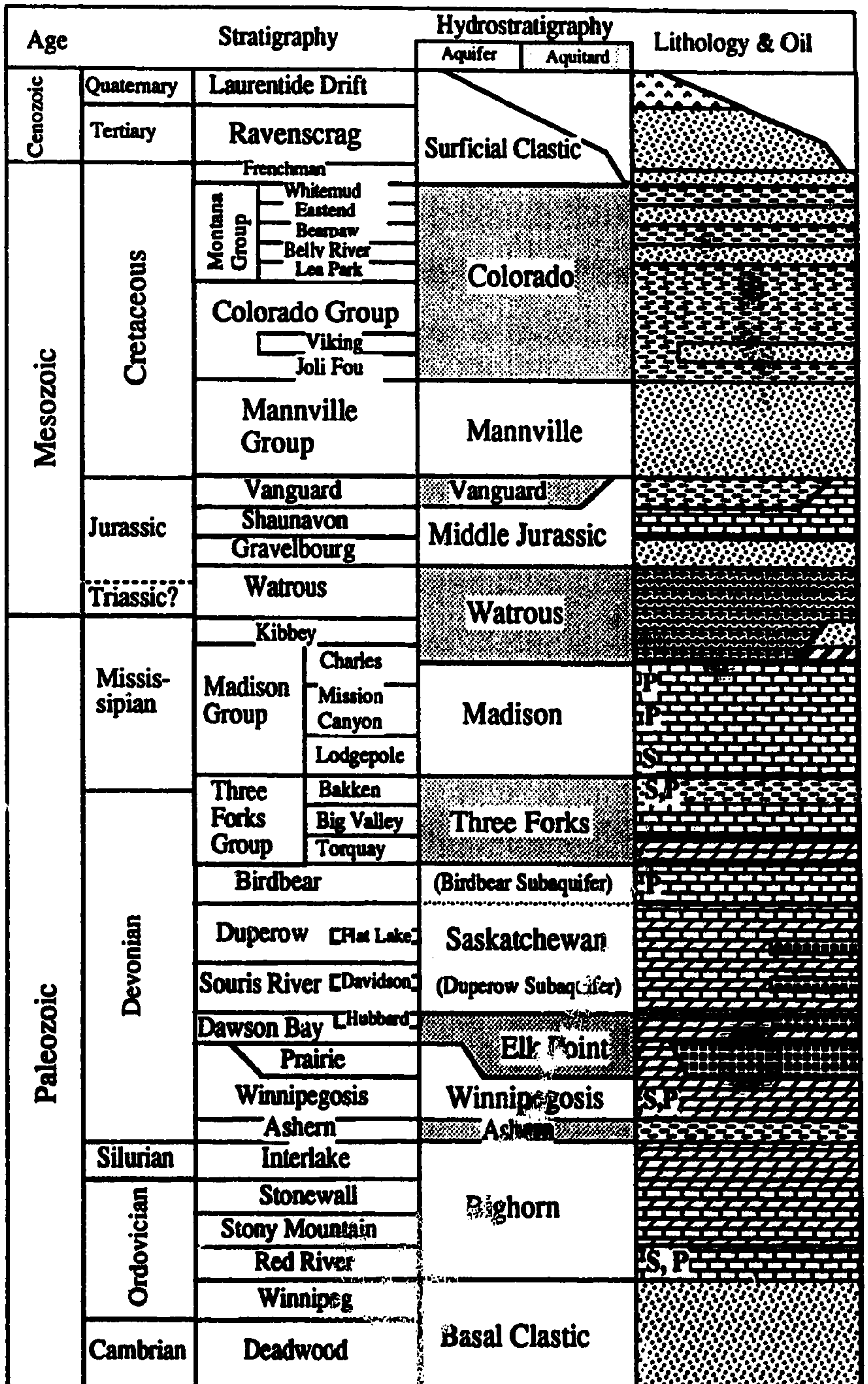


Figure 1.3 Stratigraphy, hydrostratigraphy, lithology and petroleum source beds and production in south-central Saskatchewan. Stratigraphy and lithology are modified from Vigrass and Jessop (1986).

Key to Lithology

- Glacial Till
- Sandstone
- Shale
- Red beds
- Halite or Sylvite
- Anhydrite
- Limestone
- Dolomite

S=oil source bed
P=oil Production

fragmental limestone in the Stonewall Formation and Interlake Group (Porter and Fuller, 1959). A number of thin anhydrite beds are found within the sequence and may reach up to three metres in thickness. They are best developed in the southeastern study area.

Emergence and erosion followed the deposition of the Interlake Group and lasted until Middle Devonian time, when sedimentation of the Elk Point Group was initiated. The Elk point group is composed of evaporite, carbonate and clastic rocks up to two hundred metres thick.

The Ashern Formation, which forms the base of the Elk Point Group is an 8-15m thick succession of dolomitic shales of basal redbed facies, grading upward into argillaceous dolomite. The overlying Winnipegosis Formation consists of a reef platform of microsucrosic dolomite and numerous small reef mounds of structureless, vuggy dolomite. The platform has a fairly constant thickness of 13m including small mounds. Larger mounds may reach thicknesses of up to 105m. Porosity is often filled with halite from the overlying Prairie Formation.

The Prairie Evaporite Formation consists mainly of halite, with sylvite and carnellite in the top thirty to sixty metres. A thin bed of Prairie Formation anhydrite covers the entire study area, however, salt distribution is quite irregular due to removal by dissolution and is limited to the northern and eastern half of the study area. Its thickness changes rapidly over short distances from 0 to 100 metres and may surpass 150m in the region. The Roncott Remnant in the south-central study area is a peninsula-like salt body. It is separated from the main evaporite body by a wide dissolution band in the central map area known as the South Regina Trough and the thinner dissolution channel of the Hummingbird Trough in the south. The western edge of the Roncott remnant is bounded by the Coronach Trough (Figure 1.4). Dissolution and collapse around the Roncott Remnant have left overlying strata structurally higher than the surrounding area, creating the Roncott Platform.

The Middle Devonian Dawson Bay Formation ranges from 35 to 75 metres total thickness. Six to nine metres of red and green dolomitic shales, known as the Second Red Bed grade upward into porous dolomitic limestone and fragmental carbonates. Pores of the upper part of the unit are salt filled in areas proximal to halitic portions of the Hubbard Evaporite, which is found in the upper part of the Dawson Bay. The anhydrite and halite Hubbard Evaporite is limited to the northern third of the region and ranges from 0 to 20 metres thickness. It is overlain by the 4-14 metre thick red and green dolomitic shales of the First Red Bed.

The Middle to Upper Devonian Souris River Formation consists of 100 to 180 metres of argillaceous, fragmental and dolomitic limestones. The 0 to 60m Davidson halite evaporite occurs near the top of the unit. Its distribution is almost identical to that of the Prairie Evaporite. The Souris River Formation is overlain by limestone, dolomite and argillaceous dolomite of the Upper Devonian Duperow Formation, which is generally uniform throughout its distribution, averaging 175 to 200 metres in thickness. The Flat Lake Evaporite, a 25m interval of halite and thin anhydrite laminae, is found 45 metres below the top of the succession. It is overlain by the 40-50m thick Upper Devonian Birdbear Formation a unit of uniform dolomite, dolomitic limestone, and minor anhydrite. The Duperow and Birdbear formations together form the Saskatchewan Group.

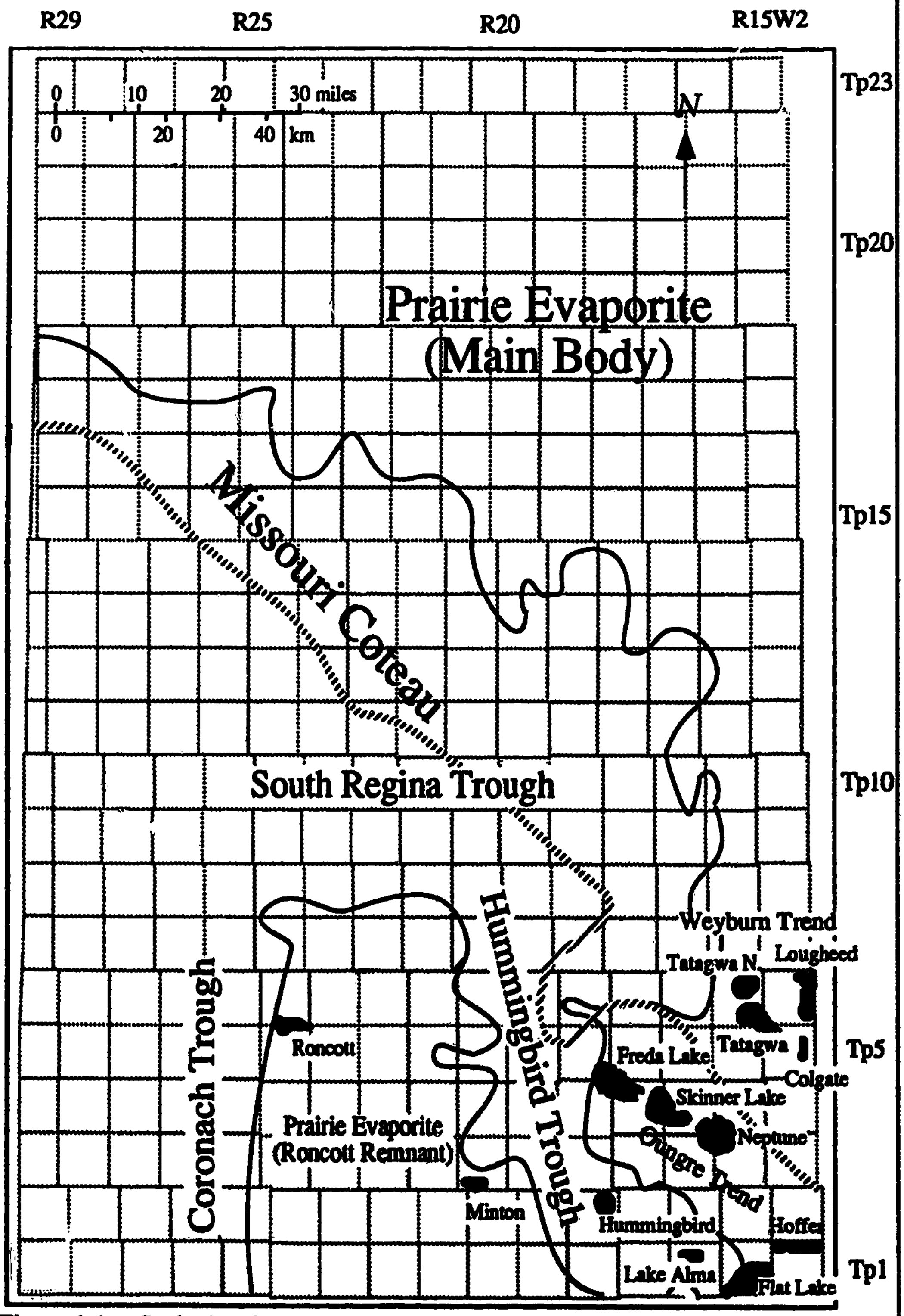


Figure 1.4 Geological features and oilfields of south-central Saskatchewan; showing the distribution of the Prairie Evaporite Formation and adjacent zones of salt removal - the Coronach, South Regina and Hummingbird troughs (after Holter, 1969), the surface position of the Missouri Coteau escarpment based on National Topographic Survey maps (1974) and the name and location of oil pools and oil trends in the region.

The Upper Devonian to Mississippian Three Forks Group consists of the Torquay, Big Valley and Bakken formations. It averages 70 metres in thickness, and is composed dominantly of fine terrigenous clastics (shale, siltstone, sandstone and dolomite). The Bakken Formation is separated from the underlying formations by an unconformity. It consists of a basal kerogenous shale, a middle fine sandstone unit and an upper thin bituminous shale and has a variable thickness from eight to forty metres. The Bakken Formation is significant as an oil source bed and producing zone, and as a regionally extensive confining unit.

The Mississipian Madison Group, well known for its prolific oilfields, consists of the Lodgepole (Souris Valley), Mission Canyon, Charles and Kibbey formations. Its total thickness ranges from zero along the northern edge of the area, to 60m in the north, where most of the unit has been removed by erosion to over 400m in the south. Considerable thinning takes place along the subcrop of the Mission Canyon Formation, particularly across Tp 16, where the unit is reduced from 300m to 100m.

The Lodgepole Formation is made up of argillaceous and fossiliferous limestone. It subcrops along the northern boundary of the study area. Porosity is generally poor in the Lodgepole, but locally it is much enhanced by weathering along the subcrop. The Mission Canyon Formation is limited to the southern two thirds of the study area. It is divided into the Tilston, Frobisher, and Alida Beds, consisting of fragmental (fossiliferous or oolitic) and silty limestone. Dolomitic, slightly anhydritic quartz sandstones make up the Kisbey Beds. The Midale and Ratcliffe Beds of the Charles Formation, found in the southern third of the area contain argillaceous, fossiliferous limestones and dolomites that become interbedded with anhydrite in the overlying Poplar Beds. The calcareous shaly sandstone of the Kibbey Formation of the Big Snowy Group is found only along a very limited area adjacent to the international boundary.

The transition from Paleozoic carbonates to Mesozoic clastics is marked by the SubMesozoic erosional unconformity. The Lower Jurassic and possibly Triassic Watrous Formation is made up of red to reddish-brown as well as green and grey shale, siltstone, sandstone and dolomite, which is overlain by finely to coarsely crystalline anhydrite. Thickness, which is locally controlled by the topography of the Paleozoic weathering surface, ranges from 30 metres in the northwest to 250 metres in the southeast.

The Middle Jurassic Gravelbourg and Shaunavon formations are composed of dense limestone, calcareous claystones, sandy shales, and thin quartz sandstones, with an irregular total thickness ranging from 100 to 170m. The Upper Jurassic Vanguard Formation varies from 210m at the American Border to 0m in the extreme northeast and northwest corners of the study area. It is composed of calcareous shales containing thin sandstone beds in the upper part, overlain by slightly calcareous and silty non-calcareous shales.

The Jurassic formations are truncated further north by the SubCretaceous Unconformity. Highly permeable, clean fine-grained poorly cemented quartzose sandstone with some shale interbeds and minor coal, comprise the Lower Cretaceous Mannville Group, which ranges in thickness from 75 to 125m. It is overlain by the 260m thick Upper Cretaceous Colorado Group, made up of predominantly shale with some sand interbeds. The most significant sand body, the Viking Formation consists of silty sandstone usually less than 6 metres thick, but sometimes reaching 20m, in its limited range in the southeastern third of the study area.

The Colorado Group is overlain by the Late Cretaceous, 400-700 metre thick Montana Group. The Montana Group is composed of 300m of silty and bentonitic shales of the Lea Park Formation, marine sandstone of the Belly River Formation, and the Bearpaw Formation (up to 350m thick). It is composed of marine shale, minor sandstone and bentonite beds. The Upper Cretaceous sediments of the Battle and Frenchman formations total up to 70m thickness of mainly bentonitic shales and shaly siltstones.

The remaining succession consists of the Tertiary Ravenscrag and Wood Mountain formations, which are limited to the uplands in the southern third of the study area. They are composed of fine sandstones, with coal interbeds. A thick covering of Quaternary Laurentide drift blankets the eroded Cretaceous and Tertiary strata, except where they outcrop in the southwest highlands. The drift is predominantly till and lake clay with few sand aquifers.

1.34 Hydrostratigraphy

The basic unit of hydrogeology, the aquifer is defined as a saturated, permeable body of earth material capable of transmitting significant quantities of water under normal hydraulic gradients (Freeze and Cherry, 1979). Less permeable beds, which restrict the movement of water are called aquitards. What may be deemed an aquifer or aquitard is dependent on the scale or representative elementary volume (V_3) considered (Bear, 1972). The representative elementary volume is the minimum volume required to allow a meaningful statistical average value for porosity to be calculated. For instance, channel sands that are significant fluid migration pathways locally or within a single oil pool, may be irrelevant in a basinwide study. The time scale and fluid type are also determining factors. Materials that may be permeable in the context of a geological time scale may be effectively impermeable in the short term (Tóth and Millar, 1983). Strata capable of transmitting water may not be capable of transmitting the larger molecules of more viscous hydrocarbons.

The geological column in the study area was divided into water conveying and water restricting units. Because of the regional extent of the study, limited availability of data and the likelihood of significant heterogeneities, particularly in carbonate units, quantifying permeability for each formation was considered to be neither practical nor feasible. Aquifers were designated based on rock type, thickness, availability of pressure and chemical analyses, and separation by a regionally extensive aquitard.

The rock type provided a basis for the subdivision of thick aquifers. The physical character, or lithology of the rock will influence the geometry and distribution of porosity and permeability and consequently the hydraulic conductivity of the rock. Hydraulic conductivity (K) is a function of both the porous medium and the fluid involved. It is related to permeability through the equation $K = k\rho g/\mu$, where "k" is the intrinsic permeabilty of the medium, "ρ" is the density of the fluid, "g" is the force of gravity, and "μ" is the dynamic viscosity of the fluid.

The rock type provided the basis for the subdivision of thick aquifers. Potentiometric maps are constructed to illustrate the distribution of fluid-potential in the horizontal plane. Measurements taken over a large vertical interval, where there is an upward or downward component of flow could translate differences in potential from the vertical plane into the horizontal plane. Anomalies in the potentiometric surface could result.

The topographic surface forms the upper boundary and the Precambrian basement the lower boundary of the study area. The intervening column was divided into seven aquifers "A", and six aquitards or confining units "C", listed in Figure 1.3 and Table 1.1:

Table 1.1

Unit	Name	Stratigraphic Interval
A1A	Basal Clastic	Deadwood and Winnipeg formations
A1B	Bighorn	Red River Formation to Interlake Group
C1	Ashern	Ashern Formation
A2	Winnipegosis	Winnipegosis Formation
C2	Elk Point	Prairie and Dawson Bay formations
A3	Saskatchewan	Souris River to Birdbear formations
A3A	Duperow	Souris River and Duperow formations
A3B	Birdbear	Birdbear Formation
C3	Three Forks	Torquay to Bakken formations
A4	Madison	Lodgepole Formation to Ratcliffe Beds
C4	Watrous	Poplar Beds to Watrous Formation
A5	Middle Jurassic	Gravelbourg and Shaunavon formations
C5	Vanguard	Vanguard Formation
A6	Mannville	Mannville Group
C6	Colorado	Joli Fou to Whitemud formations
A7	Surficial Clastic	Frenchman Formation to Laurentide Drift

1.35 Petroleum Geology

Distribution

Most of the oil found in the study area lies within the Madison Group carbonates of Mississippian age. The Mississippian contains 75% of all proven oil reserves in the Williston Basin (Kent, 1984). The most significant traps, such as those along the Oungre trend, lie along the Mississippian subcrop where Madison Group formations pinch out against the SubMesozoic Unconformity, trapping oil through a combination of stratigraphic and structural controls. Smaller oilfields occur in internal stratigraphic traps or on structural highs or structurally related drape features caused by localized dissolution of the Prairie Evaporite, and collapse of the overlying strata.

Current Mississippian production in the area comes from twelve fields located between Townships 1-6 and Ranges 15-19W2 (Figure 1.4). These fields mark the western known limit of the extensive Mississippian subcrop play. The API gravity of oil gradually decreases westwardly along this play. The Ratcliffe Beds form the producing horizon in the Oungre trend, while four fields associated with the Weyburn trend produce from the Midale Beds.

The Upper Devonian/Lower Mississippian Bakken Formation produces oil from a geographically isolated pool at Tp 5-6, R 25W2, along a structural high related to the Roncott Remnant. The Roncott pool is considerably farther west than any other field and it is associated with meteoric water (<4000 mg/L total dissolved solids). The Bakken has likely not been buried deeply enough in Saskatchewan for thermal maturation to occur. The oil, which has a unique geochemical signature (Osadetz et al., 1991) and high gravity (40.5° API), likely migrated from the deeper centre of the basin (LeFever et al., 1991).

The Ordovician Red River Formation has produced oil for a number of years from scattered wells within the study area and from fields in the United States. The Minton Red River Formation and Winnipegosis Formation Oil Pool was discovered in 1989 along a gentle structural high at Tp 3, R 21W2. The Winnipegosis Formation has additional potential, since known pools related to reef buildups, and to the shelf margin are found outside the study area. Small quantities of oil sourced from the Winnipeg Formation are produced from the Upper Devonian Birdbear Formation on structural highs at Lake Alma and at Hummingbird.

Exploration History

Interest in southeastern Saskatchewan began in the early 1940's, when a small scattering of wells were drilled randomly through the study area. Exploration activity continued into the late forties with renewed interest after the discovery of Leduc in Alberta and became more intense with the discovery of the Mississippian subcrop trend in the early 1950's. A small flurry of incentive-related drilling occurred in the 1960's. Most early wells were drilled into the Lower Paleozoic. By the late 1960's onward, most explorers concentrated on extending the subcrop discoveries westward, leaving central Saskatchewan and the deeper Paleozoic units largely ignored. Most wells were drilled along established producing trends no deeper than the Mississippian. In addition, a number of potash wells were drilled near Belle Plain (Halabura, 1987). In recent years, there has been a renewed interest in deeper zones with the discovery of oil in the Winnipegosis Formation east of the area at Tableland in 1982, and the discovery of Ordovician oil at Minton in 1989.

Current Outlook on Exploration Potential

For many years, interest in southeastern Saskatchewan has remained in the zone of established production, and this trend is likely to continue, unless new models can be applied outside this area. Insufficient thermal maturity, lack of known Paleozoic source rock and degradation caused by deep penetration of meteoric waters all increase the risk of exploring in southcentral Saskatchewan. Even so, oil shows have been found in the area and the possibility exists for a new type of play to be discovered. The Roncott Bakken field was discovered in the central Saskatchewan barren zone by early wildcatters in 1956. It likely would not have been found using the present day focus.

Potential for new discoveries is considered to be best in the Mississippian, the Bakken Formation and in the Ordovician. Much of the focus is likely to be placed on the Upper Ordovician, which has not been well explored despite favourable estimates of reserve potential (Osadetz et al., 1989). The most favourable prospects for Ordovician oil appear to be southeast of the study area, however, the recent discovery of oil at Minton demonstrates promising potential in southcentral Saskatchewan as well.

2.0 Concepts of Fluid Flow, Water Chemistry and Petroleum Migration

Hydrogeology is the study of the interaction between subsurface water and the surrounding rock framework. Fluid flow is significant as a mechanism for transport and accumulation processes below the land surface. As an agent of transport of dissolved matter, moving groundwater determines patterns of salinity and isotope distribution and may cause the dissolution, cementation and diagenesis of rocks. Groundwater flow in combination with buoyancy establishes the direction of secondary migration of hydrocarbons from source beds to accumulation sites. As a mechanism of heat transport, moving groundwater may alter temperature distribution in the subsurface, initiating maturation of organic matter in areas that might not otherwise be thermally mature or, respectively, inhibiting maturation in otherwise favourably distributed source rocks. Mechanical phenomena may result from lubrication of fault zones, or from removal of the rock framework through dissolution, which may cause subsidence at the land surface (Tóth, 1984).

2.1 Fluid Flow

The energy state, or potential of a fluid is a function of pressure and elevation. The mechanical energy per unit mass of fluid may be expressed as hydraulic head, that is the height to which water will rise in a vertical column open to the atmosphere at the top and to the fluid at the base. It is measured in the dimension [L], (usually metres) against a datum, such as sea level. Flow occurs when a fluid moves from a place of high potential to a place of low potential. Fluid flow is governed by Darcy's Law, a natural law expressed as:

$$Q= -K\,A\,{}^{dh}/_{dl}$$

where

Q= flow rate, or discharge rate	$[L^3/T]$
K= hydraulic conductivity of the medium	$[L/T]$
A= cross sectional area	$[L^2]$
h= hydraulic head	$[L]$
l= distance between points of measurement	$[L]$
dh/dl = the hydraulic gradient	$[L^0]$

The physical process of flow is caused by a potential gradient. Water will move from a higher energy location (high hydraulic head) to a lower energy location (low hydraulic head) unless a completely impermeable boundary separates the two locations. Regionally extensive impermeable strata are rare or nonexistent in nature, as all natural materials have a tendency to fracture. Water restricting units, such as shales may transmit water in a geological time scale, but may be considered to be effectively impermeable when dealing with shorter time spans (Tóth and Millar, 1983).

Gravity is the main force driving fluid flow in sedimentary basins (Tóth, 1984), although sediment compaction, tectonic compression, chemical osmosis, capillarity, electro and thermal osmosis and thermal convection may also play a role. In unconfined flow systems, the water table is commonly a subdued replica of topography, as water travelling in the subsurface moves from areas of high topographic elevation to areas of low elevation. In large sedimentary basins, topographically induced flow may result in deep penetration of meteoric waters in the subsurface along regional flow paths.

The hydraulic head at a given point in the groundwater may be calculated using the equation

$h = z + p/\rho g$ where:

$h =$ hydraulic head in metres

$z =$ elevation of point of measurement in metres, relative to sea level

$p =$ pressure in kilopascals

$\rho =$ density of the fluid (density of fresh water = 1000 kg/m^3)

$g =$ acceleration due to gravity = 9.81 m/s^2

Point-water head is defined as the elevation of the top of the water column above a datum, in a well filled with sufficient water of density found at the point of measurement to balance the pressure at that point (Lusczynskj, 1961). Fresh-water head is the elevation of the top of the water column in a well filled with sufficient water of freshwater density to balance the existing pressure at the point of measurement. In a fluid column of salt water, or variable density water, the fresh-water head will be higher than the point-water head, because a greater amount of the lower density fresh water is required to balance the measured pressure.

Environmental-water head at a measured point in groundwater of variable density is the freshwater head reduced by an amount corresponding to the difference in dissolved solids mass in the fresh water and that in the actual fluid column between the point of measurement and the fluid surface (Lusczynskj, 1961). Environmental-water heads define hydraulic gradients in the vertical, and are only comparable along a vertical. Fresh-water heads define hydraulic gradients in variable density groundwater in the horizontal and are only comparable along a horizontal. Freshwater heads calculated in regions of rapidly changing water density, may not accurately define the true flow directions. Point-water heads define heads at individual points and may not be compared.

Hydraulic head distribution may be portrayed in two dimensions by plotting head values calculated to conform to a single density, usually that of fresh water, in plan view for a single aquifer. The points may be contoured to portray the potentiometric surface, giving an indication of the direction of flow within that aquifer. The potentiometric surface is only strictly valid for horizontal flow of constant density fluids in a horizontal aquifer of constant thickness. When interpreting potentiometric surfaces it is important to remember that conditions listed above are rarely satisfied in the natural environment, but in most cases are insufficient to cause significant error.

An alternative means of displaying the potential of a fluid in the vertical is the pressure versus elevation curve. In a static, unconfined, saturated, hydraulically continuous fluid column, pore pressure will increase with increasing depth at a constant rate as a function of the mass density of the fluid. In a column of variable density fluids, pressure will increase in a cumulative manner, at a rate dependent on the density of the fluid over each given interval. The continuous increase in fluid pressure with increasing depth is called the "nominal curve" or "hydrostatic pressure curve".

At a single geographical locality, the relationship between pressure measurements plotted versus elevation and the hydrostatic pressure gradient may indicate whether the measurements are hydraulically connected or if vertical flow is taking place. Pressures taken from the same hydrogeological system will plot on a single curve, while pressures taken from diverse hydrogeological systems will generally plot on separate curves.

The presence of vertical flow may be indicated by the dynamic pressure increment (Tóth, 1979). In a hydraulically continuous environment, where the force field is conservative, any departure from the hydrostatic pore pressure must be attributed to vertical motion of the fluid. The dynamic pressure increment is the difference between the measured pressure at a given elevation and the hydrostatic pressure at that elevation, established by the hydrostatic pressure curve. A negative dynamic pressure increment indicates downward motion of the water, while a positive increment indicates upward motion. Where the dynamic pressure increment is zero, no vertical flow is taking place.

Horizontal flow between two hydraulically connected geographical localities may be ascertained from the relative positions of the actual pressure curves. In a fluid at a constant elevation, flow will be from areas of high pressure toward areas of low pressure. Because variations in fluid density are incorporated into the nominal pressure curve, pressure versus elevation plots are particularly useful for establishing directions of flow in areas where significant density contrasts render potentiometric surface maps unreliable.

2.2 Groundwater Chemistry

The classification of formation waters according to chemistry is often useful for the identification of regional flow systems, allowing for clearer definition of regional flow patterns. It may be used as an indicator of the water's age, flow pathway and suitability for petroleum accumulation and preservation. Formation waters contain dissolved organic and inorganic constituents, of which several inorganic ions are typically most abundant. Major cations and anions, those usually found in concentrations of greater than one mg/L are sodium (Na^{+}), potassium (K^{+}), magnesium (Mg^{2+}), and calcium (Ca^{2+}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^{-}), sulphate (SO_4^{2-}) and chloride (Cl^{-}). Sodium and potassium are not differentiated in most analyses.

In Canada, ionic concentration is most commonly determined in the mass-per-volume unit of "milligrams per litre" (mg/L). Concentration of an individual ion may also be expressed as its reacting value, typically in units of "milligram equivalents per litre" (meq/L). Mass-per-volume is usually used for expressing total dissolved solids concentrations, while reacting values are most useful for analyzing chemical reactions and establishing water classifications.

The chemical nature of groundwater changes in a systematic manner as it migrates through the subsurface. The total dissolved solids (TDS) content of groundwater will increase with increasing length of flow path and residence time. Low ionic concentrations can be expected in shallow systems, where the principal source of recharge is rainwater and where the flow paths and residence times are short. In deep systems, concentrations will be high due to increased time of water-rock contact and increased solubility due to higher temperatures and pressures.

Chebotarev (1955) noted that groundwater will tend to evolve chemically toward the composition of seawater. This evolution is characterized by the following regional changes in the dominant anion species with increasing residence time and increasing length of travel along flow path:

HCO_3^- --> $HCO_3^- + SO_4^{2-}$ --> $SO_4^{2-} + HCO_3^-$ --> $SO_4^{2-} + Cl^-$ --> $Cl^- + SO_4^{2-}$ --> Cl^-

The transformation takes place as water moves from near-surface zones of active flushing through intermediate zones, to deep quasi-stagnant zones, where the water is of great age. Likewise, major cations progress through a less pronounced series of changes in dominance from Ca^{2+} to Mg^{2+} to Na^+. Cation facies are less diagnostic than anion facies, since cation exchange sequences are commonly altered or reversed.

Ionic progression is governed by various chemical processes, the dominant process being the exchange of ions between water and the surface of minerals, notably clay minerals, evaporites and carbonates. Ionic exchange is controlled by mineral solubility, availability and distribution along the flow path. Subsurface lithology, can have a pronounced effect on water chemistry, sometimes short-circuiting or even reversing the generalized evolution of major ions.

The HCO_3^- content of subsurface water is most commonly derived from soil zone CO_2 and from the dissolution of calcite ($CaCO_3$) and dolomite

($CaMgCO_3$). Sulphate is usually obtained from gypsum ($CaSO_4 \cdot 2H_2O$) or anhydrite ($CaSO_4$), which both dissolve readily in contact with water. Sulphate is considerably more soluble than bicarbonate and will quickly become the dominant anion if it is available in sufficient quantities, which is a condition rarely met in shallow zones. Chloride minerals such as halite (NaCl) and sylvite (KCl) have solubilities several orders of magnitude higher than gypsum, anhydrite, dolomite or calcite, and are most commonly found in deep sedimentary basins as salt strata. Groundwater that comes into contact with abundant amounts of halite, will evolve directly into the Cl^- phase, regardless of its length of flow path or other minerals present in the system.

Groundwater chemical data may be compiled and presented in various manners for visual appraisal, or characterized according to type. The kind of presentation used will depend on the focus of the researcher. Some commonly used water classification systems include those of Palmer (1911), Sulin (1946) and Back (1960). The two most commonly used methods of presentation were devised by Piper (1944) and Stiff (1951).

Sulin (1946) in his system of water characterization, divided formation waters into four main classes. The primary division was based upon whether or not the ratio $rNa^+:rCl^-$ was greater than one (sulphate-sodium type and bicarbonate sodium type waters) or less than one (chloride-magnesium type and chloride-calcium type waters). Bojarski (1970) found that the likelihood of petroleum occurrence and preservation increased when the ratio $rNa^+:rCl^-$ decreased. The most favourable waters for hydrocarbons were those with a ratio less than 0.75.

As ionic dominance changes, ionic ratios will also be transformed. The ratio of reacting values $rNa^+:rCl^-$ tends to shift from >1 in meteoric systems to <1 in deep saline systems (Sulin, 1946). The ratio of $rNa^+:rCl^-$, sometimes known as the metamorphism index, is a useful tool in determining the relative age of formation water. In shallower meteoric systems, especially where sodium rich clay minerals are present, the process of cation exchange will substitute 2 mol of Na^+ for one mol of Ca^{2+}, causing an increase in total dissolved solids and a gradual shift in absolute cation dominance from Ca^{2+} to Na^+. In deep basin systems, progressive chloride enrichment caused by halite dissolution forces the exchange of Na^+ for Ca^{2+} on clay minerals and decrease in the $rNa^+:rCl^-$ ratio (Dickey, 1966; Kreijci-Graf, 1963). An $rNa^+:rCl^-$ ratio very close to one often indicates salinity altered by the rapid dissolution of significant amounts of halite.

Ultimately, the Chebotarev Sequence and cation progression are simplifications. Mixing of flow zones, biogenesis, antecedent water composition, and the surrounding lithological framework are additional factors determining the chemical makeup of groundwater.

2.3 Groundwater and Petroleum Migration

According to Tóth (1980), gravity-induced cross-formational flow is the principal agent of transport and accumulation of hydrocarbons in geologically mature basins. Topographically driven flow becomes dominant as surface relief is developed on an emerging basin as compaction driven flow ceases. Hydrocarbons expelled from source rocks will migrate with formation waters toward potentiometric lows, until they are trapped by permeablility, structural, stratigraphic, diagenetic, hydrodynamic or composite boundaries. Oil will preferentially accumulate in areas of converging and ascending flow and in zones of stagnation. These areas are characterized by relative potentiometric minima, a downward increase in hydraulic head, reduced lateral hydraulic gradients and relatively high groundwater salinity. Because flow is topographically driven, these are typically areas of low surface relief. The correlation of hydrocarbon discoveries to lowland areas and valleys was first noted by early drillers. Exploration for oil based on topography was called "creekology" (Selley, 1985).

The correspondence of subsurface flow systems to topography is dependent on the existing age of the topographic surface. A change in relief will cause a proportionate, but delayed readjustment of flow paths to match the new topography. A subsequent redistribution of petroleum accumulations will occur although residual deposits may remain. Deep regional flow systems and aquifers beneath thick regional aquitards will take the longest time to readjust to the new topography. Relict flow systems, adjusted to paleotopography may remain active for millions of years (Tóth and Millar, 1983).

Fluid chemistry is a major factor in the preservation of petroleum. Degradation of subsurface hydrocarbons may result from water washing, which removes the more soluble light hydrocarbons leaving the heavier ones behind, or through bacterial action or inorganic oxidation. Degradation is favoured in oxygenated near surface waters and is discouraged by deep saline waters, which provide the best environment for hydrocarbon preservation.

3.0 Investigation

3.1 Scope of Study

This study is regional in nature to match the distribution and availability of data. It attempts to characterize the hydrogeological environment of a specific block of basin, by outlining regional flow systems and chemical patterns, their origin, distribution and relevance to hydrocarbon movement and entrapment. Its purpose is to establish hydrogeologically favourable locations for oil exploration.

3.2 Source of Data and Approach

Potentiometric surface maps and pressure versus elevation plots were constructed using pressure data obtained from drill stem tests (DST's). The drill stem test is a method of temporarily completing a well that allows formation fluids to enter the drill pipe and be sampled and for formation pressures to be measured. It is the most accurate and widely used method for measuring deep subsurface pressures. Most DST's are not run long enough for pressures within the drillpipe to reach equilibrium with formation pressures. A technique of extrapolating final formation pressures from DST charts was developed by Horner (1951).

Extrapolated pressures for this study were provided by the Canadian Institute of Formation Evaluation (CIFE). CIFE provides a quality code of A (best quality), B (nearing stabilization), C (caution), or D (questionable) for each test based on mechanical reliability and stabilization of pressures. Over

1200 DST charts and descriptions from Saskatchewan Energy and Mines files provided with the assistance of Petro-Canada were individually examined to determine the reliability of each test. The tests were graded on a sliding scale as "pass", "caution", "warning" or "fail", based on CIFE's quality code, shape of the shut in curve, amount and type of recovery, size and location of the interval tested and the production history of the surrounding area. Upon closer examination, many of the DST's labelled "caution" and most labelled "warning" were eventually downgraded to "fail" status.

With a number of exceptions, mainly in the Madison Aquifer where some mixed recoveries were allowed, only water recoveries greater than 100 metres were used. Few cases involved intervals that were too large, or straddled more than one aquifer. Where an interval included two or more aquifers, the tests were discarded unless the interval was predominantly in one zone. Most intervals extended less than ten metres. When an interval included an aquifer and an aquitard, the test was assumed to be representative of the aquifer.

In areas of oil production, pressures were examined for possible drawdown effects. DST's taken within a one mile (1.6 km) radius of producing wells were discarded if production preceded the date of the test by more than thirty days. A wider radius was used if production had been carried on for a number of years prior to the test. More than half of the original DST pressure data were eventually discarded. Freshwater heads were calculated using extrapolated pressures interpreted to be reliable and were plotted for each unit aquifer.

Complete water analyses from the Saskatchewan Energy and Mines records provided through Petro-Canada were also individually examined. Bad tests were discarded based on sample descriptions, comparisons of Stiff diagrams, relative amounts and proportions of chemical constituents, pH, sample size, and method of collection. Samples of DST recoveries were the most reliable, especially where there was a significant recovery of water. Samples taken from the base of the fluid column were favoured over those taken from the middle. Samples from the top of the column were usually discarded, as were most analyses taken from the perforations, wellhead or separator. Water samples of pH greater than eight or less than five were considered to be suspect. Chemical analyses were quality coded on the same sliding scale used for pressure measurements. Calculated total dissolved solids (TDS) in mg/L that were designated as being reliable were plotted in a similar manner to pressure data. Both hydraulic heads and total dissolved solids concentrations were contoured first by computer, and then by hand, after trends had been established.

In addition to the maps, a regional cross section running from the southwest to northeast study area and two cross sections spanning the Hummingbird Trough between Tp 1, R 21W2 to Tp 5, R 15W2 and Tp 8, R 22W2 to Tp 1, R 15W2 were constructed (Figure 3.1). Hydraulic head and total dissolved solids distributions were plotted on the sections, according to the zonations established on the maps.

The chemistry of formation waters is often useful for the delineation of regional flow systems, allowing clearer definition of regional flow patterns. To distinguish regions favourable to petroleum preservation and most effectively utilize the number of samples available, a study of the metamorphism index, or ratio of the reacting values of Na^+ to Cl^- (Sulin, 1946), was conducted for the region. The chemical analyses interpreted to

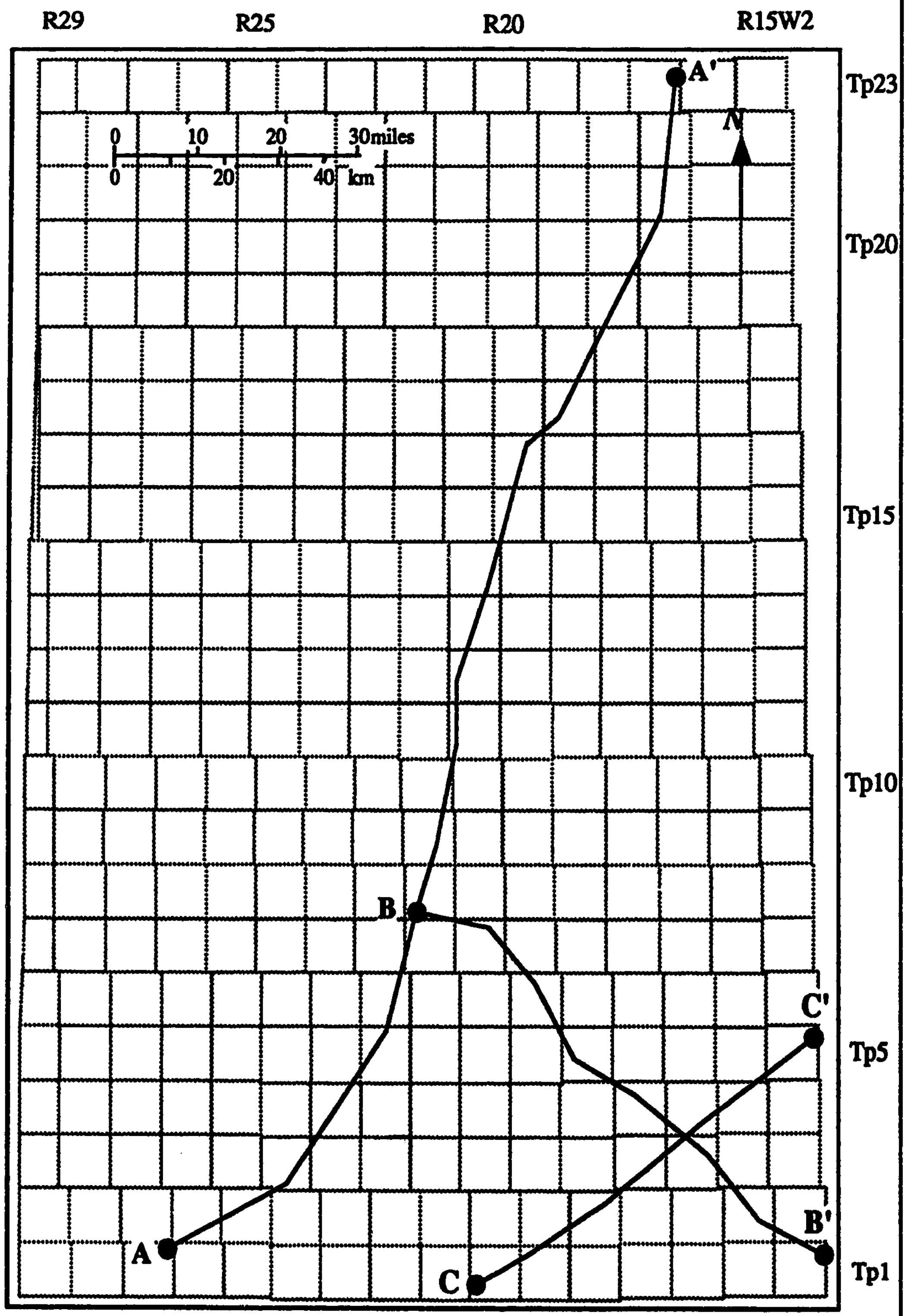


Figure 3.1 Locations of cross sections, constructed to show subsurface distributions of fluid potential and total dissolved solids in the study area.

be reliable for total dissolved solids mapping were used. In the Madison Aquifer, only the best two analyses from each township were selected.

The metamorphism index was plotted in graph format, with sodium values on the horizontal axis and chloride values on the vertical axis. The line $rNa^{+}:rCl^{-}=1$ was added as a reference. A single flow regime would be expected to provide a continuous decrease in the $rNa^{+}:rCl^{-}$ ratio indicating progression along the flow path. Where more than one flow regime is present, or where significant lithological influences occur, two or more populations may appear, which may be identified by clustering of data.

4.0 Results

4.1 Potentiometric Surface Maps

The potentiometric surfaces in each of the Paleozoic aquifers exhibit remarkably similar trends, suggesting that the units act as a single hydrogeological system. Close correspondence was found amongst the three aquifers (Basal Clastic; Bighorn; Winnipegosis) below the Elk Point Aquitard and amongst the two aquifers (Saskatchewan; Madison) immediately above it. The potentiometric pattern closely resembles that of the topography, both in form and elevation. In southern areas, freshwater head decreases upwards through the geological column. It remains fairly constant in the north and central areas and increases upsection in the northeast.

Regional flow is from southwest to northeast in the Basal Clastic Aquifer (Figure 4.1), with the eastward flow component increasing in the upper Paleozoic, becoming almost west to east in the Madison Aquifer (Figure 4.5). Flow radiates outward from three potentiometric highs along the southern and western map edges. The strongest high is located in the southwestern corner of the study area, in the region of Wood Mountain (Figure 4.1). Two weaker highs occur in the south, one following the outline of the Roncott Remnant, extending northward from R 20-25W2 along the southern boundary, the other somewhat smaller high occupying the southeastern townships. The Wood Mountain and Roncott highs coalesce somewhat.

In the Basal Clastic Aquifer, a potentiometric high greater than 950m follows the outline of Wood Mountain in the southwest (Figure 4.1). It corresponds to a topographic elevation of about 900 metres. Zones of >900m

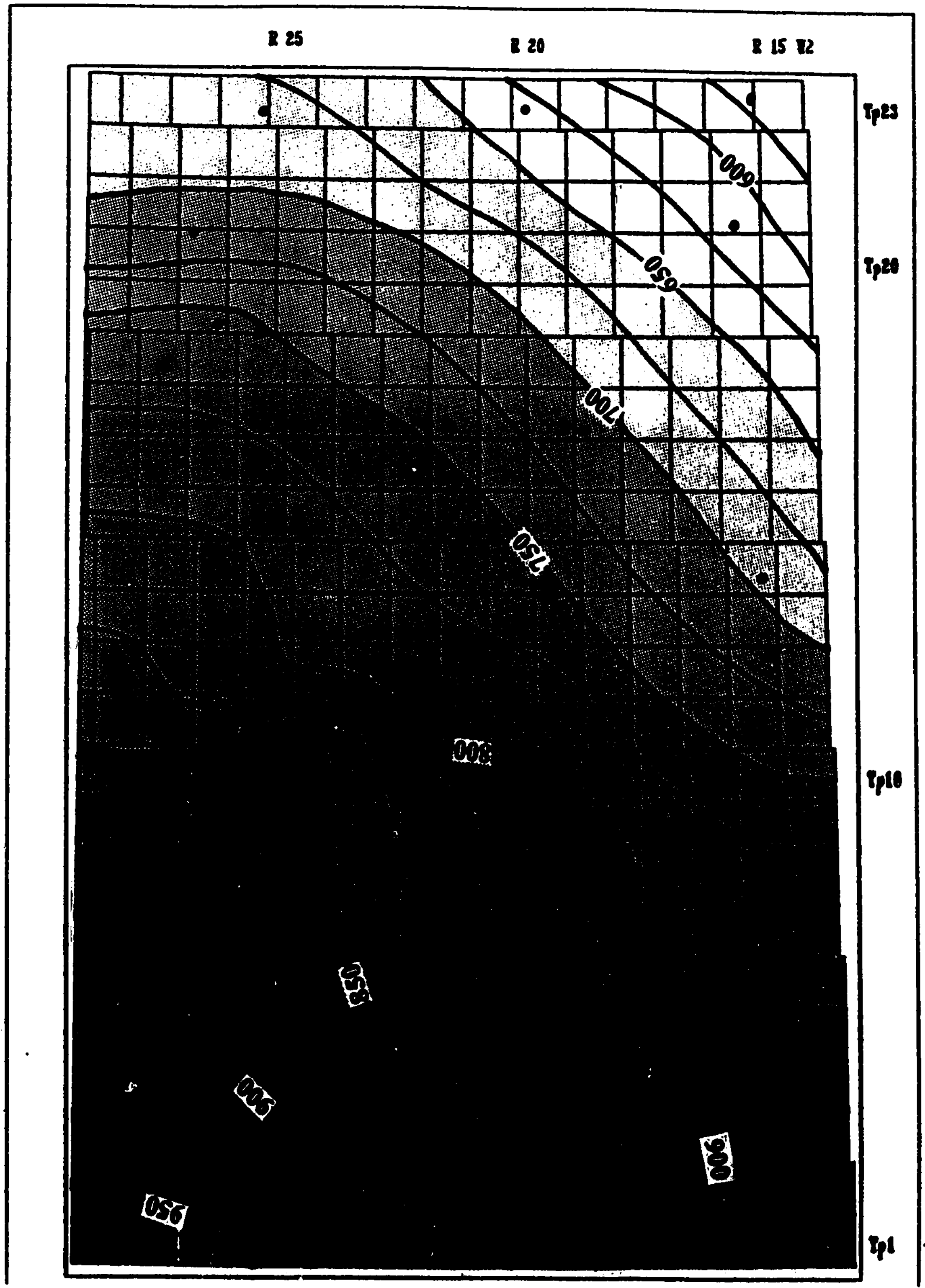


Figure 4.1 Potentiometric surface of the Basal Clastic Aquifer. Elevations are relative to sea level; contour interval =25m; • = control point. Zones of hydraulic head are shaded at 50m intervals to emphasize regional trends.

0 10 20 30 miles
0 20 40 km

head occupy the southwest area from Wood Mountain to Roncott and the southeast map area. The three highs are separated by elongate lows of 850-900m, one following the Coronach Trough (Tp 3-6, R 23-25W2), the other occupying the Hummingbird Trough (Tp 1-4, R 18-20W2). Potentiometric contours tend to be fairly evenly spaced, with some congestion of contours east of the Hummingbird Trough at Tp 4-5, R 15-17W2, along the solution edge of the Prairie Evaporite and at Tp 11-12, R 25-26W2, where a high intersects the Missouri Coteau. Contours are undulate in the southwest, but straighten out along the Missouri Coteau. They remain subparallel to the Coteau throughout the northeast, decreasing to a low of 575 metres in the extreme northeastern map area.

The elevation of the potentiometric surface of the Bighorn Aquifer (Figure 4.2) is marginally lower than in the Basal Clastic Aquifer in the south, much the same in central areas and somewhat higher in the far northeast corner. Highs of >900m occur at Wood Mountain, Roncott and the southeast, separated by lows of 825-850m that follow the Hummingbird and Coronach Troughs. The potentiometric surface decreases gradually to a low of <600m in the northeast. Contours are fairly widely spaced and lobate in the southwest and central areas becoming constricted surrounding the Roncott Remnant, along the Hummingbird Trough and the southeastern edge of the Prairie Evaporite. A slight tightening of contours occurs northeast of the Missouri Coteau, where contours become straighter and are subparallel to each other and to the Coteau.

The potentiometric surface of the Winnipegosis Aquifer (Figure 4.3) is lower than the Bighorn Aquifer in the south, much the same in central areas and is marginally lower in the northeast. Lobate highs >900m correspond to

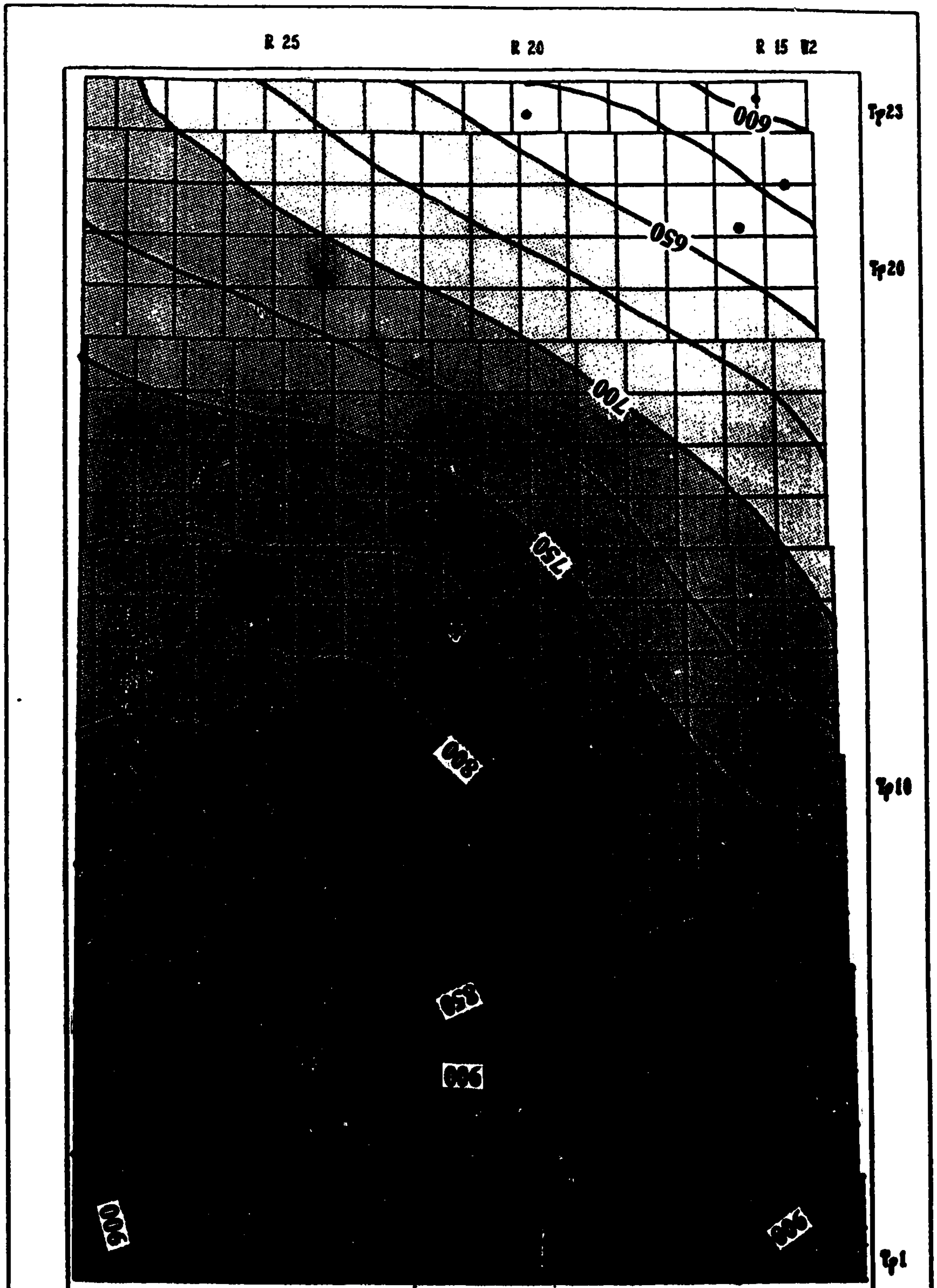
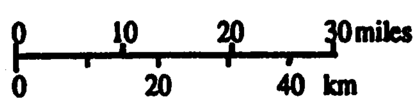


Figure 4.2 Potentiometric surface of the Bighorn Aquifer. Elevations are relative to sea level; contour interval =25m; • = control point. Zones of hydraulic head are shaded at 50m intervals to emphasize regional trends.



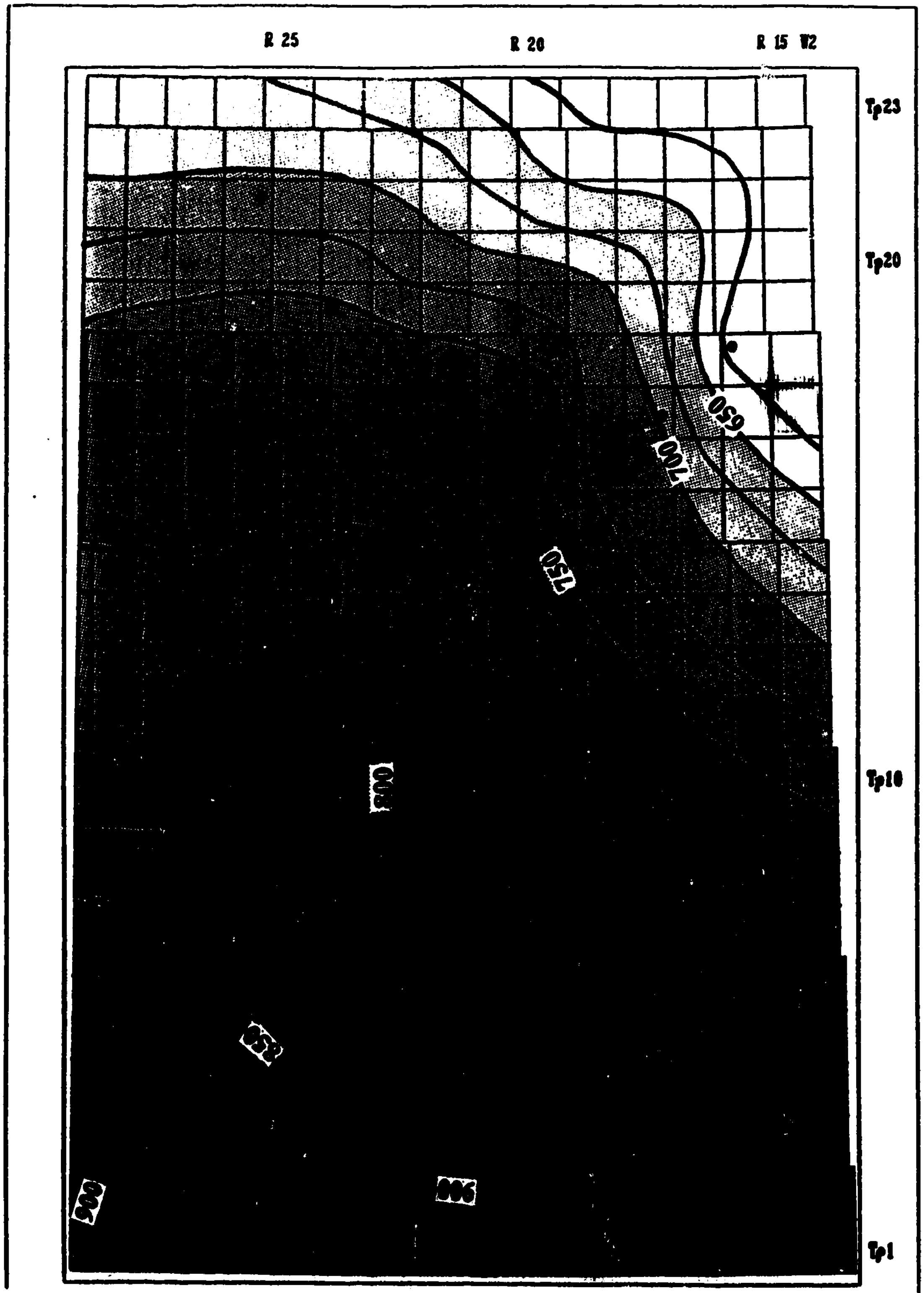


Figure 4.3 Potentiometric surface of the Winnipegosis Aquifer. Elevations are relative to sea level; contour interval =25m; • = control point. Zones of hydraulic head are shaded at 50m intervals to emphasize regional trends.

0 10 20 30 miles

Wood Mountain and Roncott, and a high of >875m occupies the southeastern townships. Lows between 825-850m follow the Hummingbird and Coronach Troughs, mimicking the pattern seen in the underlying units. A significant constriction in the contours occurs in the northeastern quadrant of the area and in the south, corresponding to the outline of the overlying Prairie Evaporite salt.

The Saskatchewan Aquifer (Figure 4.4) is separated from the Winnipegosis Aquifer by the Elk Point Aquitard. The Elk Point Aquitard contains thick beds of halite, which are often regarded as the only naturally occurring, truly impermeable materials in sedimentary basins. In spite of the presence of this aquitard, the potentiometric surface of the Saskatchewan Aquifer bears a strong resemblance to those of the underlying units. Regional flow is from west-southwest to east-northeast, from a high of >900m at and immediately north of Wood Mountain, to a low of >650m in the northeast. Highs at Roncott (>875m) and the southeast (>750m) are more subdued. Hydraulic head is lower in the south and east and somewhat higher in the far southwest and northeast compared to the Winnipegosis Aquifer. Some tightening of contours occurs along the Hummingbird Trough, around the two southwestern highs and in the northeast quadrant.

The Madison Aquifer contains the greatest number of data points of any of the aquifers (Figure 4.5). Data density is good over much of the area and very good between Townships 1 to 7 and Ranges 15 to 21W2 in the southeast, however, there are no control points north of Township 15, beyond the Mission Canyon subcrop. Regional flow is from west-southwest to east-northeast, from highs of nearly 900m to a low of 625m. A potentiometric high of >875m hugs the western map boundary between Townships 1 and 11.

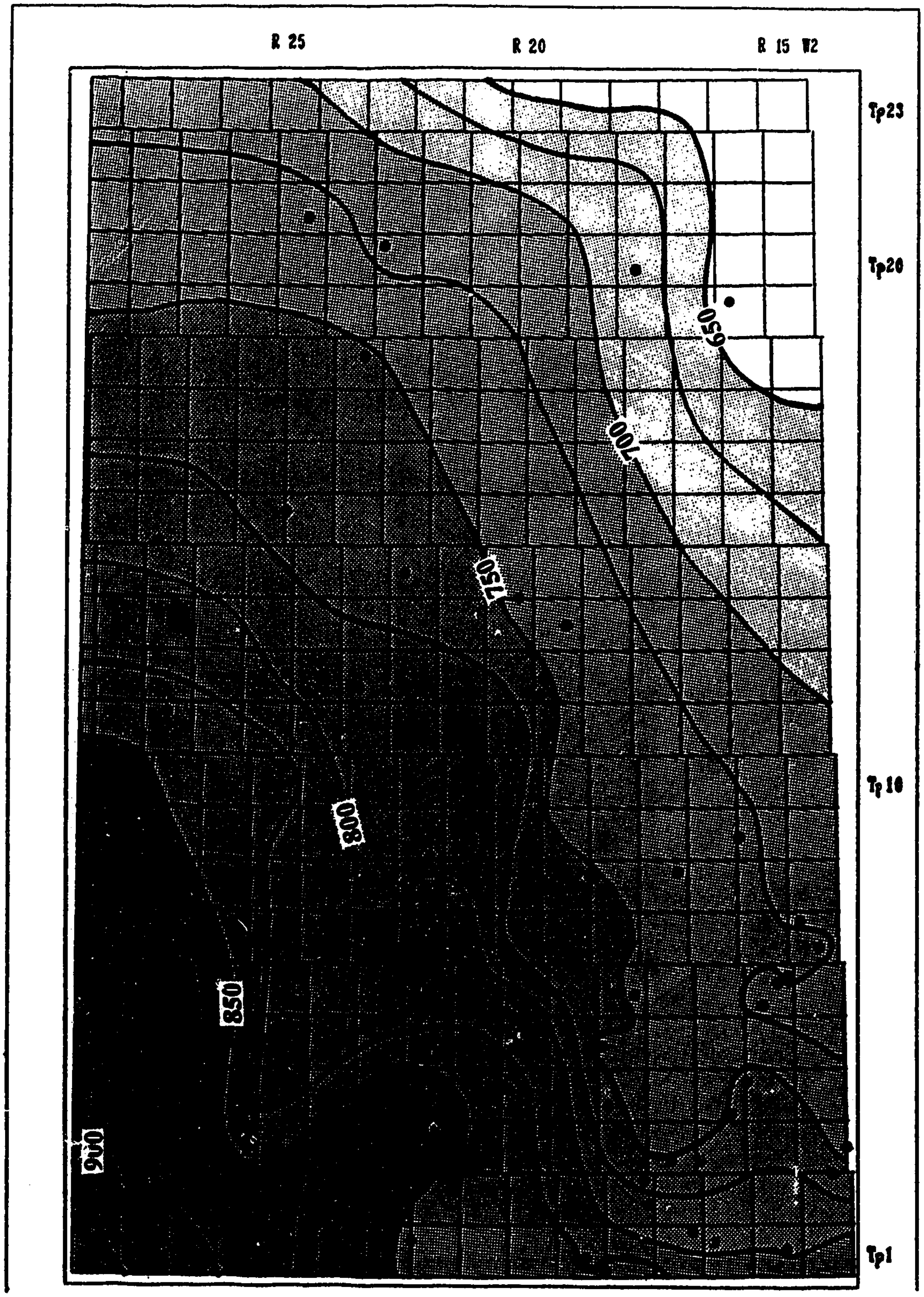
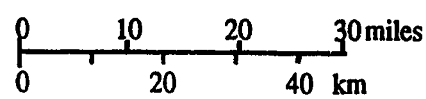


Figure 4.4 Potentiometric surface of the Saskatchewan Aquifer. Elevations are relative to sea level; contour interval =25m; • = control point. Zones of hydraulic head are shaded at 50m intervals to emphasize regional trends.



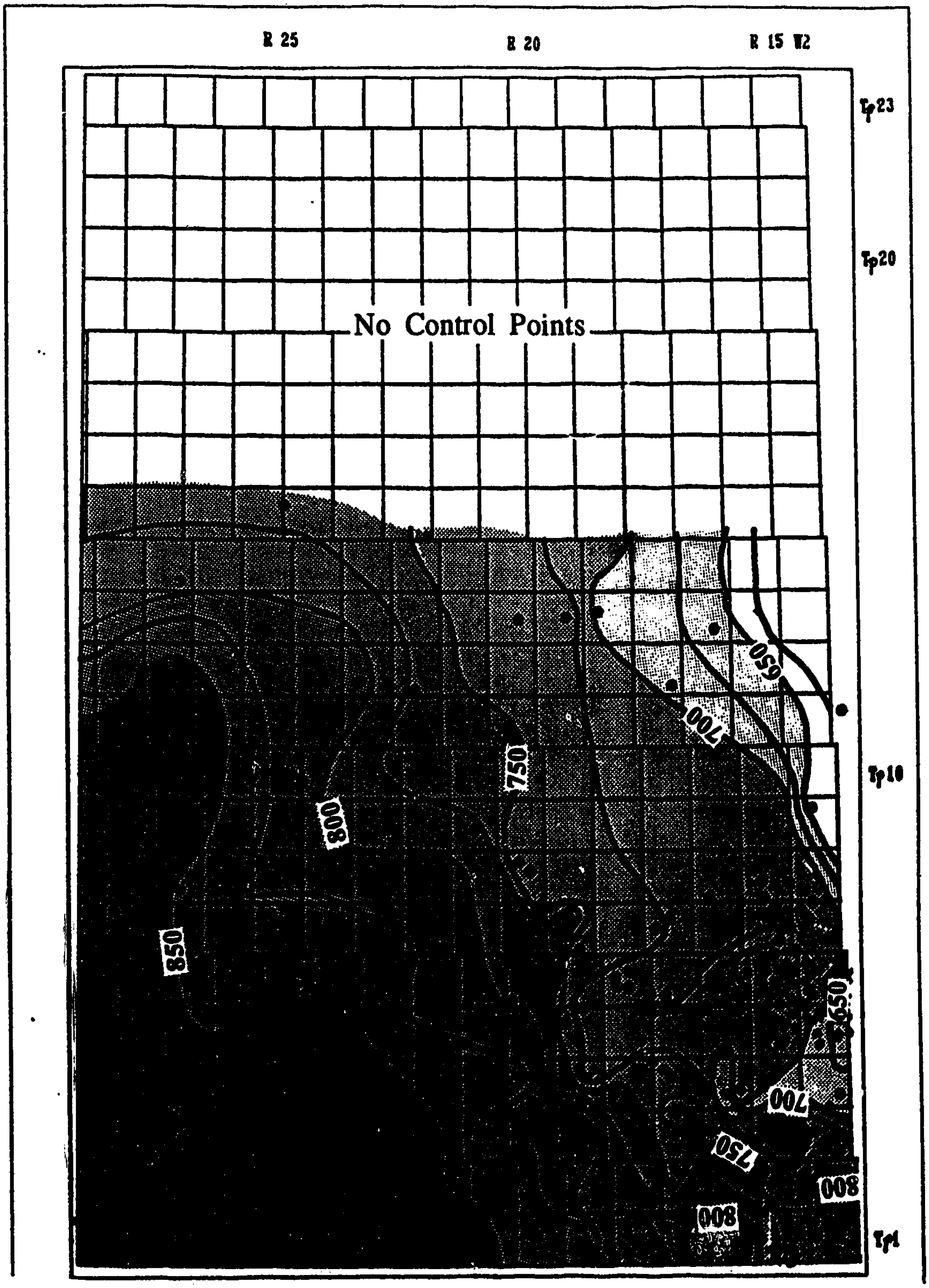
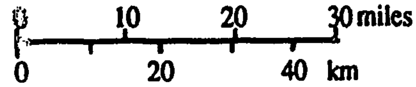


Figure 4.5 Potentiometric surface of the Madison Aquifer. Elevations are relative to sea level; contour interval =25m; ● = control point. Zones of hydraulic head are shaded at 50m intervals to emphasize regional trends.



It is separated from a high of >875m at Tp 1-2, R 25-26W2 near Roncott, by a low that follows R 28W2. The Roncott high has gradually shifted westward up through the section and is centred three townships west of its position in the Basal Clastic Aquifer. Two local highs of >800m occur along the southeastern borders. A congestion of contours follows the Hummingbird Trough as well as the eastern border of the area.

The potentiometric surfaces of the two Mesozoic aquifers are distinctly different from those of the Paleozoic aquifers and from each other. The Middle Jurassic potentiometric surface (Figure 4.6), is on average about 100 metres lower than that of the Madison Aquifer. The data are limited to a zone between Townships five and eleven. Regional flow is from south-southwest to north-northeast as in the Paleozoic, ranging from a high of 770m in the southwest (Tp 5, R 25W2) to a low of 585m in the southeast (Tp 11, R 14W2). Contours are congested along a zone that closely follows the Missouri Coteau.

The Mannville Aquifer has a limited number of data points, not all of ideal quality or distribution. Data are absent in the southwest. Regional flow is from northwest to southeast (Figure 4.7), from a potentiometric high in the northwest of 696m (Tp 12, R 20-29W2) toward a low of 438m in the southeast (Tp 5, R 15W2). Contours are generally evenly spaced but become more congested in the southeast, where well control is greatest. In the south, contours curve to follow the trend of the Missouri Coteau. The potentiometric surface of the Mannville Aquifer shows no correspondence to topographic variations or elevations or to the potentiometric surface of the Middle Jurassic Aquifer.

Potentiometric Cross Section A (Figure 4.8) extends from the southwestern to northeastern map areas, parallel to the regional flow trend.

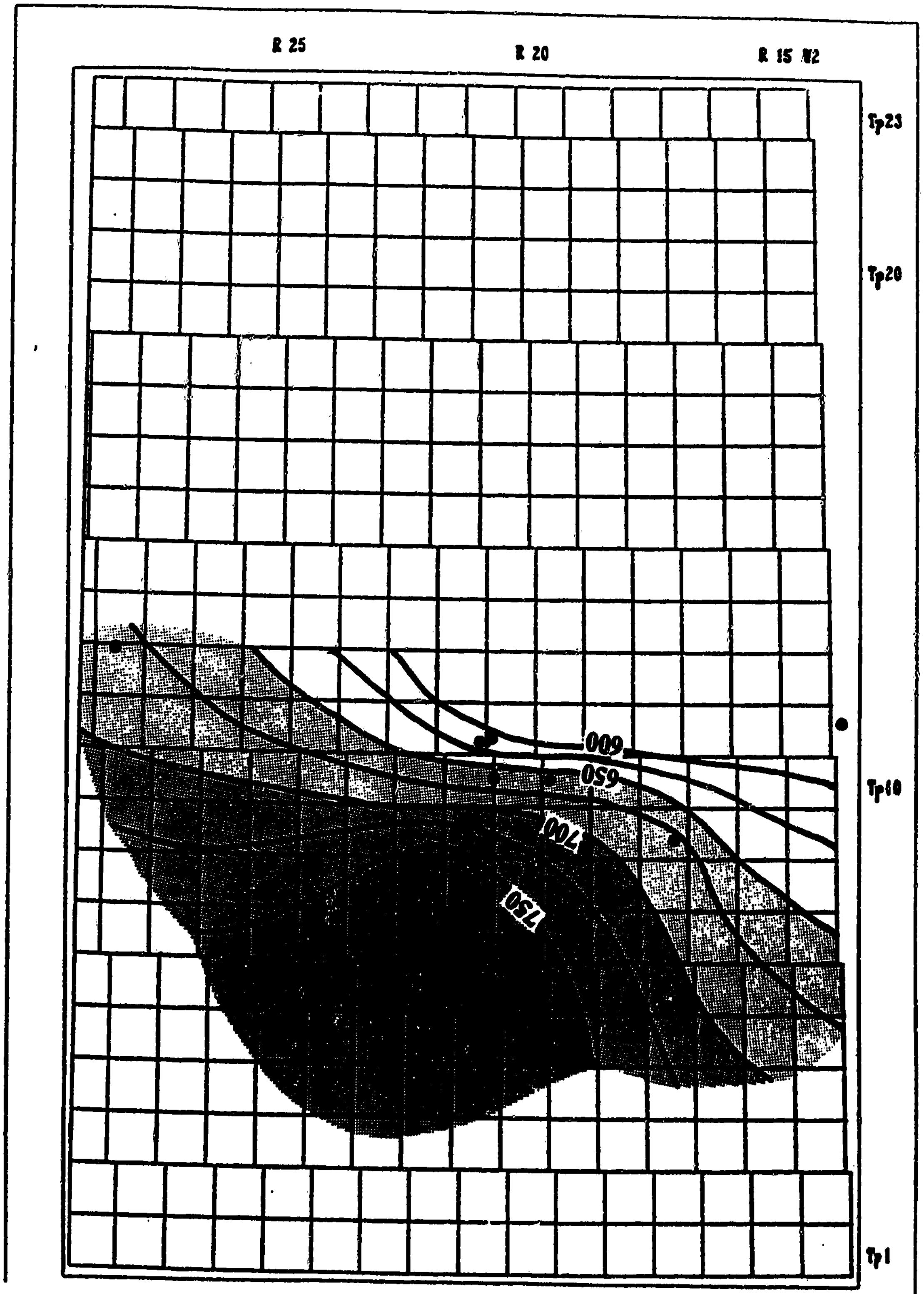


Figure 4.6 Potentiometric surface of the Middle Jurassic Aquifer. Elevations are relative to sea level; contour interval =25m; ● = control point. Zones of hydraulic head are shaded at 50m intervals to emphasize regional trends.

0 10 20 30 miles
0 20 40 km

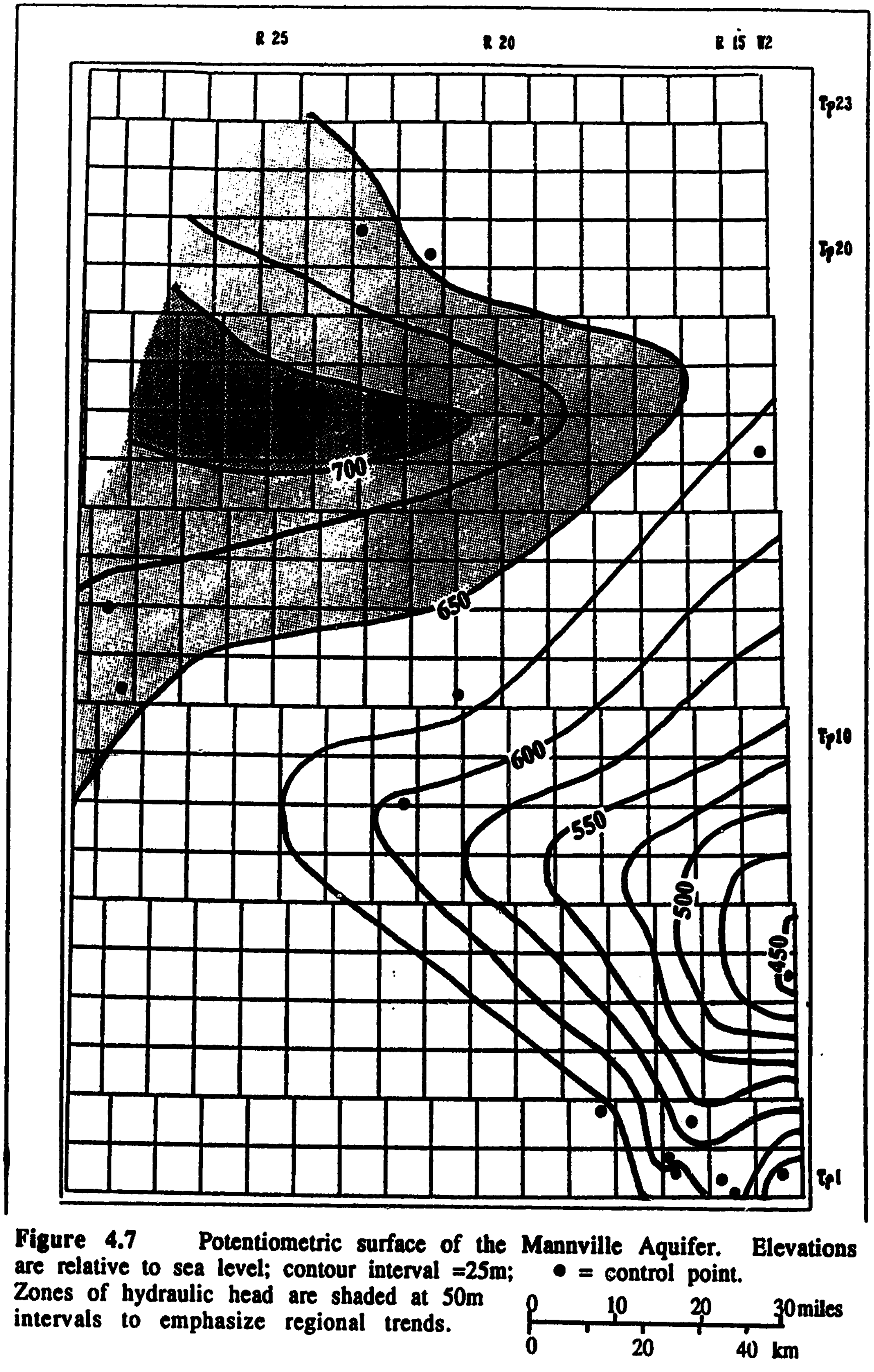
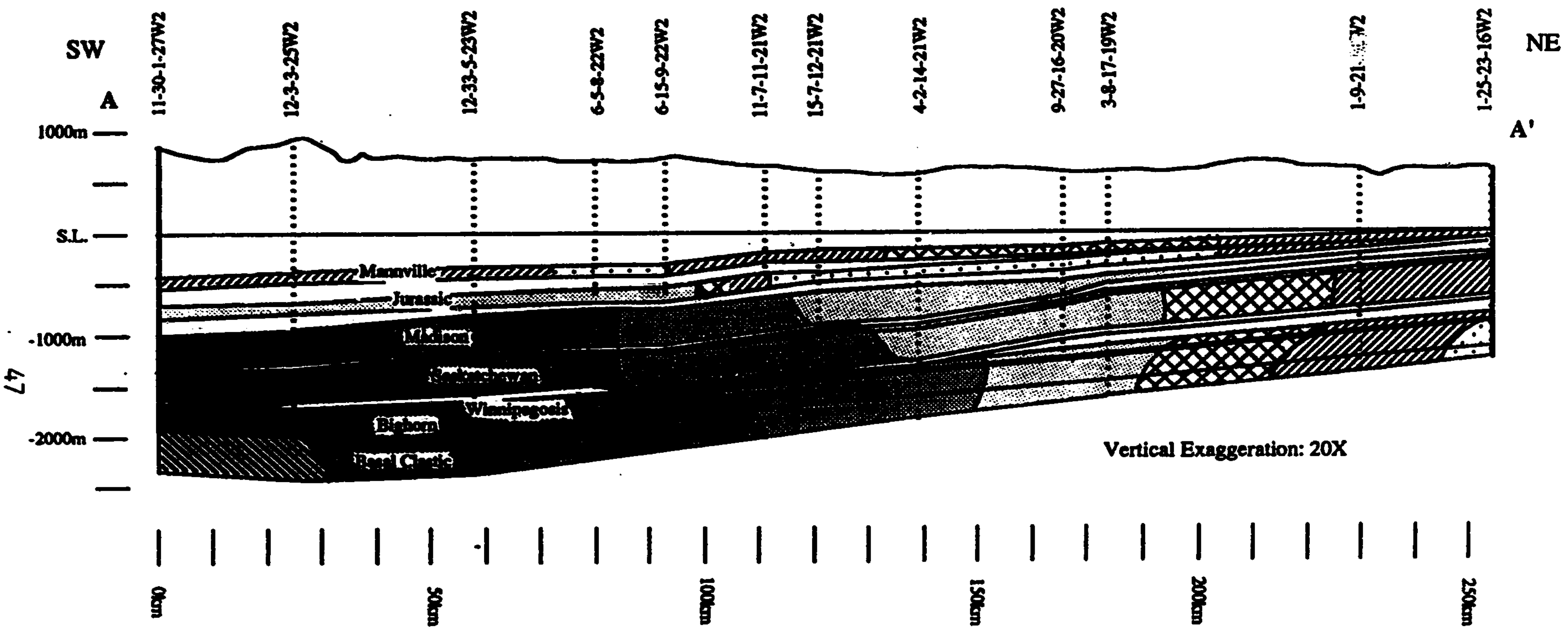


Figure 4.7 Potentiometric surface of the Mannville Aquifer. Elevations are relative to sea level; contour interval =25m; ● = control point. Zones of hydraulic head are shaded at 50m intervals to emphasize regional trends.



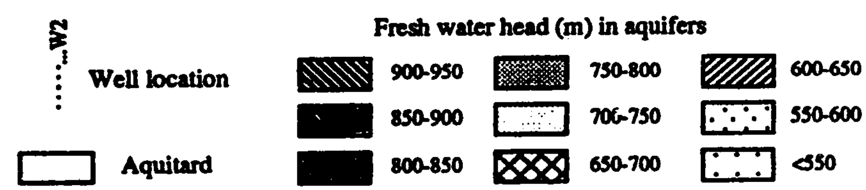


Figure 4.8 Potentiometric cross section A. The section illustrates freshwater head distribution parallel to the regional flow trend in the study area. Aquifers are are identified in the section.

It indicates mainly lateral, updip flow toward the northeast, with little cross-formational movement of water. A potentiometric high of >900m occurs in the Basal Clastic Aquifer near Wood Mountain and a potentiometric low of <600m occurs in the Basal Clastic and Bighorn aquifers in the northeast indicating an upward component of flow in the southwest and a downward component in the northeast. In contrast, Cross Sections B (Figure 4.9) and C (Figure 4.10) in the southeast map area illustrate upward decreasing potential toward and up through the Hummingbird Trough. Highs of >900m in the Basal Clastic and Bighorn aquifers resolve toward lows of <650m in the Madison Aquifer. Heads in the Mesozoic Aquifers were distinctly lower, bearing little or no relation to hydraulic heads in the Paleozoic.

4.2 Total Dissolved Solids Maps

The Paleozoic aquifers share a common pattern of concentrations of total dissolved solids, although there is a greater vertical transformation than was seen with fluid potential. In all units, lowest salinities are found in the topographically elevated area of the southwest and west-central regions. Highest salinities are found in the deep basin area of the south and southeast and in areas immediately adjacent to evaporite beds. Average concentrations decrease upward through the section, except in parts of the Winnipegosis Aquifer and the Duperow Subaquifer where halite beds are present. Often the variability of concentrations may be very great. In the Winnipegosis and Duperow, there is nearly a 350 000 mg/L TDS difference between the least and most saline areas of the aquifers.

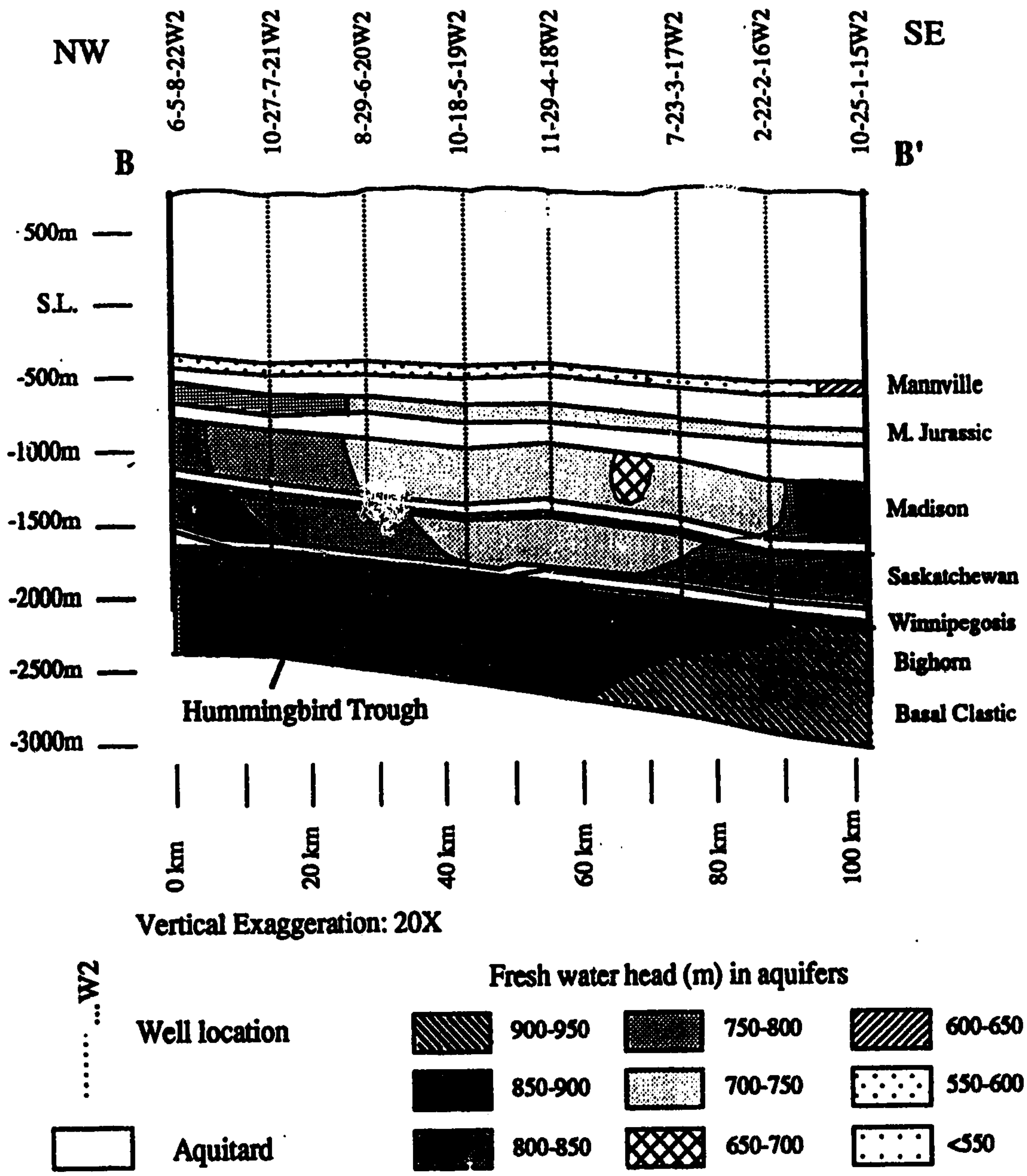


Figure 4.9 Potentiometric Cross Section B, Hummingbird Trough area. Freshwater head is illustrated relative to the Hummingbird Trough zone of salt removal. Aquifers are named adjacent to their level in the section.

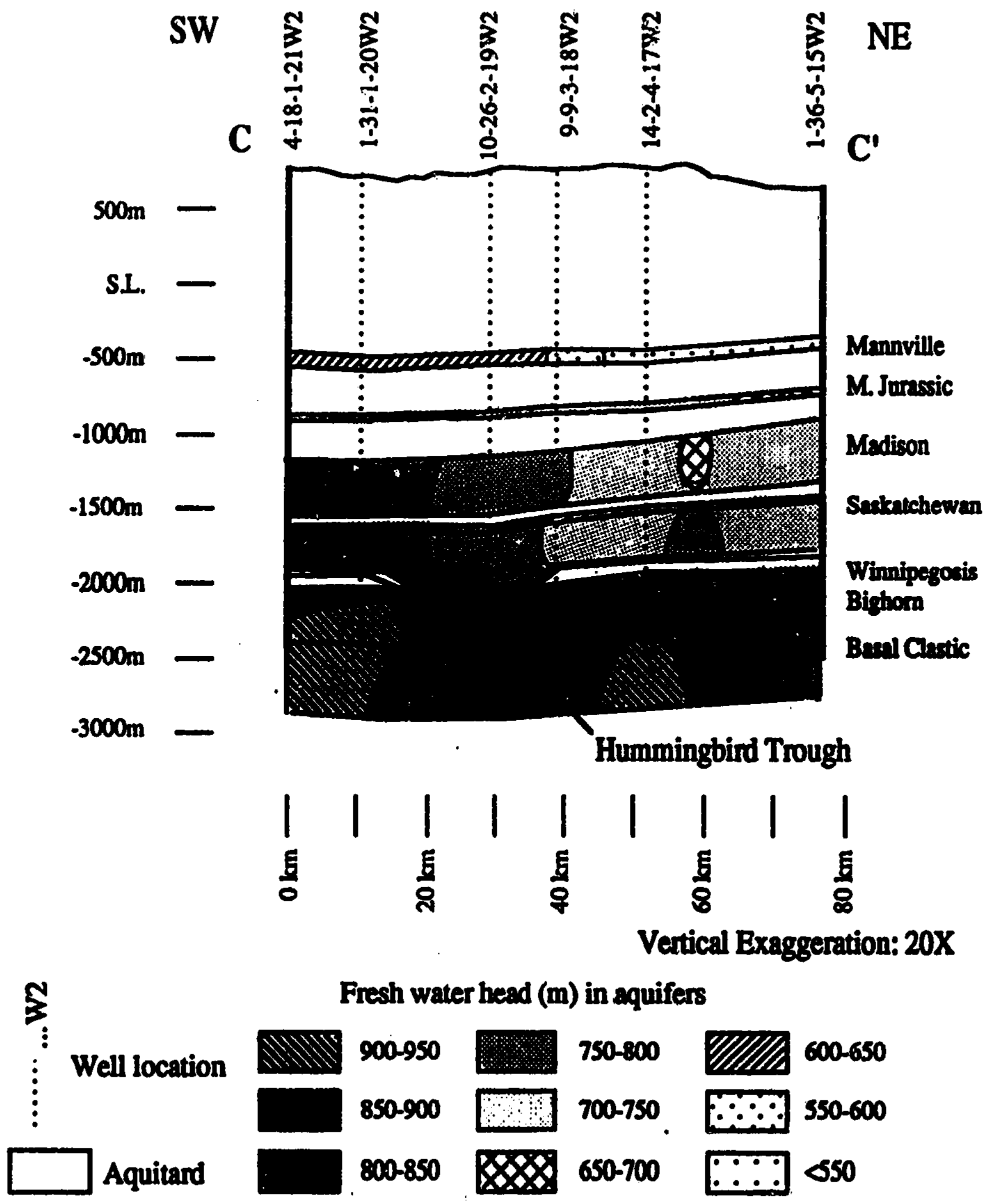


Figure 4.10 Potentiometric Cross Section C, Hummingbird Trough area. Freshwater head is illustrated relative to the Hummingbird Trough zone of salt removal. Aquifers are named adjacent to their level in the section.

In the Basal Clastic Aquifer (Figure 4.11), salinity decreases from the southeast toward the northwest, increasing slightly in the northwestern study area. The concentration of ions is lowest in the southwest and western map area (95 000 mg/L TDS) and highest in the southeast (315 000 mg/L), which is the deepest part of the basin in the area. Concentrations of 240 000 mg/L in the northwest are separated from the main saline zone by a broad trough of 100 000 to 200 000 mg/L TDS. In the southwest, there is a north-south constriction of contours and a rapid eastward increase of 200 000 mg/L over a distance of five townships, crossing the Coronach Trough.

Overall, total concentrations of ions decrease from the Basal Clastic Aquifer to the Bighorn Aquifer (Figure 4.12). In the Bighorn Aquifer, TDS concentrations range from a high of >300 000 mg/L in the southeast area to a low of 10 000 mg/L in the southwest. Salinity decreases from the southeast, toward the west and the northwest. A low of <250 000 mg/L extends south from the South Regina Trough along the length of the Hummingbird trough. The 200 000 mg/L contour forms a low extending three townships into the Regina Trough. Salinities increase rapidly from <50 000 mg/L to 250 000 mg/L along five townships crossing the Coronach Trough.

In the Winnipegosis Aquifer (Figure 4.13), concentrations of salinity range from a high of >350 000 mg/L TDS in the southeast and 275 000 mg/L in the northwest to a low of less than 10 000 mg/L in the southwest and west-central areas. The contours follow the general trend outlined by the solution edge of the Prairie Evaporite. There is a broad trough shaped low extending from the central map area (Tp 15 R 22W2) to the northeast. Another branch of the low follows the South Regina Trough. A high of >350 000 mg/L TDS extends along the eastern half of the Hummingbird trough. Contours are

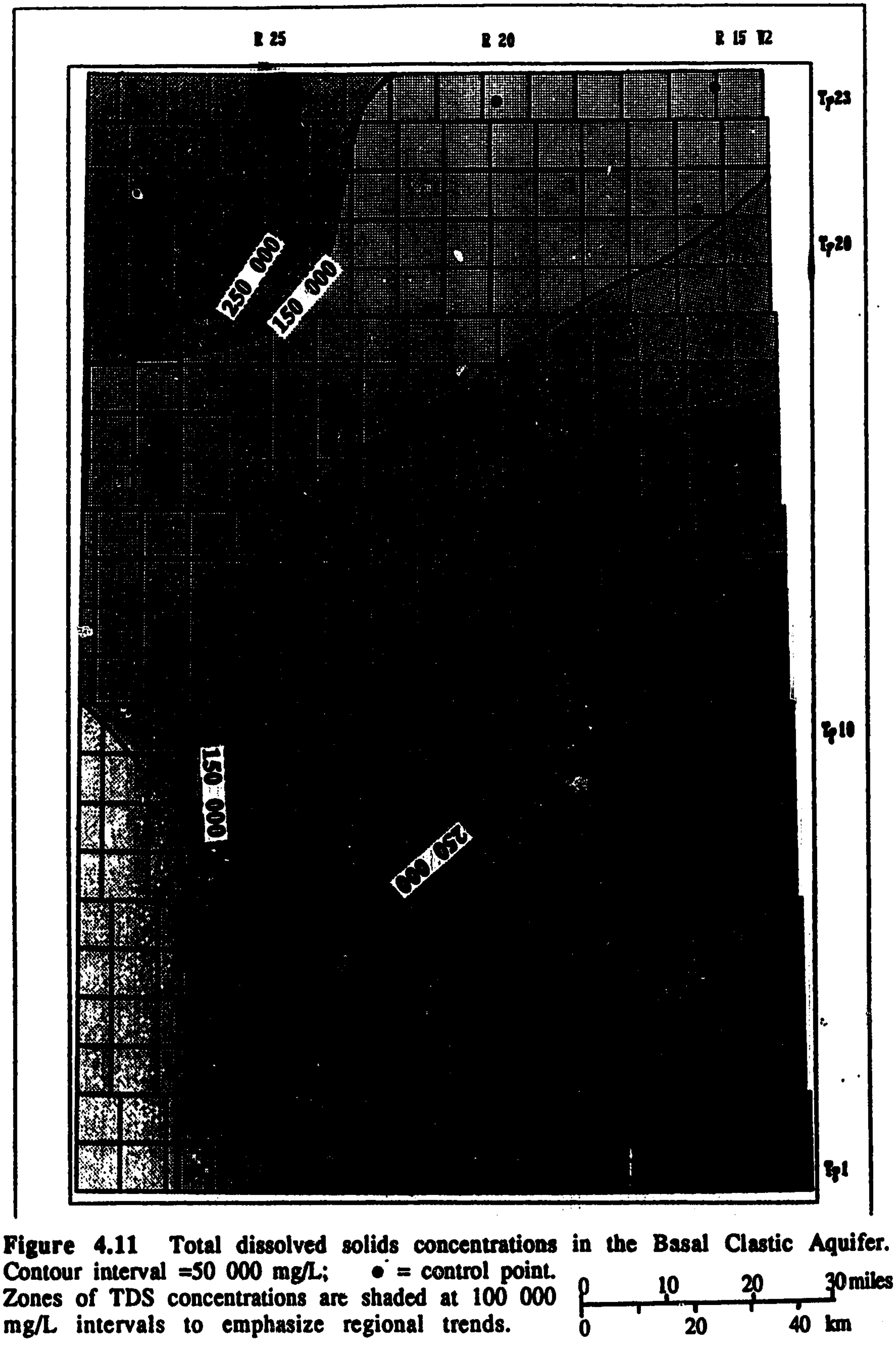


Figure 4.11 Total dissolved solids concentrations in the Basal Clastic Aquifer. Contour interval =50 000 mg/L; • = control point. Zones of TDS concentrations are shaded at 100 000 mg/L intervals to emphasize regional trends.

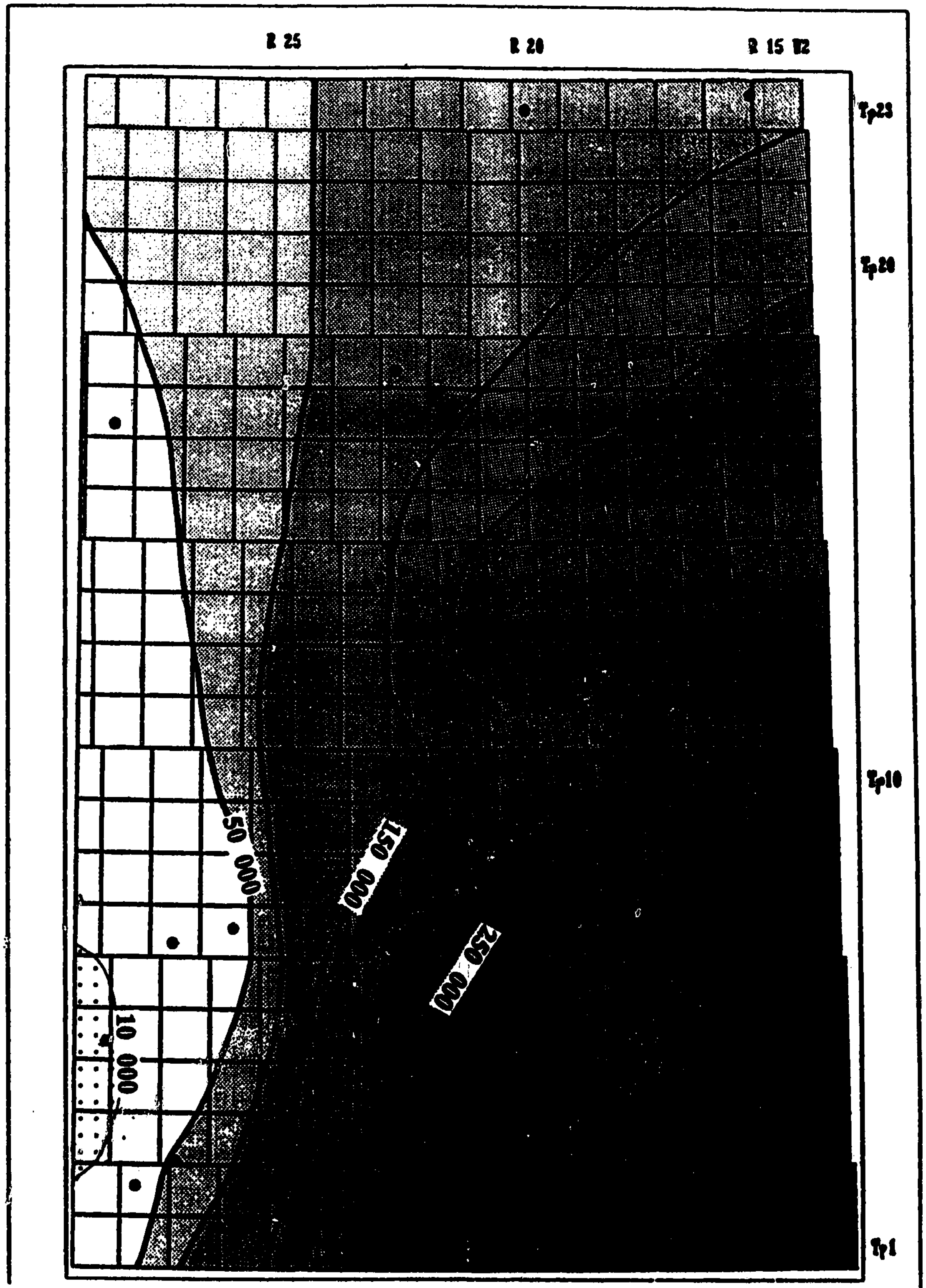


Figure 4.12 Total dissolved solids concentrations in the Bighorn Aquifer. Contour interval =50 000 mg/L; • = control point. Zones of TDS concentrations are shaded at 100 000 mg/L intervals and the 10 000 mg/L contour has been added to emphasize regional trends.

0 10 20 30 miles
0 20 40 km

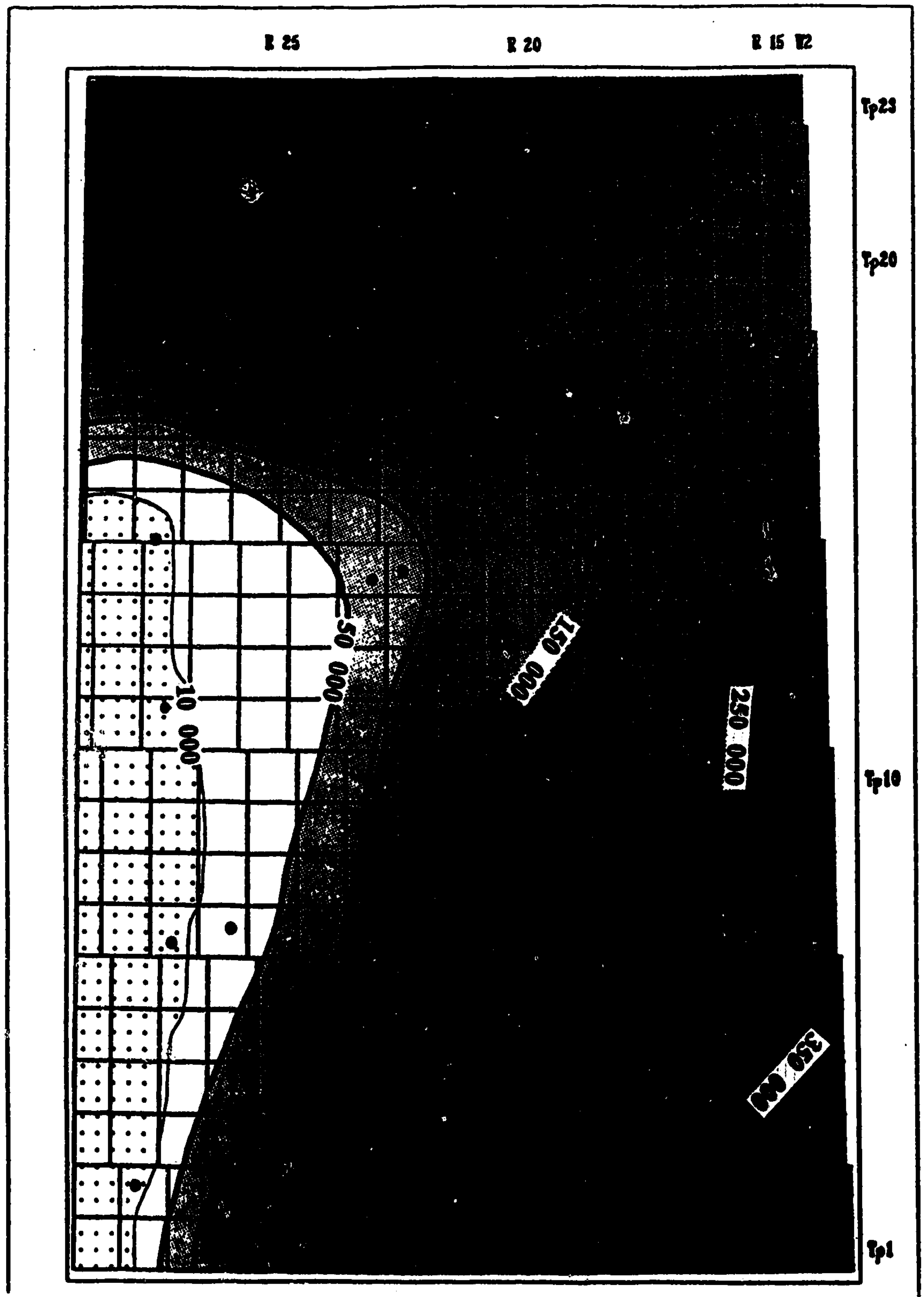


Figure 4.13 Total dissolved solids concentrations in the Winnipegosis Aquifer. Contour interval =50 000 mg/L; • = control point. Zones of TDS concentrations are shaded at 100 000 mg/L intervals and the 10 000 mg/L contour has been added to emphasize regional trends.

0 10 20 30 miles
0 20 40 km

congested in the area beneath the Roncott Remnant increasing eastward from under 10 000 mg/L in the west to over 350 000 mg/L in the east, over a span of ten townships. A more dramatic increase occurs along the northwestern edge of the Prairie Evaporite where there is a northward increase from under 10 000 mg/L to over 275 000 mg/L across three townships.

Although the Duperow and Birdbear subaquifers have similar potentiometric surfaces, the total dissolved solids distributions are markedly different, requiring that they be dealt with separately. In the Duperow Subaquifer (Figure 4.14), total dissolved solids concentrations increase from <1500 mg/L in southwest and west-central areas, to >250 000 mg/L in northern, and eastern areas to >350 000 mg/L in the southeast. The contours are congested and are subparallel to each other, creating a pattern that outlines the edges of the similarly distributed Prairie and Davidson evaporites. The pattern is like the one seen in the underlying Winnipegosis Aquifer, however, low salinity waters have become more prevalent in the southwest and changes in salinity over short distances are much more dramatic.

Although similar trends prevail, salinities are much lower in the Birdbear Subaquifer (Figure 4.15) than in the Duperow Subaquifer. TDS concentrations increase from <5000 mg/L in the west and southwest to 30 000 mg/L in the northeast, 50 000 mg/L in the northwest and 300 000 mg/L in the southeast. Waters with <50 000 mg/L TDS occupy most of the western half the study area. Concentrations of >100 000 mg/L are restricted to a zone between Tp 1-16, R 15-21 W2. A rapid change in concentrations occurs at Tp 3, R 19W2

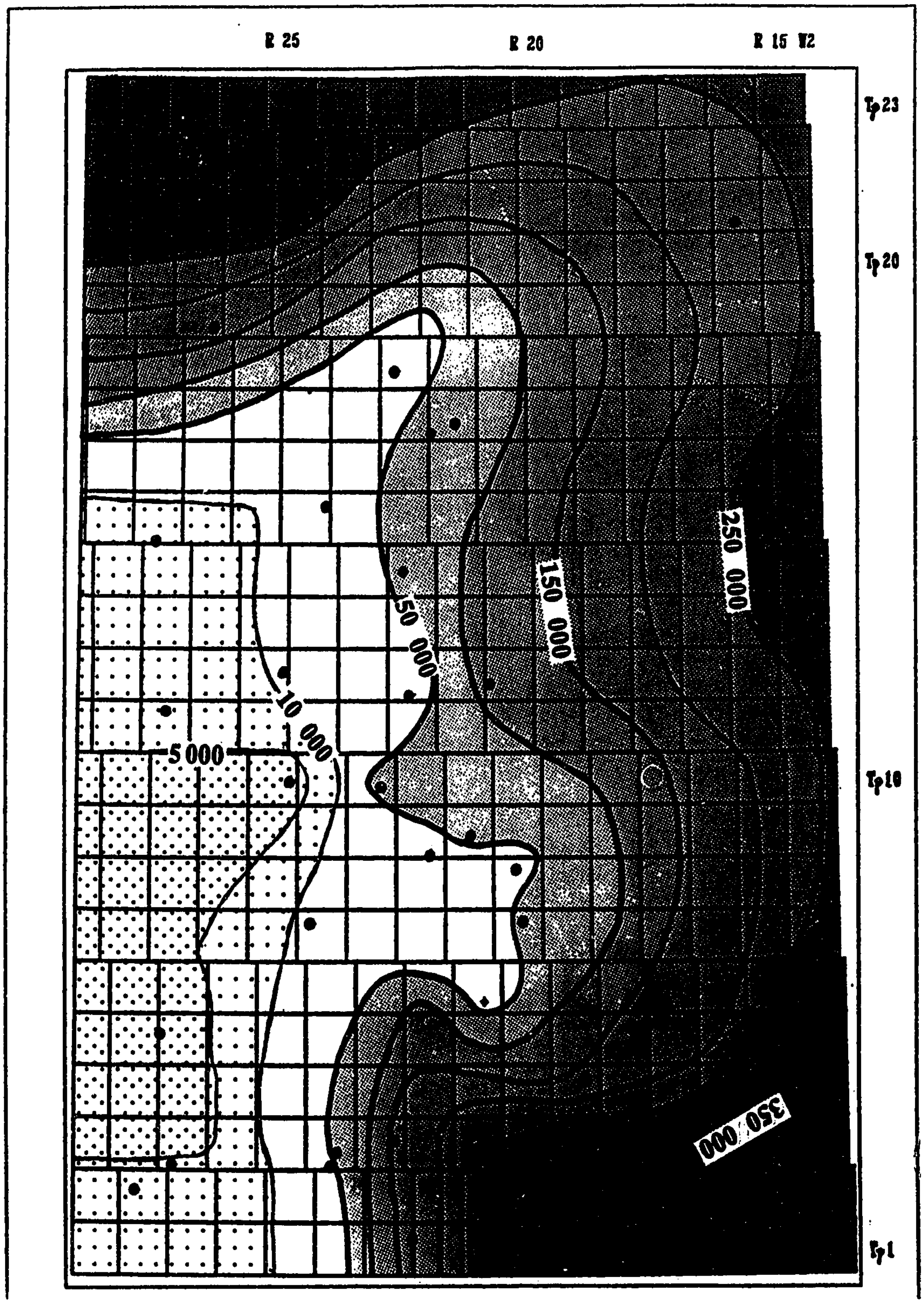
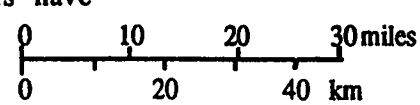


Figure 4.14 Total dissolved solids concentrations in the Duperow Subaquifer. Contour interval =50 000 mg/L; • = control point. Zones of TDS concentrations are shaded at 100 000 mg/L intervals and the 10 000 and 5000 mg/L contours have been added to emphasize regional trends.



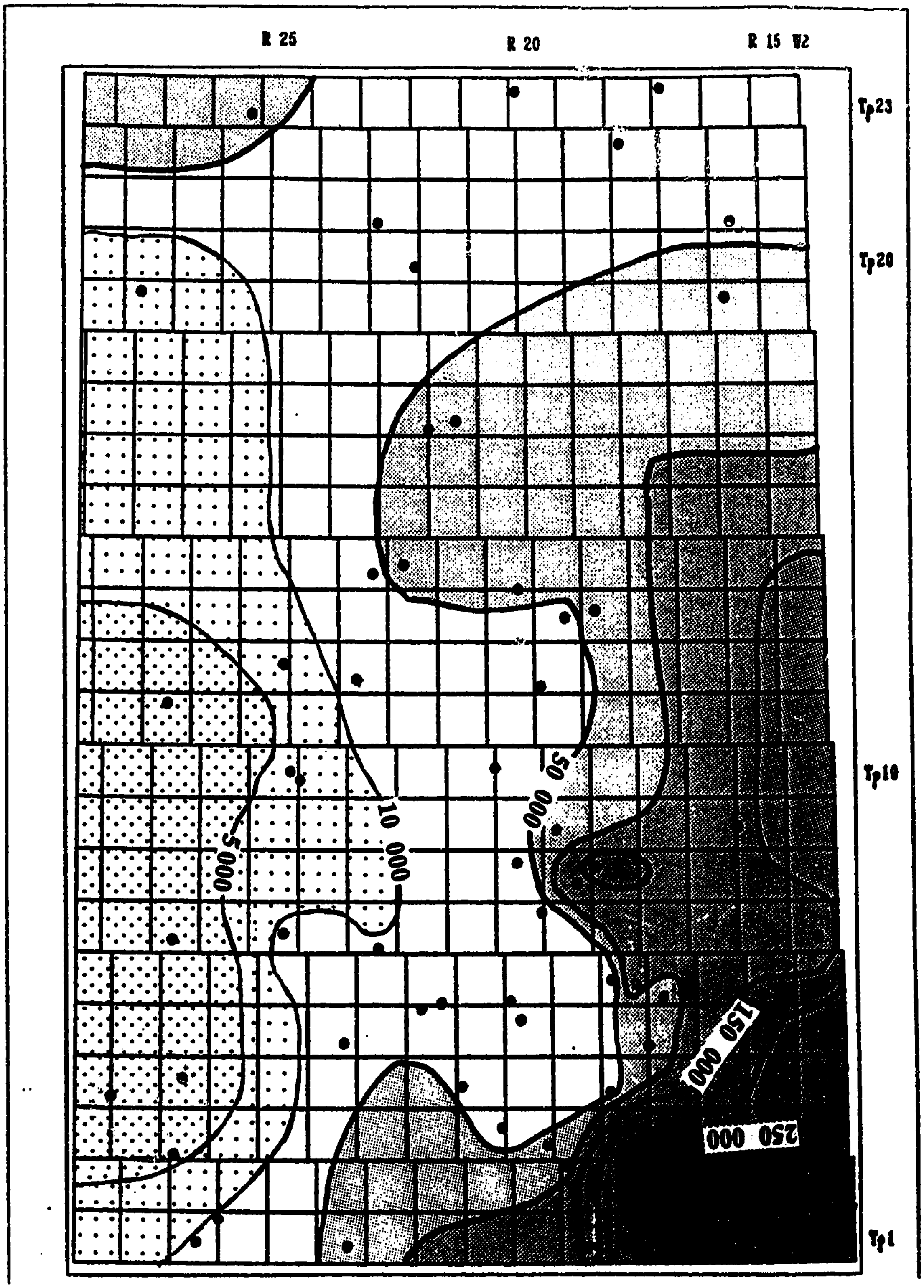
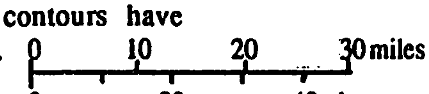


Figure 4.15 Total dissolved solids concentrations in the Birdbear Subaquifer. Contour interval =50 000 mg/L; • = control point.
Zones of TDS concentrations are shaded at 100 000 mg/L intervals and the 10 000 and 5000 mg/L contours have been added to emphasize regional trends.



in the Hummingbird Trough, where salinities increase from 35 000 to 250 000 mg/L over a distance of one township.

Formation waters in much of the Madison Aquifer are low in salinity (Figure 4.16). Concentrations range from 3500 mg/L TDS in the southwest to 15 000 mg/L in the northwest, 30 000-40 000 mg/L in the northeast to 275 000 mg/L in the extreme southeast. No data are available north of Township 19. Few significant variations in salinity occur over most of the study area, except in the southeast.

A region of elevated TDS concentrations between 100 000 mg/L and 275 000 mg/L is located in the southeast between Tp 1-4, R 15-19W2. Four oilfields lie within the region, while seven oilfields are found along the margins, where salinities range from 20 000 to 100 000 mg/L. The most dramatic changes in salinity occur along the Missouri Coteau. At Tp 4, R 16W2, salinity jumps from <40 000 to 180 000 mg/L over a distance of one township. At Tp 1-2, R 15W2, an increase of 180 000 to 275 000 mg/L occurs across less than half a township. In the southeast, zones of high salinity correspond to zones of high hydraulic head.

In the Middle Jurassic Aquifer well control is fairly poor, and is absent in the northeast (Figure 4.17). Although dissolved solids concentrations are much lower than in the Madison Aquifer, a similar regional pattern persists. Concentrations range from lows of less than 5 000 mg/L TDS in the west and west-central areas to 20 000 mg/L in central areas, to 50 000 mg/L in the extreme southeast. Contours are evenly spaced, converging somewhat in the southeast.

Control is fairly sparse in the Mannville Aquifer, particularly in the southwest and in the northeast (Figure 4.18). TDS concentrations increase

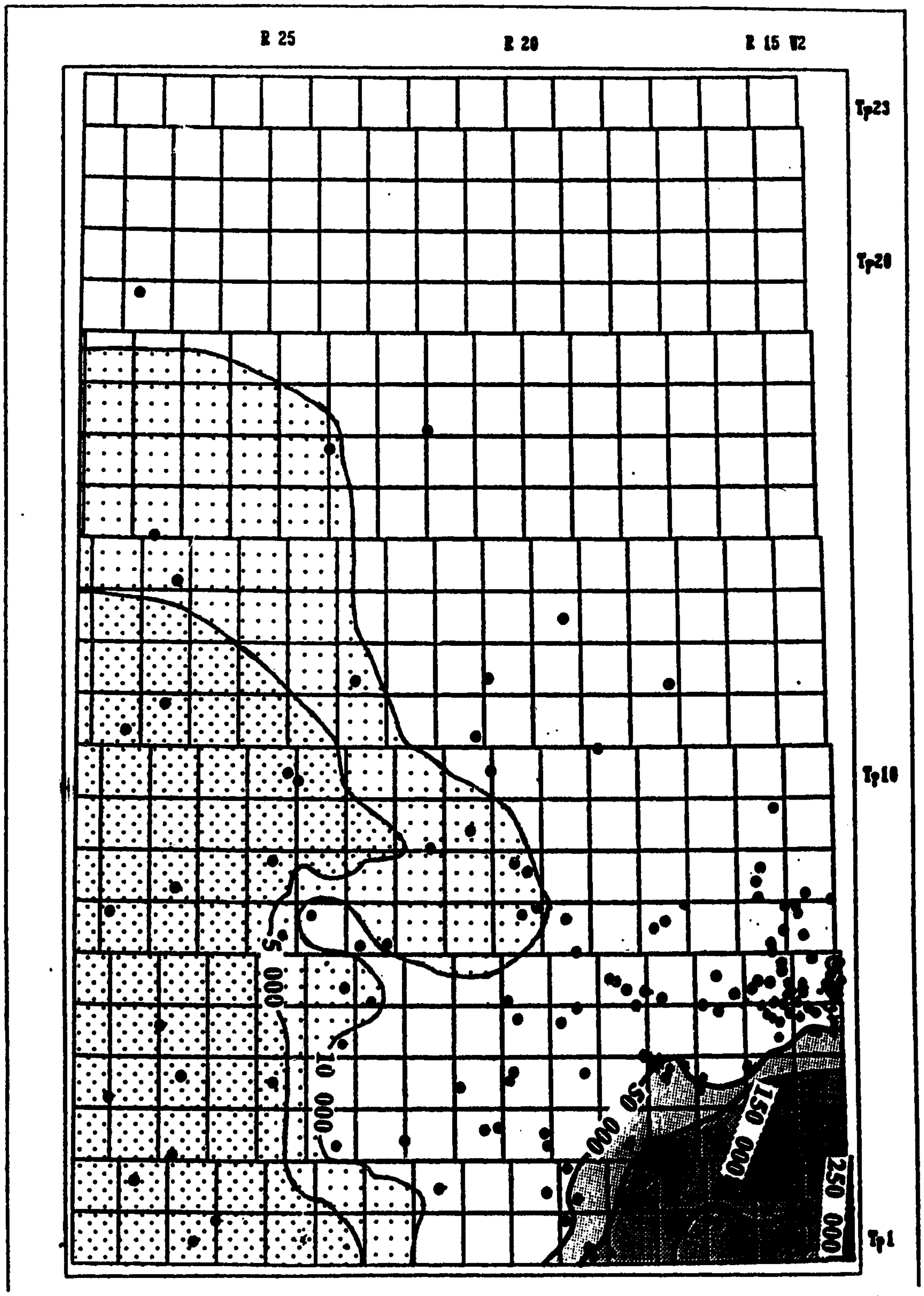


Figure 4.16 Total dissolved solids concentrations in the Madison Aquifer. Contour interval =50 000 mg/L; • = control point.
Zones of TDS concentrations are shaded at 100 000 mg/L intervals and the 10 000 and 5000 mg/L contours have been added to emphasize regional trends.

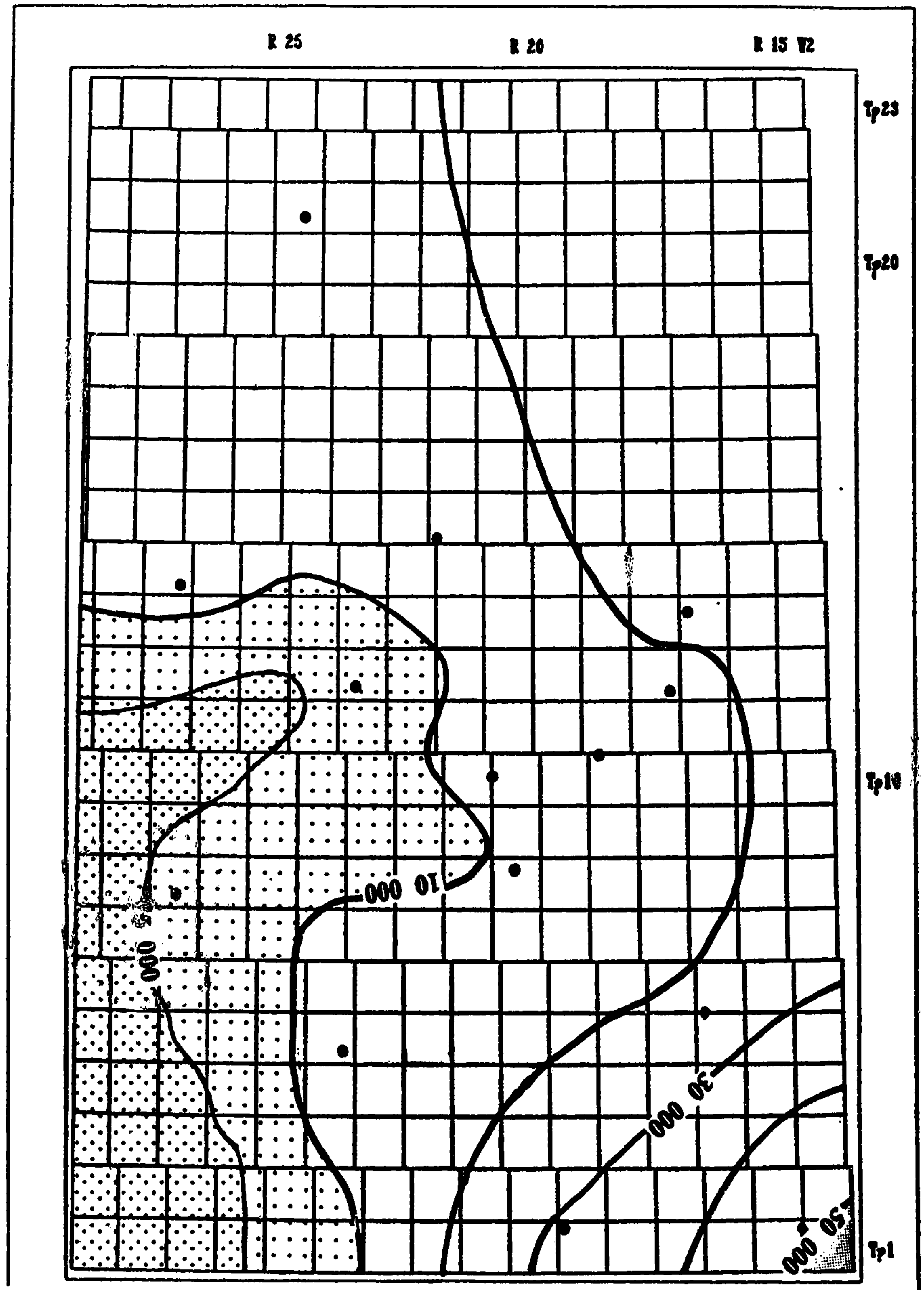


Figure 4.17 Total dissolved solids concentrations in the M. Jurassic Aquifer. Contour interval =10 000 mg/L; • = control point.
Shading of some intervals and the 5000 mg/L contour has been added to emphasize regional trends.

0 10 20 30 miles
0 20 40 km

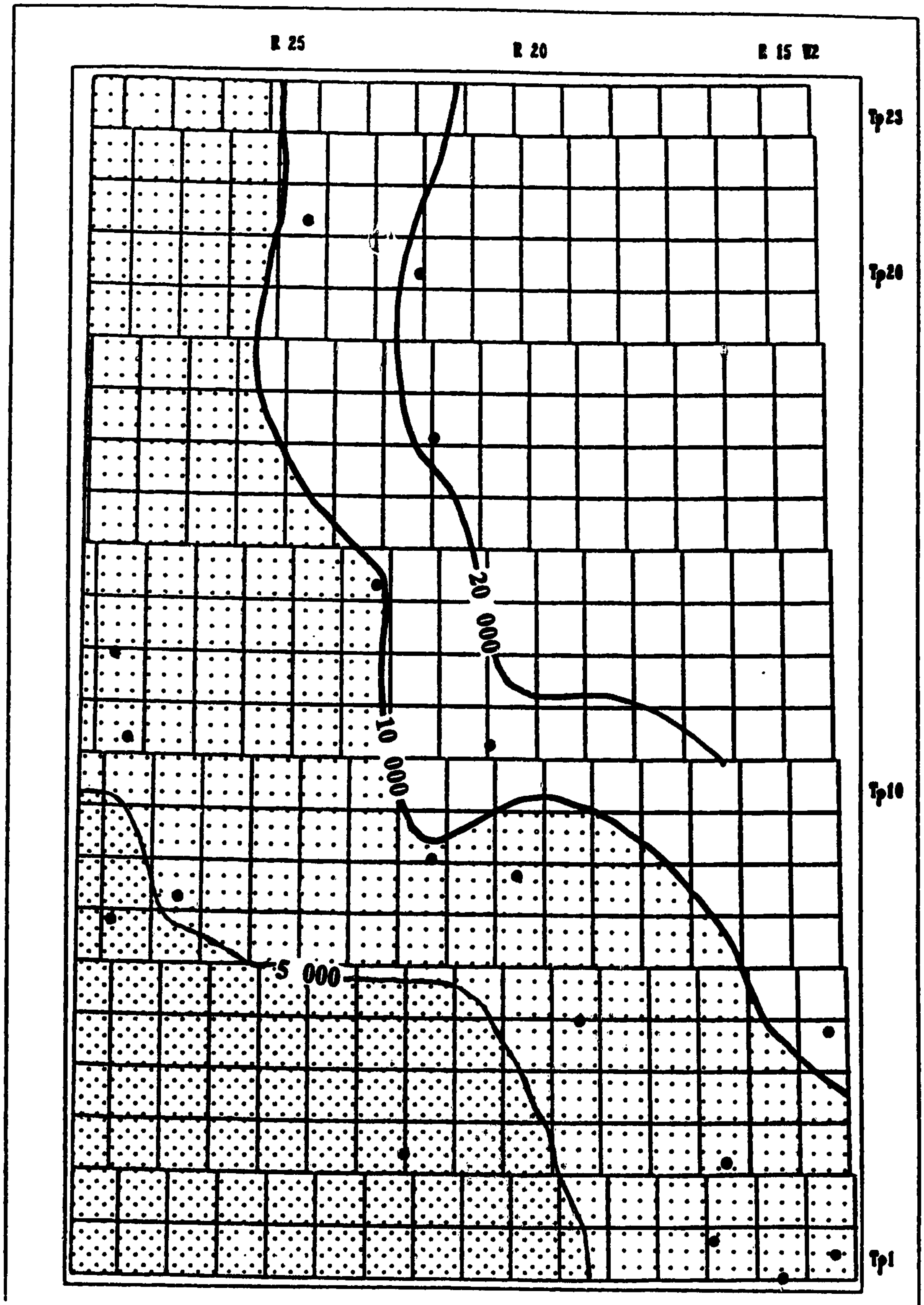


Figure 4.18 Total dissolved solids concentrations in the Mannville Aquifer. Contour interval =10 000 mg/L; ● = control point.
Shading of some intervals and the 5000 mg/L contour has been added to emphasize regional trends.

from a low of 3400 mg/L in the southwest to a high of 22 000 mg/L in the northeast. Contours are subparallel and are constricted along a northwest to southeast trending zone about four townships wide which runs parallel to the Missouri Coteau. TDS concentrations increase from 9000 mg/L to as much as 22 000 mg/L across this zone.

In the southwestern half of Cross Section A (Figure 4.19), the concentration of total dissolved solids decreases continually up the section from >250 000 mg/L in the Basal Clastic Aquifer, to 200 000 mg/L in the Winnipegosis Aquifer to 100 000 mg/L in the Duperow Subaquifer, 50 000 mg/L in the Birdbear Subaquifer and <20 000 mg/L in the overlying units. In the northeast, dissolved solids concentrations decrease away from the Duperow and Winnipegosis aquifers from >250 000 mg/L adjacent to evaporite units to 125 000 mg/L in the Basal Clastic Aquifer and <30 000 mg/L in the Mannville Aquifer. Low salinity waters are found at the greatest depths in the southwest beneath Wood Mountain. The most saline waters are found in the deep basin area of the southwest, and adjacent to evaporite beds in the northeast.

In Cross Sections B (Figure 4.20) and C (Figure 4.21), TDS concentrations decrease upwards and outwards from highs of >300 000 mg/L in the Basal Clastic Aquifer and >350 000 surrounding the Prairie Evaporite. Salinity continues to decrease up the section to <50 000 mg/L in the Madison Aquifer and <25 000 in the Mesozoic aquifers. TDS concentrations are elevated in the area above and to the east of the Hummingbird Trough in the direction of flow.

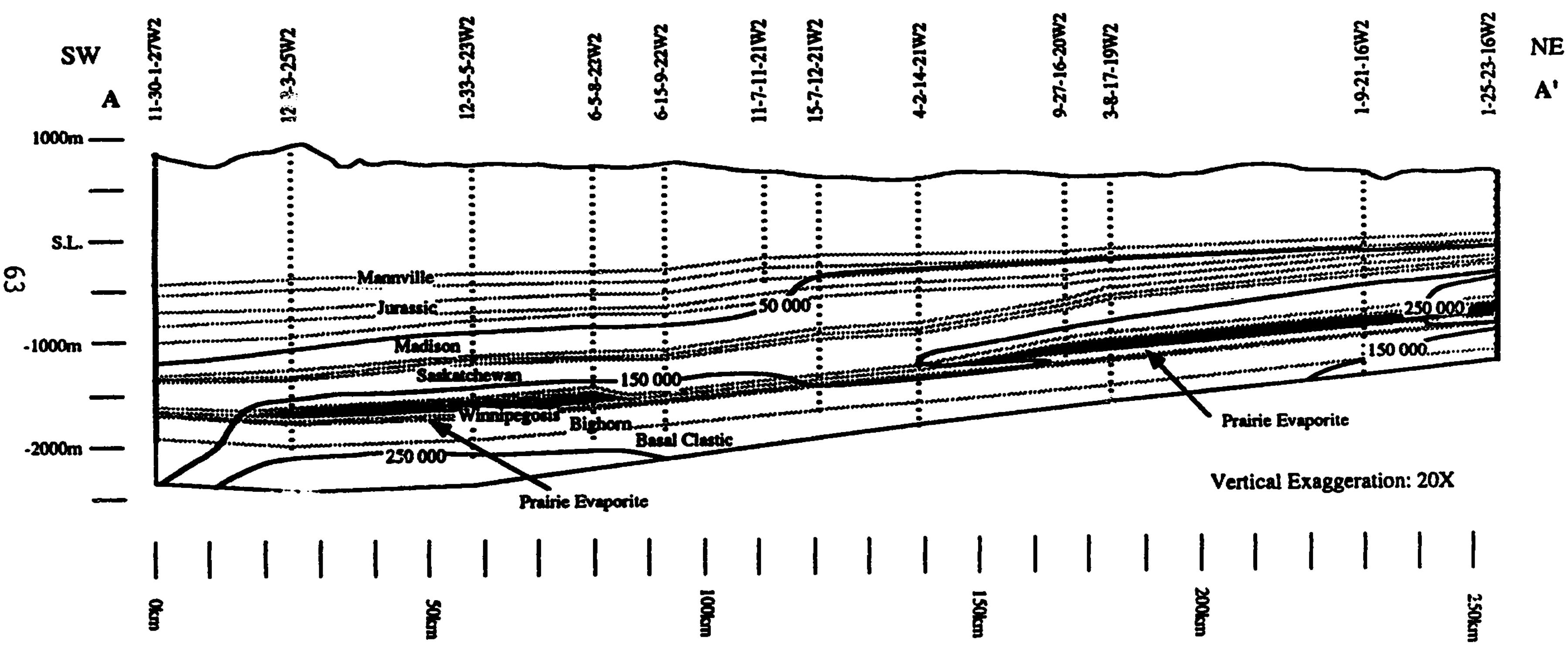


Figure 4.19 Total dissolved solids cross section A, southcentral Saskatchewan.
TDS concentrations in formation waters are contoured at a 100 000 mg/L interval, starting at 50 000 mg/L. Well locations are named and their positions are indicated by dotted vertical lines. Aquifers are labelled in the section. Aquifer boundaries are shown as grey lines. The Prairie Evaporite is shaded black.

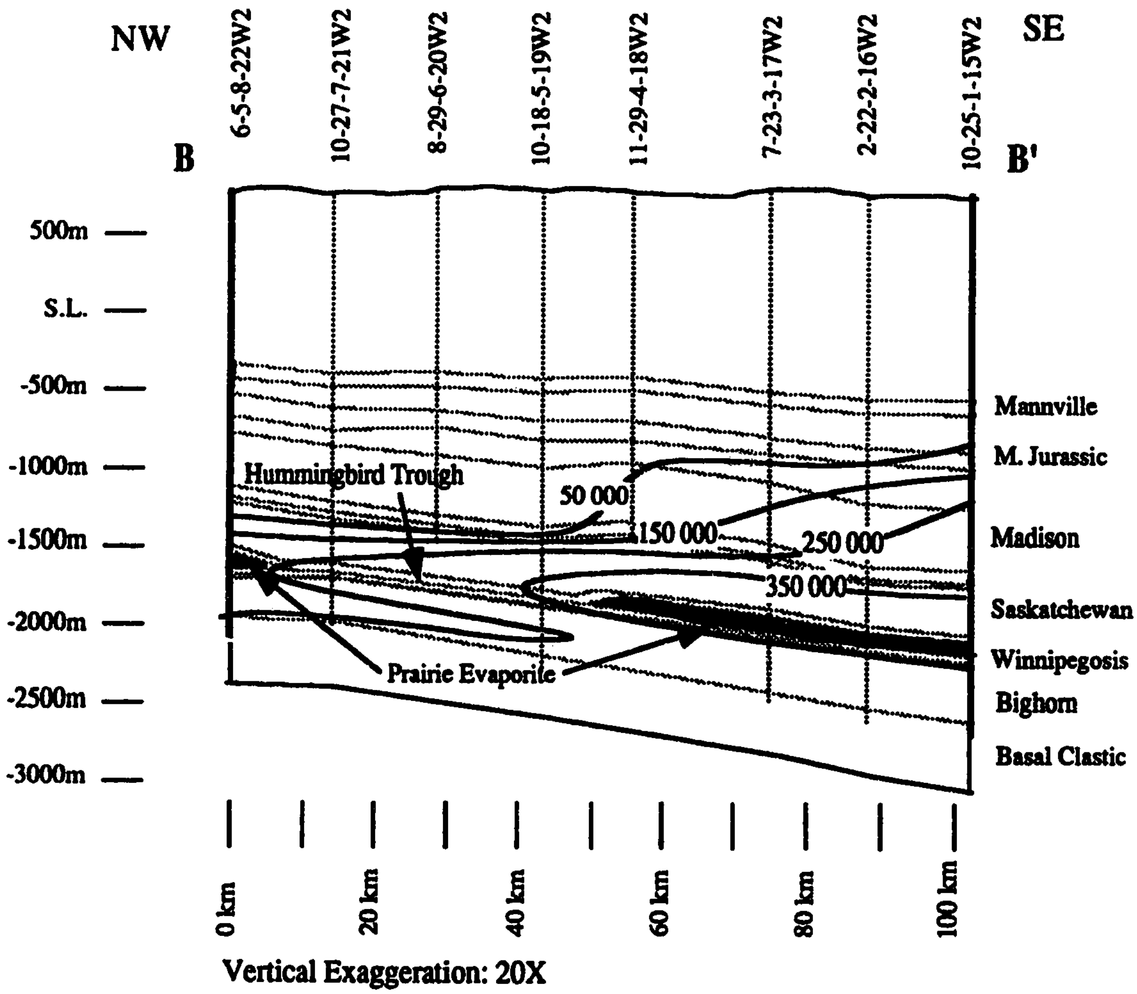


Figure 4.20 Total dissolved solids cross section B, southeast study area. TDS concentrations in formation waters are contoured at a 100 000 mg/L interval, starting at 50 000 mg/L. Well locations are named and their positions are indicated by dotted vertical lines. Aquifers are named adjacent to their level in the section. Aquifer boundaries are shown as grey lines. Note the position of the contours relative to the Prairie Evaporite and the Hummingbird Trough.

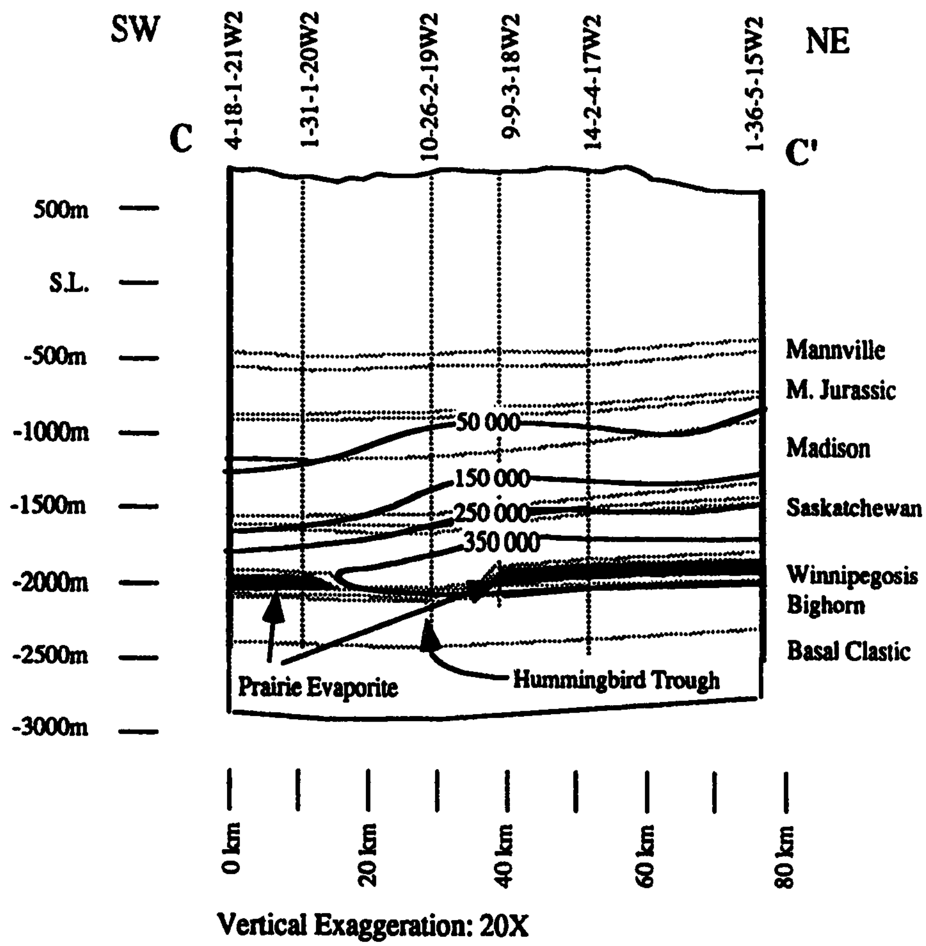


Figure 4.21 Total dissolved solids cross section C, southeast study area. TDS concentrations in formation waters are contoured at a 100 000 mg/L interval, starting at 50 000 mg/L. Well locations are named, and their positions are indicated by dotted vertical lines. Aquifers are named adjacent to their level in the section. Aquifer boundaries are shown as grey lines. Note the position of the contours relative to the Prairie Evaporite and the Hummingbird Trough.

4.3 Pressure versus Elevation Plots

Seven Pressure versus elevation "P(Z)" diagrams were constructed, in each of the four corners of the area: P(Z)-1: "Southwest" (Tp 1-3, R 27-29W2), P(Z)-2: "Northwest" (Tp 17-23, R 22-27 W2), P(Z)- "Northeast" (Tp 18-23, R 15-16W2) and P(Z)-7: "Southeast" (Tp 1-2, R 15-16 W2), one along the South Regina Trough: "South Regina" (P(Z)-4: Tp 7- 9, R 21-22W2), one following the Hummingbird Trough: "Hummingbird" (P(Z)-5: Tp 3-6, R 19-21W2) and one at the tip of the Hummingbird Trough: "South Hummingbird" (P(Z)-6: Tp 1-2, R 18-19W2) (Figure 4.22). The locations were chosen to best demonstrate regional trends of fluid pressure in the area of study, while limiting the plots to a zone of minimum topographic variation and maximizing the number and range of pressure values throughout the column. Confining the plots to a limited geographical area was difficult in the northwest, where well control was very sporadic, but was not a problem elsewhere.

Nominal hydrostatic pressure curves were calculated and plotted on each P(Z) diagram using the equation $\gamma = \rho g$, where γ is the pressure gradient measured in kPa/m, ρ is the water density in kg/m^3 and g is the acceleration due to gravity = 9.81 m/s^2. The gradient along each segment of the curve was calculated to conform to the water density along that segment, which was determined using the average total dissolved solids content of water in each aquifer in the area of interest. The origin of each curve (p=0) conforms with the average land surface elevation. The average surface elevation was determined using the KB elevations in the wells of interest and elevations given on topographic maps, then verified through comparison of pressure versus elevation plots with the corresponding pressure-depth plots. As

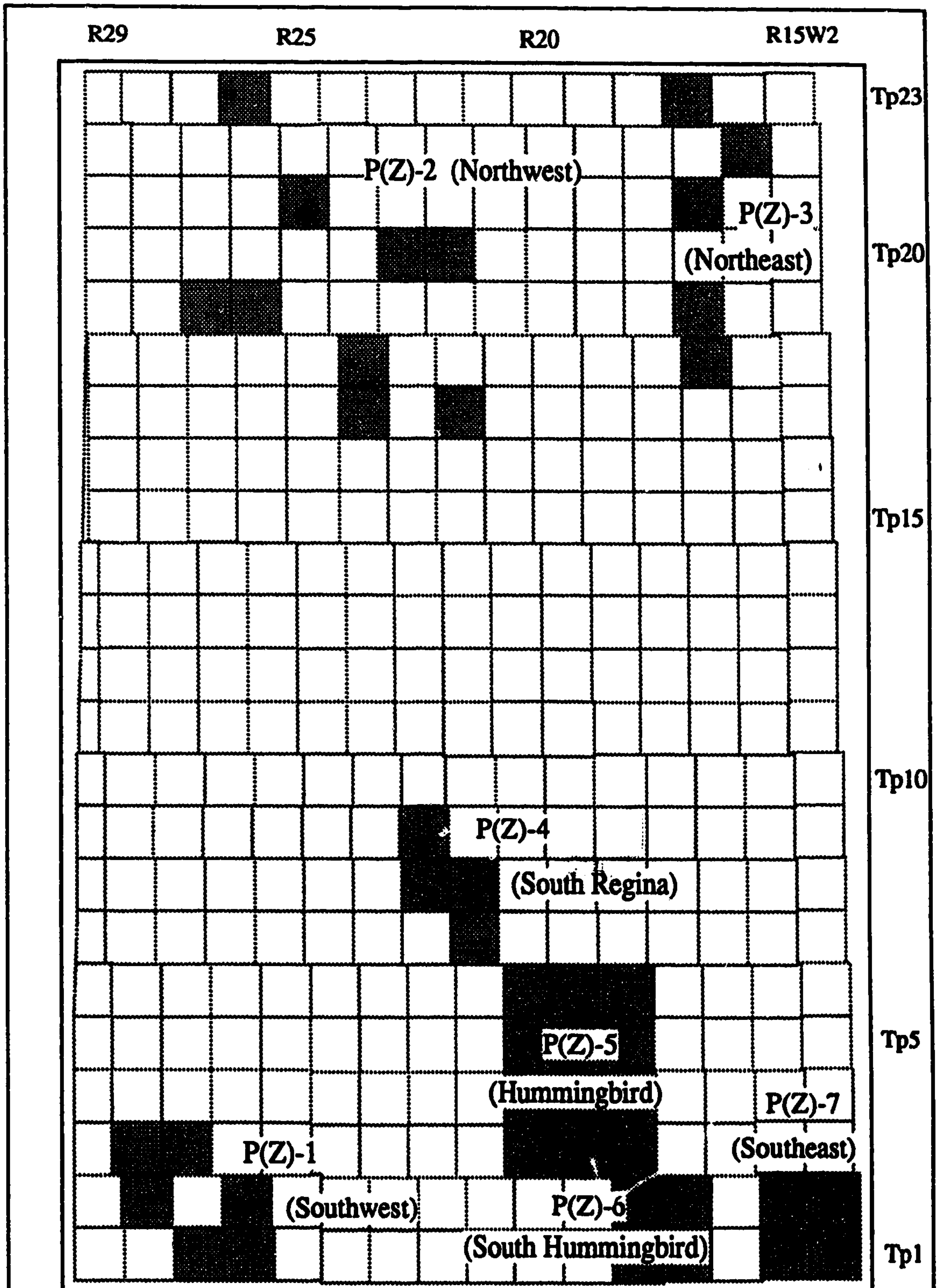


Figure 4.22 Locations of P(Z) plots generated for this study. Townships containing data used in the construction of the plots are shaded.

scattering due to topographic variation was minimal, only pressure versus elevation plots are presented here to avoid redundancy.

All available accurate DST pressures were used, including data from the Dawson Bay, Viking and Belly River formations that were excluded from the potentiometric maps. In each area, the pressure values conform to a single curve, with its origin at or near the land surface. The correspondence of the pressures to such a curve suggests that there is some form of hydraulic communication between the topographic surface and all subsurface units in the study area. The actual curve is not always coincident with the nominal pressure curve, indicating that a component of vertical flow exists.

P(Z)-1 (Southwest)

P(Z)-1 (Figure 4.23), was constructed in the Wood Mountain district in the southwest map area (Figure 4.22). The region is hydrologically unique to the area of study, due to its relatively high surface elevation, high hydraulic heads, and low salinity formation waters found at great depths. It is also the only part of the study area to have escaped Pleistocene glaciation. The surface elevation is between 800 and 900 metres, while the sedimentary column extends to a depth of over 2000 metres below sea level.

P(Z)-1 has a representation of values from the Basal Clastic Aquifer to the Madison Aquifer, in an elevation range between -900 and -1900m. All pressure points fall somewhat above (within 750 kPa), or along the hydrostatic pressure curve in this area. The curve is almost straight, due to the limited variation of water density with depth. The positive dynamic pressure increment suggests upward movement of fluids throughout the

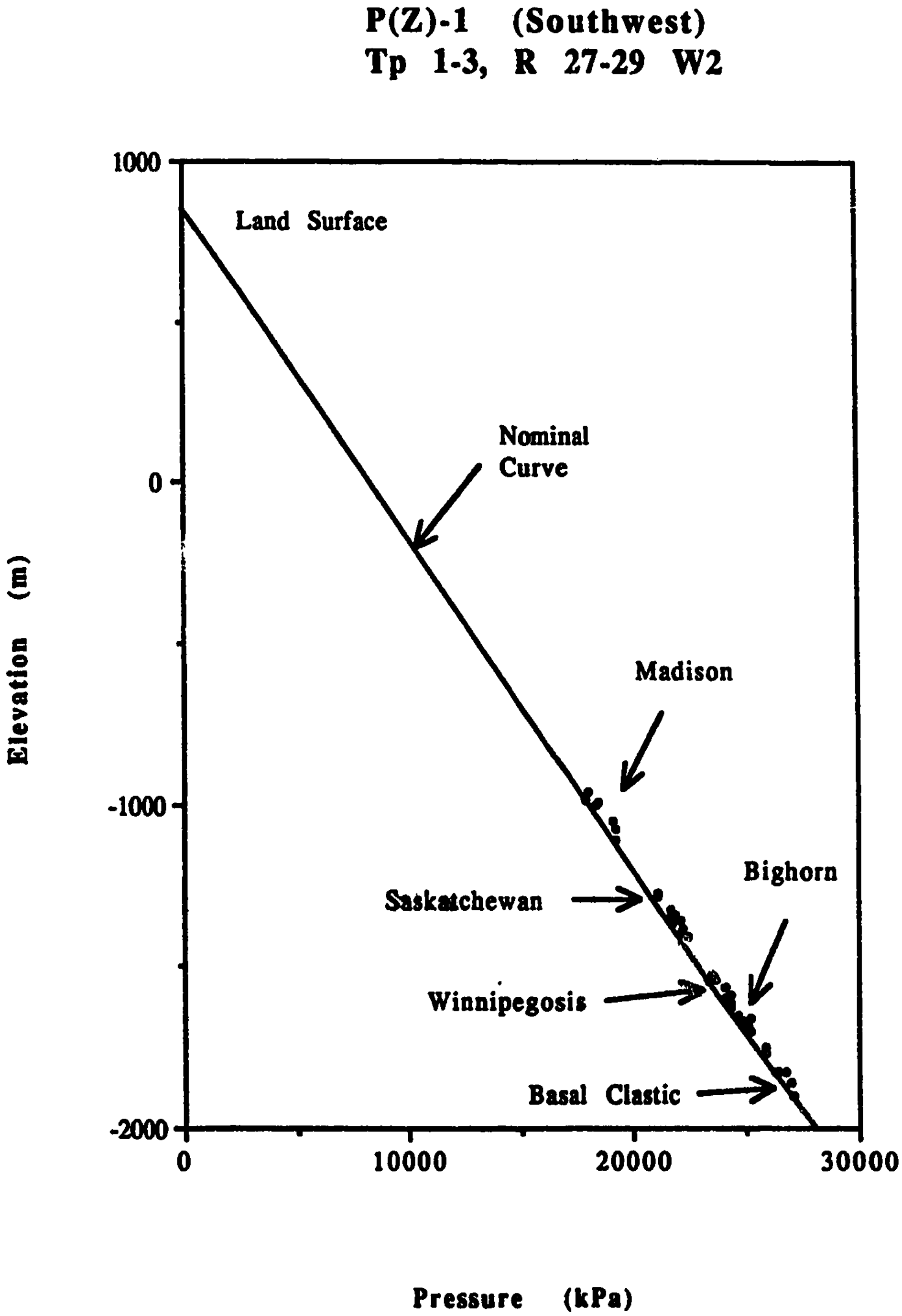


Figure 4.23 P(Z)-1 (Southwest study area)
Pressure measurements versus elevation are shown relative to the hydrostatic pressure (nominal) curve. Aquifers corresponding to the measurements are identified.

Paleozoic. The potentiometric maps indicate upward flow throughout the section.

P(Z)-2 (Northwest)

P(Z)-2 contains pressures from the Basal Clastic Aquifer to the Belly River Formation through an interval extending in elevation from -1500m to 300m (Figure 4.24). Surface elevation averages 570 metres. The hydrostatic pressure curve has a slightly unusual shape, caused by a high salinity zone in the Saskatchewan and Winnipegosis aquifers. Individual pressures from the Basal Clastic and the Winnipegosis aquifers plot along the nominal curve. One pressure from the Belly River Formation falls 500 kPa below the nominal curve.

Eleven values representing the Saskatchewan and Mannville aquifers plot along a single curve parallel to the nominal curve, with a positive dynamic pressure increment of 1000 kPa. The positive dynamic pressure increment indicates upward flow in these aquifers. Upward flow is confirmed by the corresponding potentiometric surfaces, which are superhydrostatic and decrease in the upward direction (700-750m in the Saskatchewan Aquifer and 625-700m in the Mannville Aquifer). Below the Elk Point Aquitard, pressures that correspond to the nominal curve and vertically constant hydraulic heads are evidence for a lack of vertical flow in the Basal Clastic to Winnipegosis aquifers.

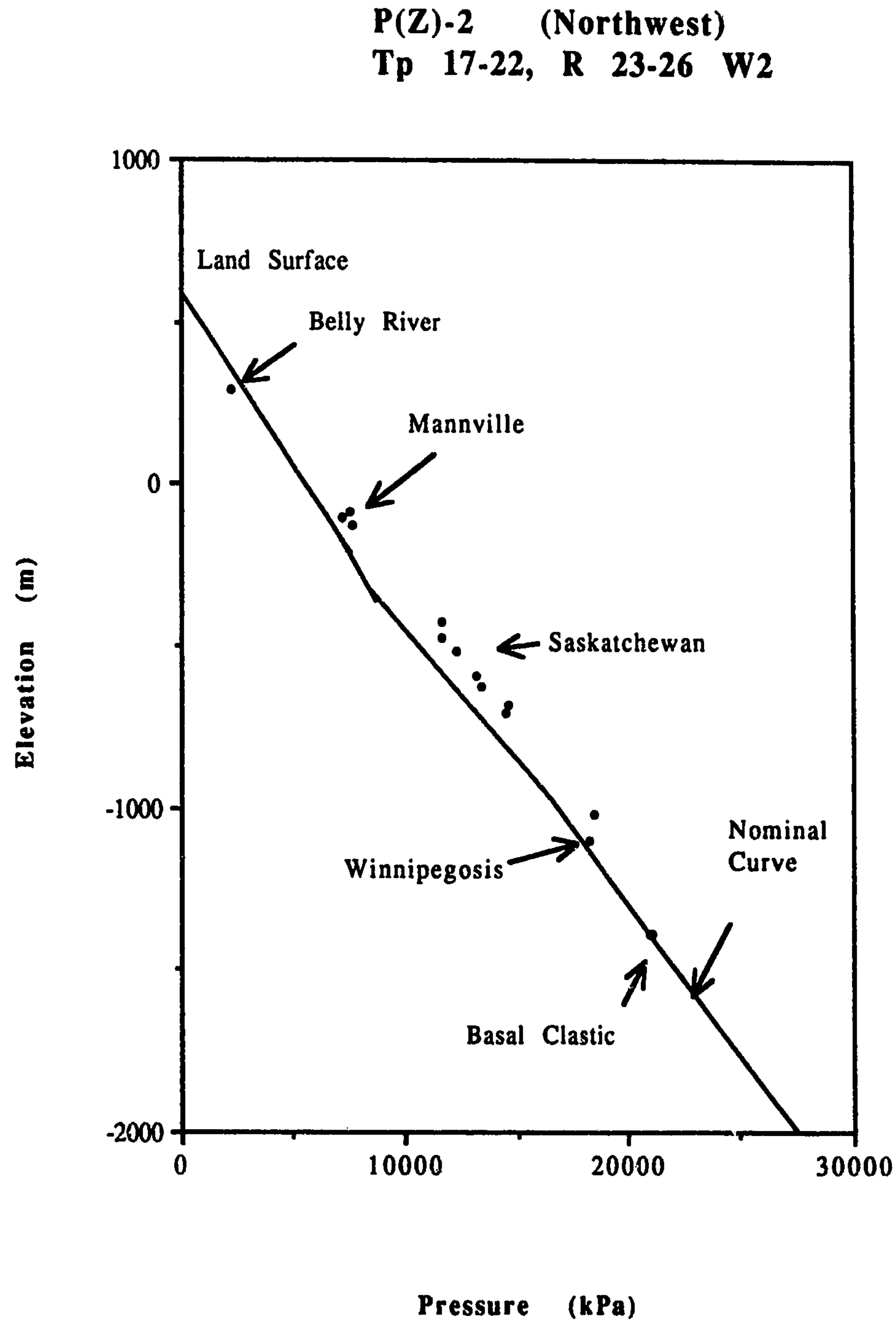


Figure 4.24 P(Z)-2 (Northwest study area)
Pressure measurements versus elevation are shown relative to the hydrostatic pressure (nominal) curve. Aquifers or formations corresponding to the measurements are identified.

P(Z)-3 (Northeast)

P(Z)-3 corresponds to the thinnest sedimentary sequence in the area, extending from -1400m elevation at its base to 600m at the topographic surface (Figure 4.25). Available pressures are limited to a -400 to -1300m elevation range between the Basal Clastic and Saskatchewan aquifers. Many of the overlying units have reduced thicknesses compared to other parts of the basin, or are absent due to erosion, or non-deposition.

In P(Z)-3, the sole pressure value from the Saskatchewan Aquifer lies on the nominal curve. The six values from the Winnipegosis, Bighorn and Basal Clastic aquifers plot about 1000-1200 kPa below the nominal curve. The relation of the pressures relative to the nominal curve is consistent with the potentiometric surfaces in this area, as both indicate downward flow in the Paleozoic, and uncertain conditions in the Mesozoic, which is lacking in control points.

P(Z)-4 (South Regina)

P(Z)-4 contains pressures from the Bighorn Aquifer (-2000m) up to the Viking Formation (-200m), in an area with an average surface elevation of 700 metres (Figure 4.26). Pressures in the Middle Jurassic Aquifer correspond to the nominal curve, while a single value from the Viking Formation plots 1500 kPa below it. Between the Winnipegosis and Madison aquifers, pressures plot on the nominal curve or above it.

The dynamic pressure increment is greatest in the Madison Aquifer where it varies between 0 and 1000 kPa. It ranges from 0 to 750 kPa in the Saskatchewan and Winnipegosis aquifers and from -250 to 750 kPa in the Bighorn Aquifer, indicating upward flow through the South Regina Trough.

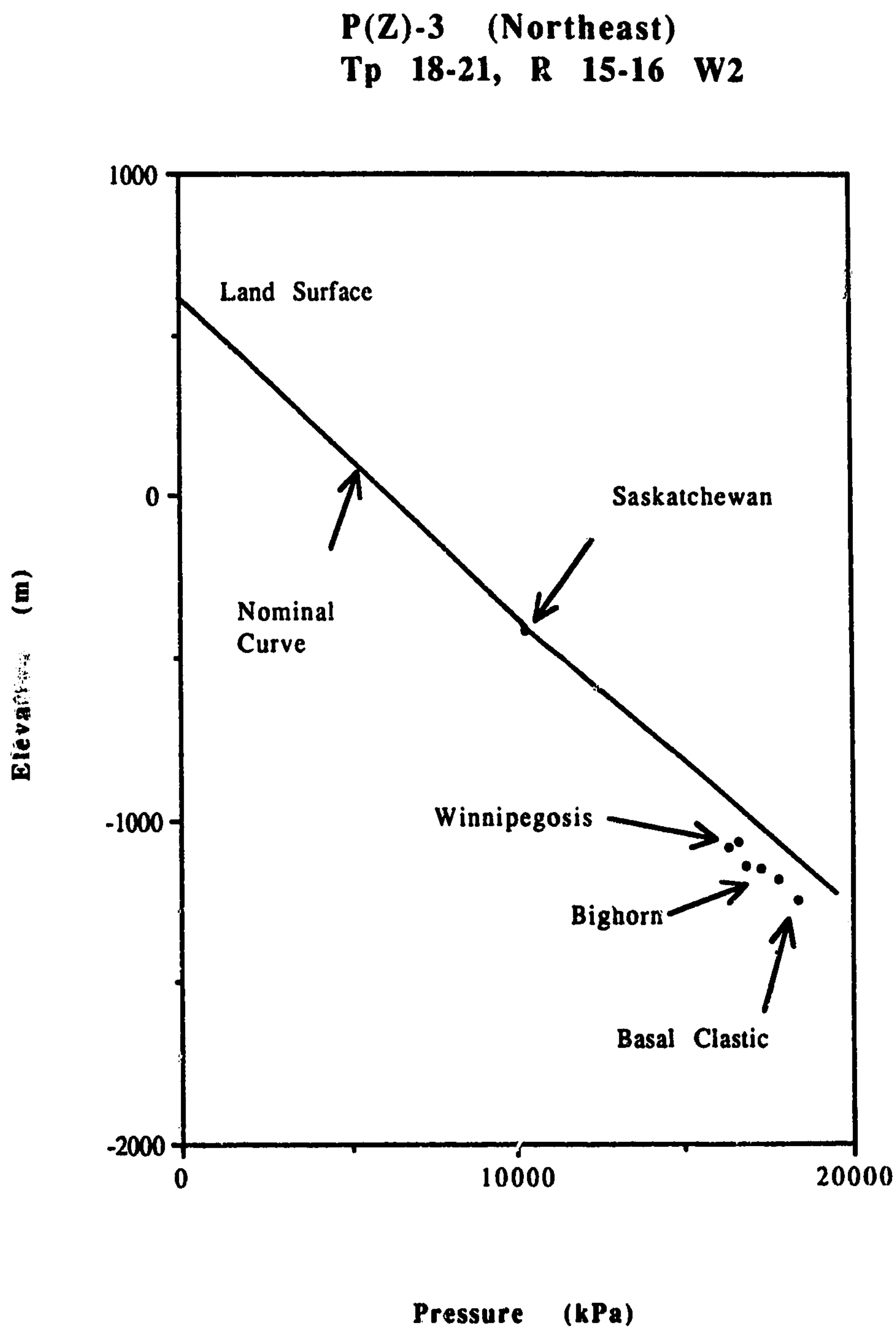


Figure 4.25 P(Z)-3 (Northeast study area)
Pressure measurements versus elevation are shown relative to the hydrostatic pressure (nominal) curve. Aquifers corresponding to the measurements are identified.

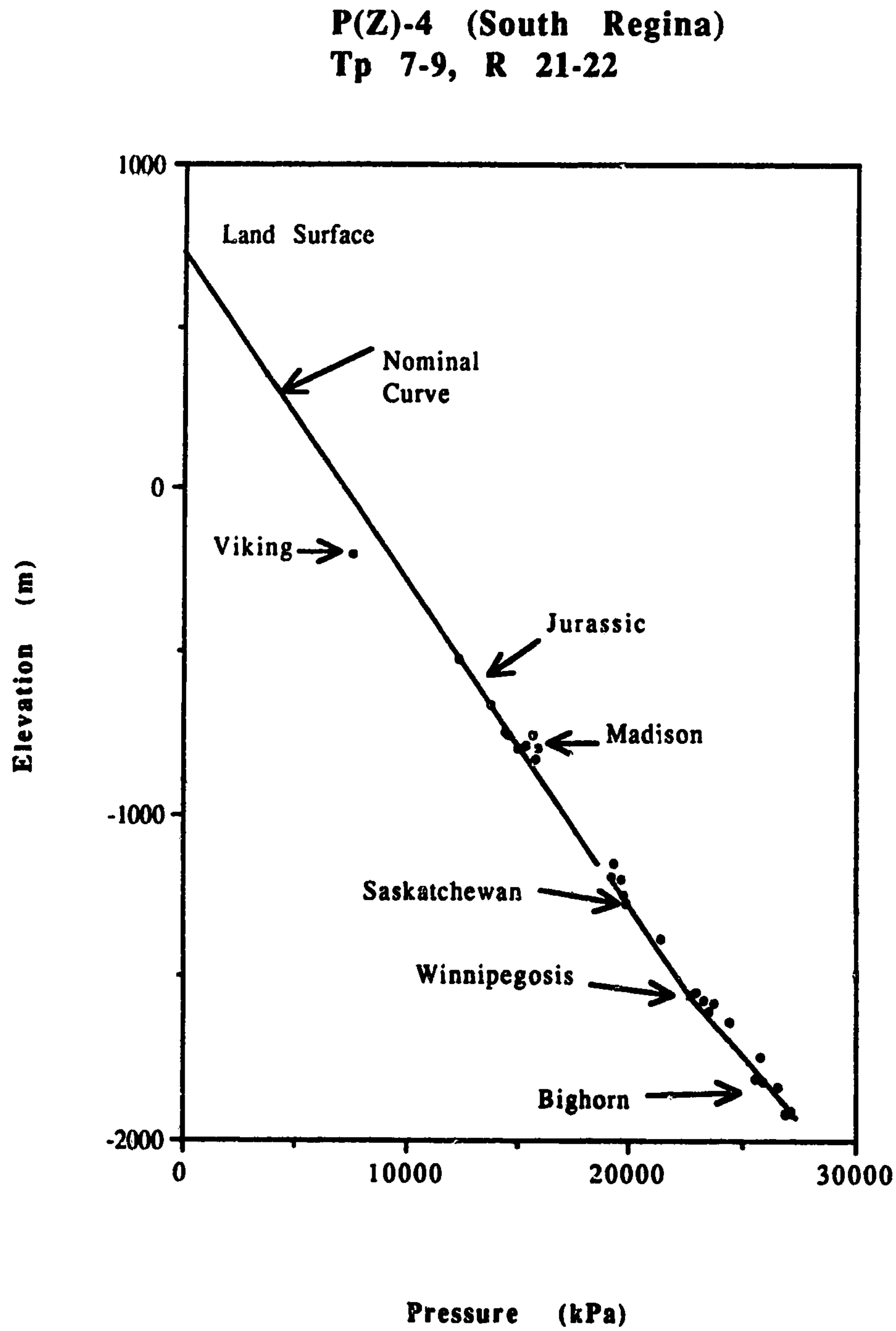


Figure 4.26 P(Z)-4 (South Regina; central study area) Pressure measurements versus elevation are shown relative to the hydrostatic pressure (nominal) curve. Aquifers or formations corresponding to the measurements are identified.

The positive increment is consistent with hydraulic heads in this area, which decrease gradually up the section, from superhydrostatic conditions in the Paleozoic aquifers to hydrostatic and subhydrostatic conditions in the Mesozoic.

P(Z)-5 (Hummingbird Trough)

P(Z)-5 contains pressures from the Basal Clastic Aquifer up to the Viking Formation, spanning a range in elevations from -2200 to -330 metres (Figure 4.27). The land surface is 740 metres. The two Mesozoic pressure values plot well below the nominal curve, while most Paleozoic values plot above it.

The two pressures from the Mesozoic, have dynamic pressure increments of -1850 kPa in the Viking Formation and -2350 kPa in the Mannville Aquifer. In the Madison Aquifer the dynamic pressure increment ranges from -400 to 950 kPa, with most points falling between 500 and 950 kPa. The range decreases to between 0 and 800 kPa in the Saskatchewan Aquifer and 0 to 500 kPa in the Winnipegosis, Bighorn and Basal Clastic aquifers. The positive dynamic pressure increment in the Paleozoic concurs with the potentiometric surface maps and sections, which indicate upward flow through the Hummingbird Trough.

P(Z)-6 (South Hummingbird)

The pressure values used to construct P(Z)-6 span an elevation range from -2500m in the Basal Clastic Aquifer, to -500m in the Viking Formation (Figure 4.28). The average elevation of the land surface is 700m. Most points plot close to, or below the nominal curve.

P(Z)-5 (Hummingbird)
Tp 3-6, R 19-21 W2

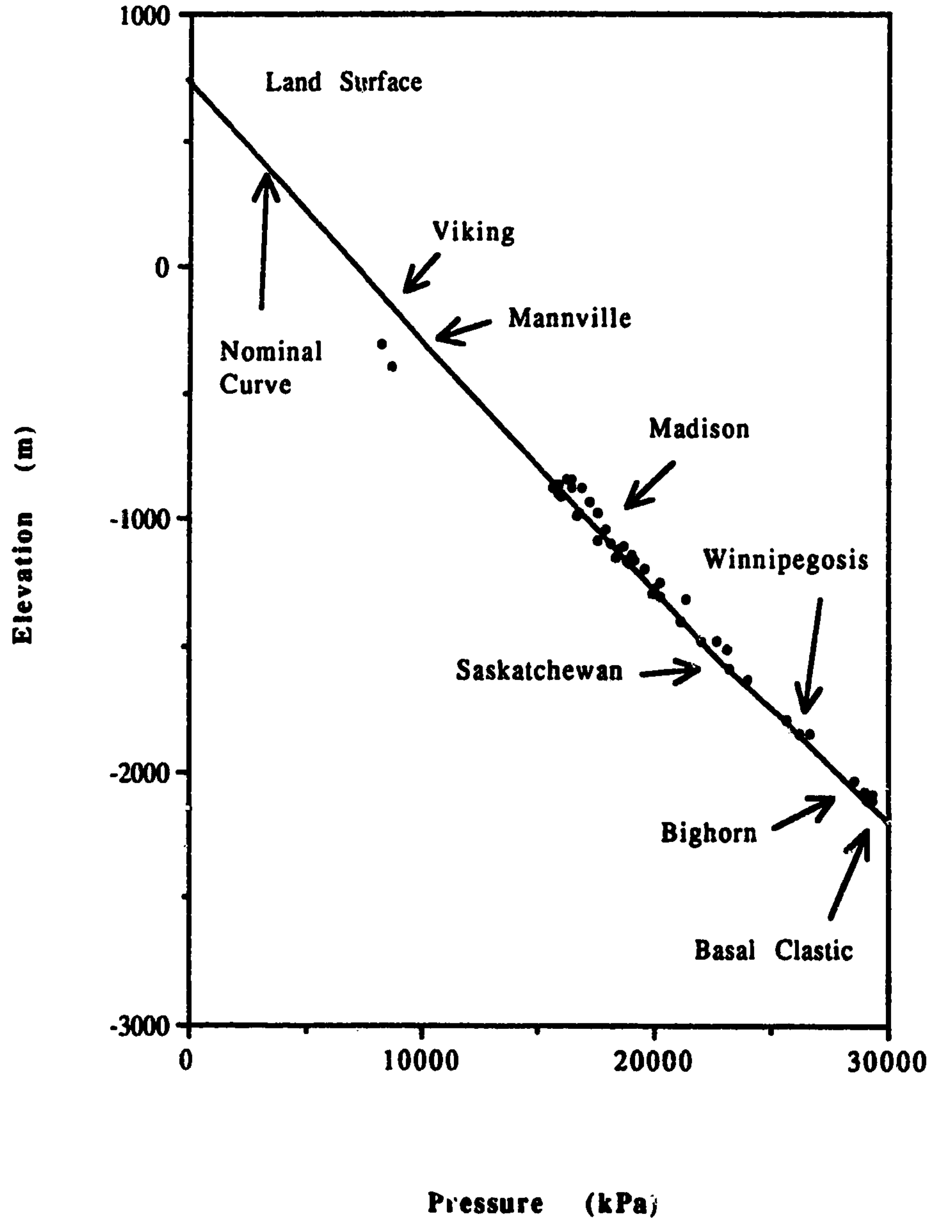


Figure 4.27 P(Z)-5 (Hummingbird region of study area) Pressure measurements versus elevation are shown relative to the hydrostatic pressure (nominal) curve. Aquifers or formations corresponding to the measurements are identified.

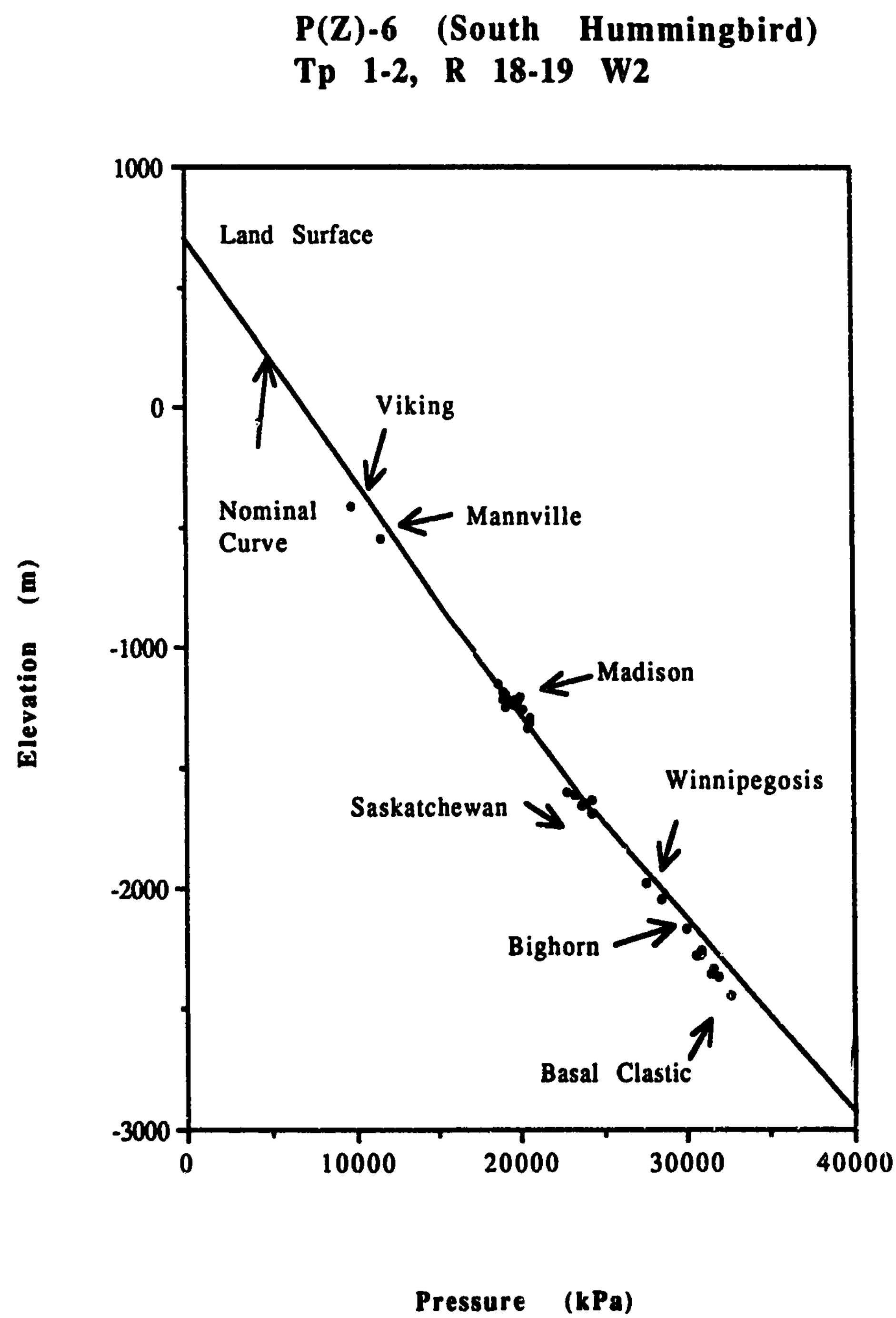


Figure 4.28 P(Z)-6 (South Hummingbird region of study area) Pressure measurements versus elevation are shown relative to the hydrostatic pressure (nominal) curve. Aquifers or formations corresponding to the measurements are identified.

The dynamic pressure increment averages -1500 to -1800 kPa in the Mesozoic aquifers and -400 to -1800 kPa in the Basal Clastic to Winnipegosis aquifers. In the Madison and Saskatchewan aquifers, pressures are scattered around the nominal curve with dynamic pressure increments between -1800 and 500 kPa.

The predominantly negative pressure increments suggest downward flow throughout much of the section, while potentiometric maps and sections suggest upward migration of fluids in this area. Strong salinity contrasts in this area render the potentiometric maps suspect.

P(Z)-7 (Southeast)

P(Z)-7 contains pressures from the Bighorn Aquifer up to the Belly River Formation in a range of elevations from -2500 to 500 metres (Figure 4.29). Apart from the Madison Aquifer, most pressures plot below the nominal curve. Nearly all pressures obtained from the Madison Aquifer plot along the nominal curve or within 100 kPa of either side of the curve. Negative dynamic pressure increments were obtained for the Belly River Formation (-500 kPa), the Viking Formation (-400 to -1000 kPa), and the Mannville (-500 to -1500 kPa), Saskatchewan (-100 to -500 kPa) and Bighorn aquifers (-1000 to -2000 kPa).

There appears to be downward flow through most of the sedimentary column in this area according the dynamic pressure increments, however, the potentiometric surface maps indicate upward flow. The potentiometric maps are suspect because of high salinity contrasts in the region.

P(Z)-7 (Southeast)
Tp 1-2, R 15-16 W2

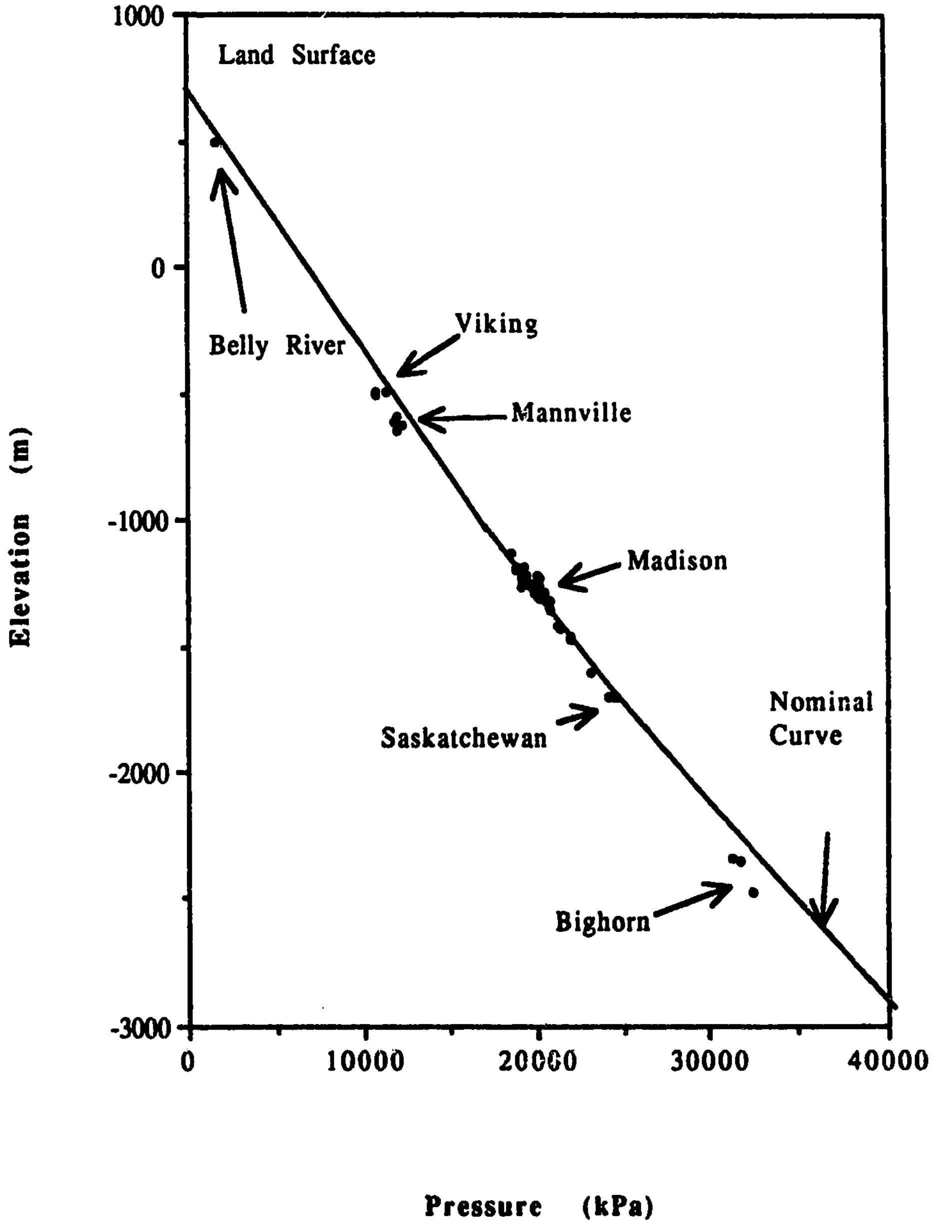


Figure 4.29 P(Z)-7 (Southeast study area)
Pressure measurements versus elevation are shown relative to the hydrostatic pressure (nominal) curve. Aquifers or formations corresponding to the measurements are identified.

Regional Comparison of P(Z) plots:

When all the P(Z) curves are plotted on a single graph, lateral relationships may be discerned, similar to those indicated by the potentiometric surface maps (Figure 4.30). Pressures decrease from P(Z)-1 (Southwest) to P(Z)-4 (South Regina) to P(Z)-5 (Hummingbird) to P(Z)-6 (South Hummingbird) to P(Z)-7 (Southeast) to P(Z)-2 (Northwest) to P(Z)-3 (Northeast) in the Paleozoic. The sequence is somewhat of a departure from dominant trend illustrated by the potentiometric maps, which indicate a lateral decrease in head from Southwest to Southeast to South Hummingbird to Hummingbird to South Regina to Northwest to Northeast.

Best-fit lines passing through each grouping are subparallel for Northwest, Southwest, Hummingbird and South Regina areas. The Northeast curve has a greater slope than the latter three, but does not intersect them. It is intersected by the Southeast and Hummingbird curves, which have slopes less than that of the regional trend. The difference in slopes for the Northwest, South Hummingbird and Southeast curves could be caused by salinity contrasts.

In general, there is a greater linear trend among the pressures taken at elevations below -1000m (Figure 4.31). Pressure measurements between -1000 metres and the land surface (Figure 4.32) have a greater tendency to scatter, suggesting interference of near-surface flow systems, or perhaps disproportionate effects resulting from glacial loading and unloading.

All P(Z) Plots Superimposed:
Land Surface to -2000m

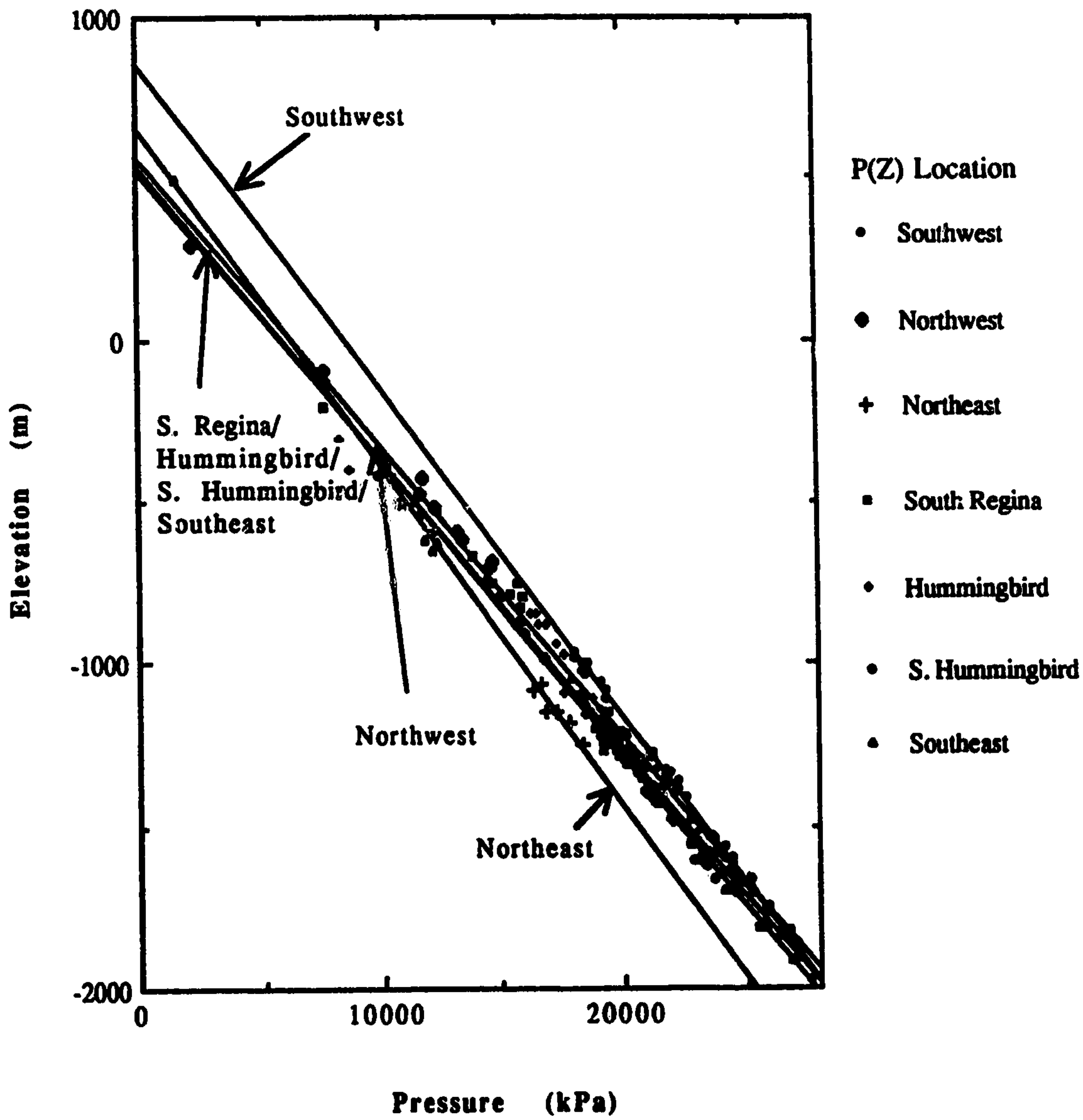


Figure 4.30 All P(Z) Plots Superimposed:Land Suface to -2000m elevation. Pressure measurements versus elevation are shown for the entire sedimentary sequence of the area. Best-fit lines are included for each set of data points corresponding to each P(Z) location. Pressure decreases from Southwest to Northeast for most elevations. The Northwest, Southeast, South Regina, Hummingbird and South Hummingbird data sets plot close to each other indicating similar subsurface pressure conditions for these locations.

**All P(Z) Plots Superimposed:
-900m to -2000m
(Paleozoic)**

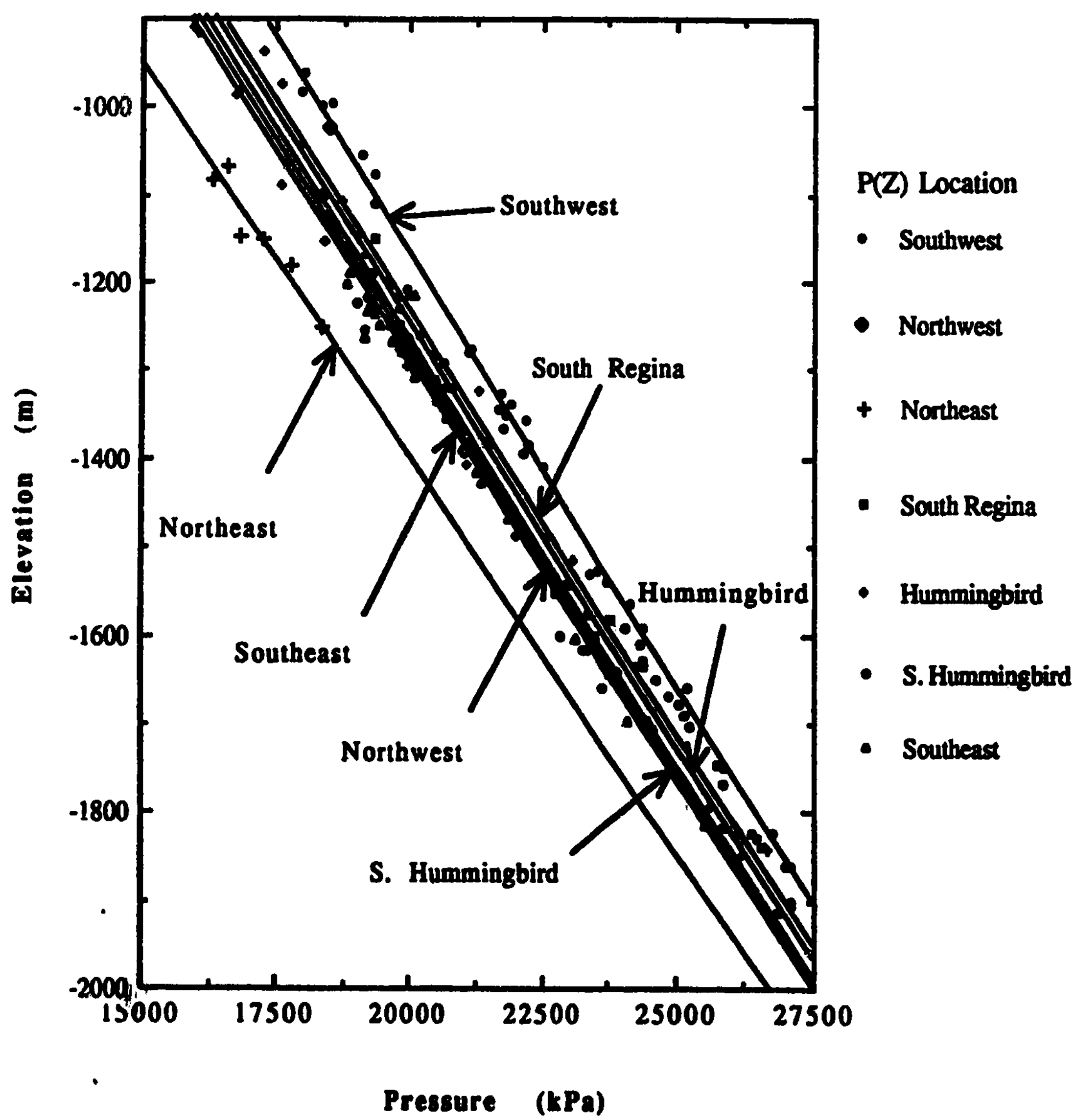


Figure 4.31 All P(Z) Plots Superimposed: -900m to -2000m (Paleozoic). Pressure measurements versus elevation are shown for the lower half of the sedimentary sequence of the area. Best-fit lines are included for each set of data points corresponding to each P(Z) location. Pressure decreases from Southwest to South Regina to Hummingbird to South Hummingbird to Southeast to Northwest to Northeast for given elevations. The Northwest, Southeast, South Regina, Hummingbird and South Hummingbird data sets plot close to each other indicating similar subsurface pressure conditions for these locations.

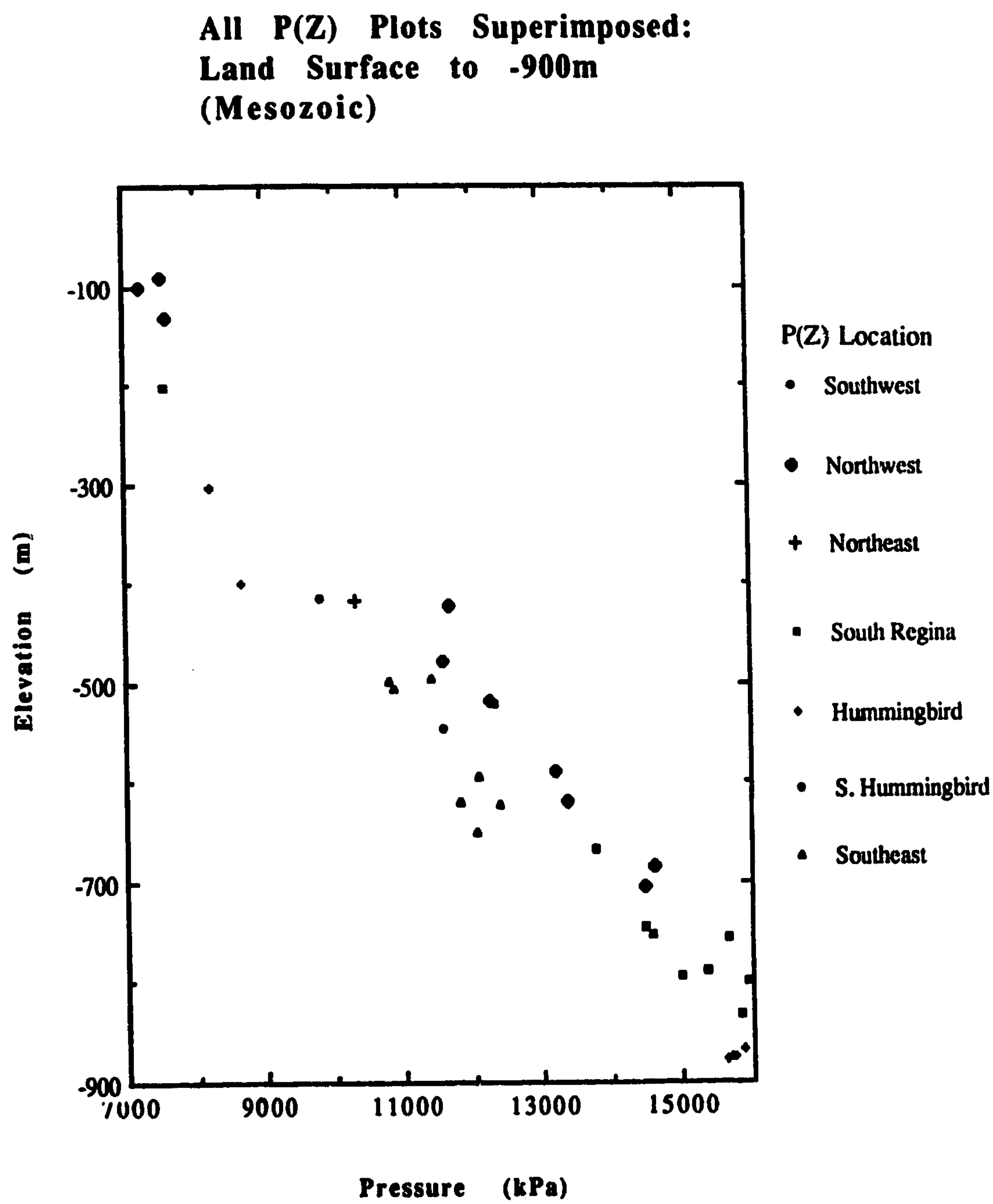


Figure 4.32 All P(Z) Plots Superimposed: Land Surface to -900m (Mesozoic) Pressure measurements versus elevation are shown for the upper half of the sedimentary sequence of the area. Best-fit lines have not been added due to the scattering of data points.

4.4 Water Characterization

The ratio $rNa^+:rCl^-$ was plotted for each aquifer to distinguish waters of differing origins (Figures 4.33, 4.35, 4.37, 4.39, 4.41). Three populations of samples were identified, each corresponding to particular geographical locations (Figures 4.34, 4.36, 4.38, 4.40, 4.42). It was found that in the Paleozoic aquifers, analyses that plotted near the origin of the graph were typically from the southwestern and western margin of the study area. Analyses from the southeastern map area plotted farthest from the origin.

The Paleozoic contains three identifiable populations of water, which for the purpose of this investigation were arbitrarily named "Group I", "Group II" and "Group III". Group I waters are of relatively low salinity (<4000 meq/L Na^+ or Cl^-), and have an $rNa^+:rCl^-$ ratio usually greater than 0.92 indicative of mildly evolved meteoric waters. Group II waters have salinities between 2000 and 5500 meq/L Na^+ or Cl^- and an ionic ratio between 0.67 and 0.98, characteristic of deep basin brines. Analyses designated to Group III have ionic ratios between 0.98 and 1.0 with ionic concentrations of 2000 to 6000 meq/L Na^+ or Cl^-. Group III waters are interpreted to be Group I or Group II waters that have been significantly altered by the dissolution of evaporite salt deposits. The deviation in the $rNa^+:rCl^-$ ratio typically decreases with increasing concentration, illustrated in the progression from Groups I to II to III.

Samples from the Basal Clastic and Bighorn aquifers are plotted on Figure 4.33. In the both aquifers, analyses designated as Group I consist of relatively low salinity waters (<3500 meq/L Na^+ or Cl^-) that have an $rNa^+:rCl^-$ ratio between 0.97 and 1.02 in the Basal Clastic Aquifer and 0.96 and 5.37 in rNa:rCl - Bighorn & Basal Clastic Aquifers

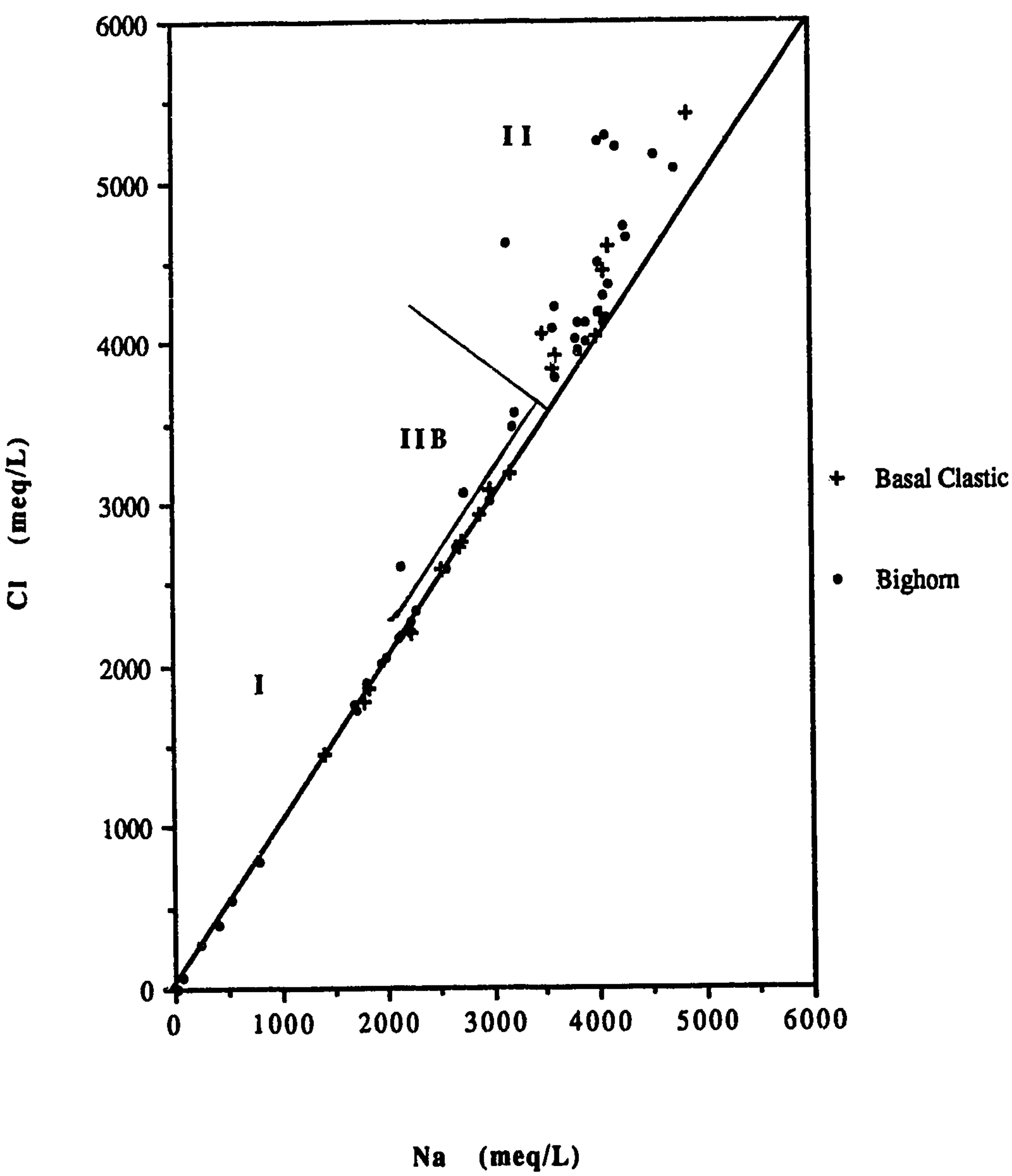


Figure 4.33 Relative concentrations of Na^{+} and Cl^{-} in water samples from the Bighorn and Basal Clastic aquifers. Samples are divided into three populations: Group I (meteoric water), Group II (basinal water), Group IIB (mixed water).

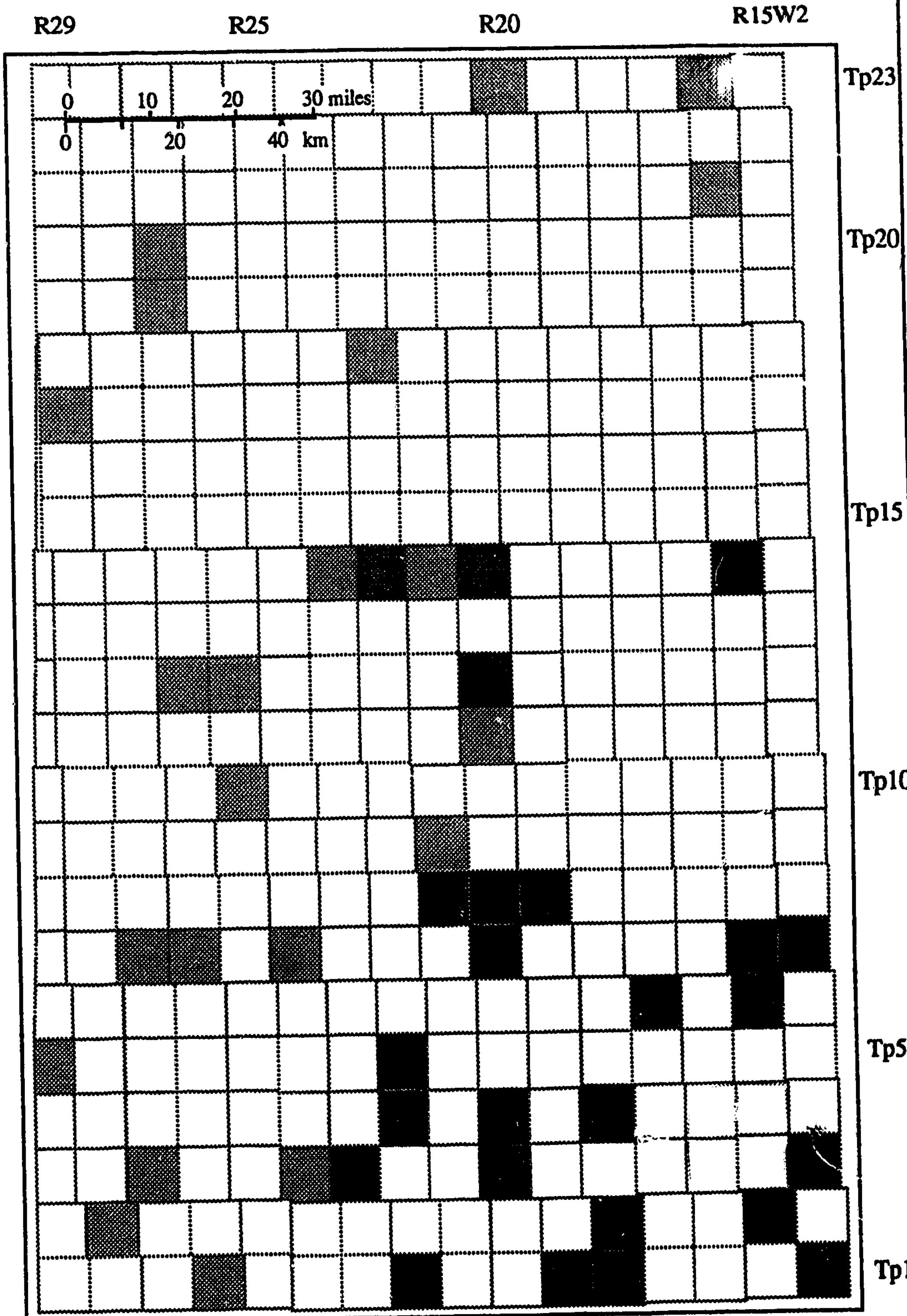


Figure 4.34 Distributions of water groupings in the Basal Clastic and Bighorn Aquifers Townships containing water analyses classified into one of three groupings, based on relative ionic concentrations of Na^+ and Cl^- are shaded: ▩ Group I (meteoric water) ■ Group II (basinal water) ■ Group IIB (mixture of I and II)

the Bighorn Aquifer. Group II waters have an $rNa^+:rCl^-$ ratio between 0.86 and 0.97 in the Basal Clastic and 0.68 to 0.97 in the Bighorn ranging in concentration between 3000 and 5500 meq/L for either ion. Group I is found in the southwestern, northwestern and northeastern quadrants of the study area, while Group II is found in the southeast (Figure 4.34).

A subgrouping within Group II of the Bighorn Aquifer, designated as Group IIB consists of four analyses, with ionic ratios from 0.83 to 0.92 $rNa^+:rCl^-$ and ionic concentrations between 2500-3550 Na^+ or Cl^-. Three of the analyses are found between Townships 12 to 14 and Ranges 21 to 23 W2 and the fourth in Township 3, Range 21 W2. Group IIB probably represents and area of mixing between groups I and II.

In the Winnipegosis Aquifer, formation waters have relatively low salinities (<5000 mg/L TDS) in the southwest and are highly saline (>350 000 mg/L TDS) in the southeast, subjacent to the Prairie Evaporite. Analyses from the Winnipegosis Aquifer have the smallest deviation of ionic ratios (Figure 4.35), which range from 0.92 to 0.99 for the three groupings identified. Nine samples taken in the salt free area and interpreted to be Group I, have $rNa^+:rCl^-$ ratios from 0.92 to 0.97 and salinities less than 2500 mg/L Na^+ or Cl^-(Figure 4.36). Nine samples with ratios of 0.98 or 0.99 are found in the region of the Prairie salt in a salinity range between 2500 and 6000 mg/L. These are designated as Group III Three samples from the southeast, which probably escaped much of the influence of the salt have $rNa^+:rCl^-$ ratios from 0.90 to 0.96 and salinities between 3500 and 6000 mg/L Na^+ or Cl^-. They were classified as Group II.

The Saskatchewan Aquifer is separated from the Prairie Evaporite by the Dawson Bay Formation and the Hubbard Evaporite. The Davidson and Flat

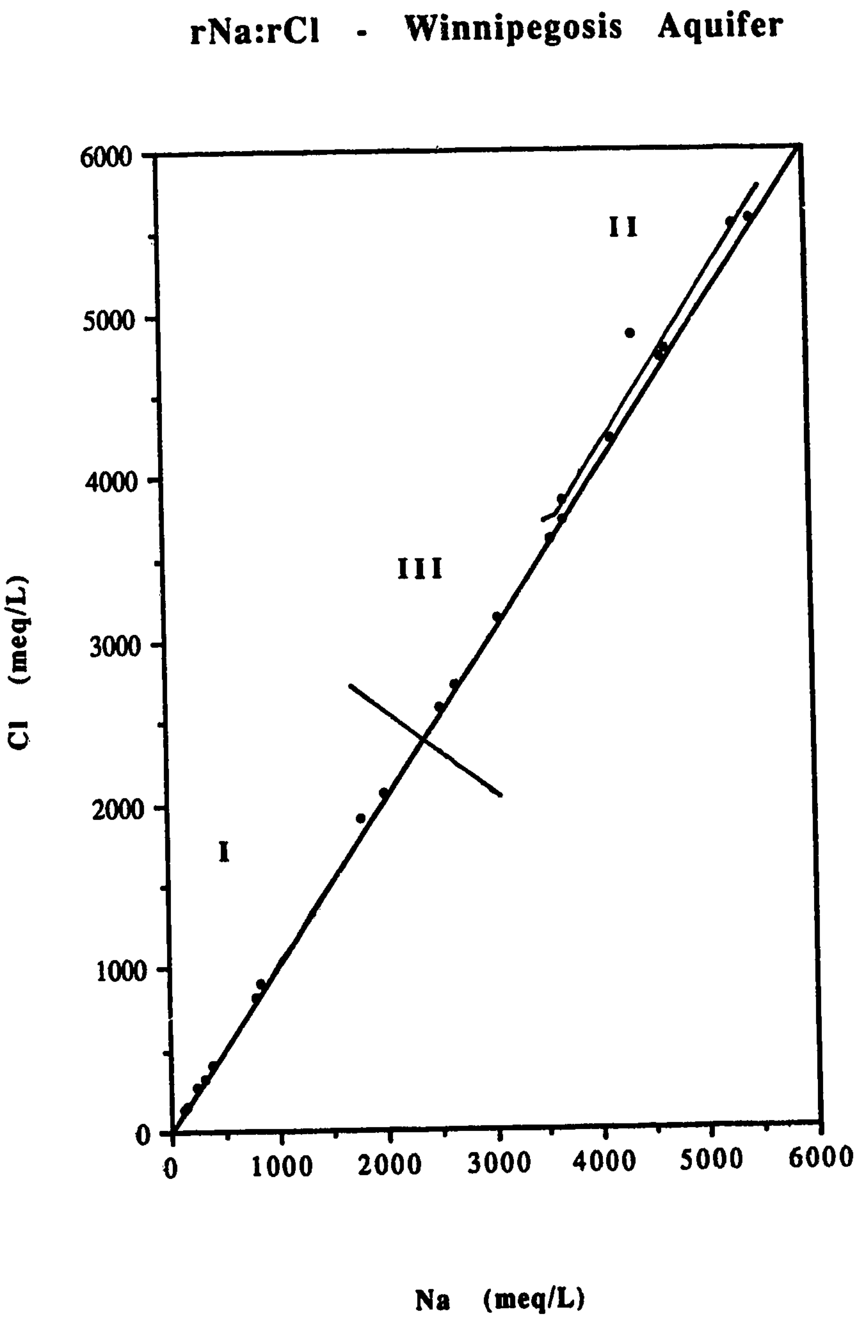


Figure 4.35 Relative concentrations of Na^+ and Cl^- in water samples from the Winnipegosis Aquifer. Samples are divided into three populations: Group I (meteoric water), Group II (basinal water), Group III (water altered by dissolution of evaporite).

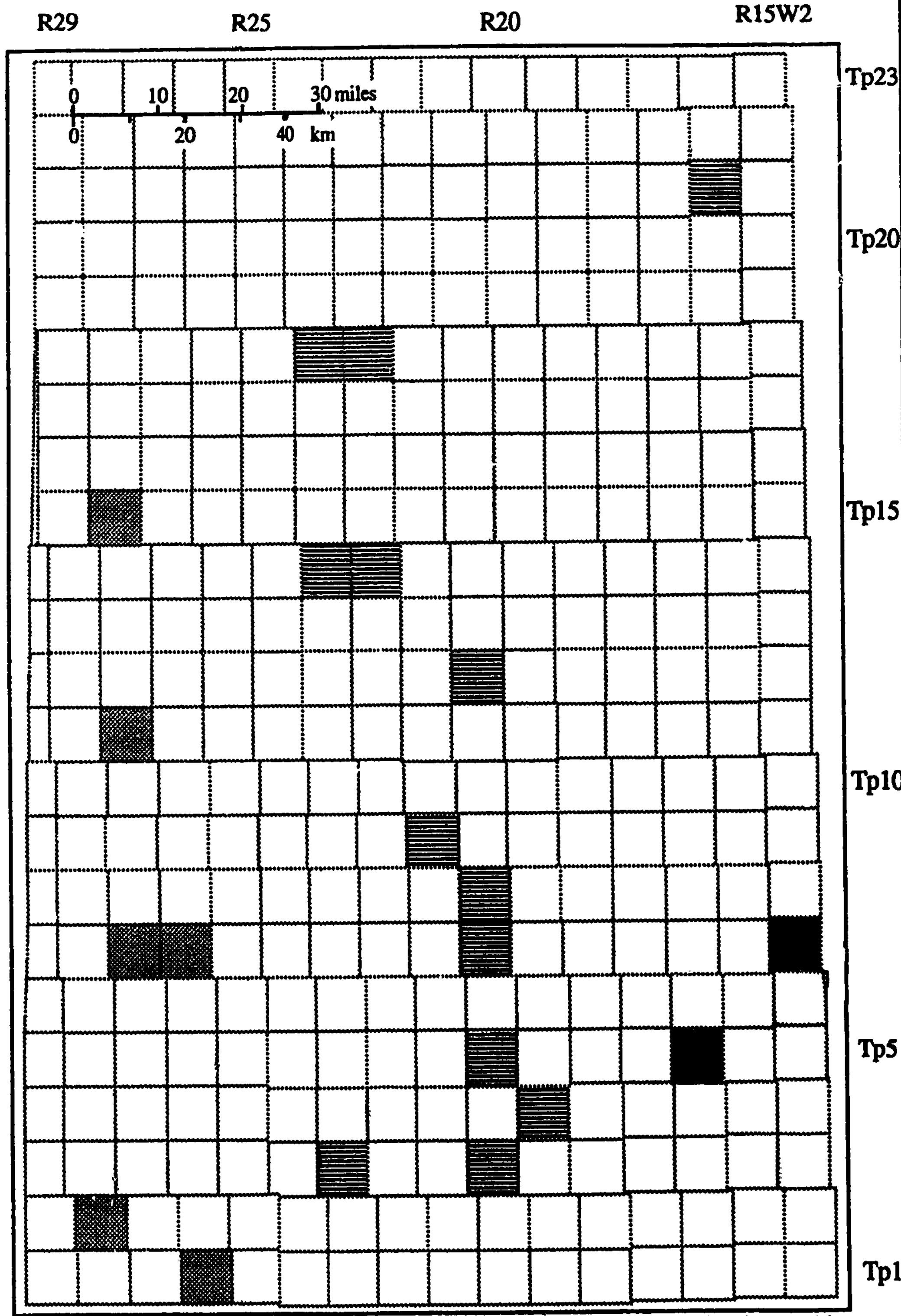


Figure 4.36 Distribution of water groupings in the Winnipegosis Aquifer. Townships containing water analyses classified into one of three groupings, based on relative ionic concentrations of Na^+ and Cl^- are shaded: Group I (meteoric water) Group II (basinal water) Group III (water altered by evaporite dissolution)

Lake evaporites are found in the Duperow subaquifer along the northern and eastern margins of the study area. Waters from all three groupings are found in the Saskatchewan Aquifer (Figure 4.37). Group I waters are typically of low salinity, with most samples containing less than 3000 meq/L Na^+ or Cl^-. These waters are found across most of the study area, excluding the southeast (Figure 4.38). The analyses have a range of ionic ratios of 0.70 to 6.37 in the Duperow Subaquifer, and 0.79 to 2.81 in the Birdbear Subaquifer. Group II waters are more saline (2000-4200 meq/L Na^+) and have rNa^+/rCl^- ratios varying between 0.83 and 0.88 in the Duperow and 0.85 and 0.95 in the Birdbear. Group II samples were taken from Townships 1-5 and Ranges 15-23 W2, a zone interpreted to be occupied by deep basin brines. Group III waters are found only in the Duperow Subaquifer, along the northern edge of the study area. They are highly saline (3500-4500 meq/L Na^+ or Cl^-) and have an $rNa^+:rCl^-$ ratio between 0.99 and 1.00. They are found in the same geographical area as the Prairie, Hubbard and Davidson evaporites.

Group I waters in the Madison Aquifer range in concentration from 3 meq/L to 1800 meq/L Na^+ or Cl^- (Figure 4.39). The majority of samples contain less than 550 meq/L Na^+ or Cl^-. Ionic ratios are between 0.73 and 12.43. A progressive decrease in ionic ratios with increasing concentration is apparent on the graph.

Group II samples have concentrations between 2000 and 5000 meq/L Na^+ and an rNa^+/rCl^- ratio between 1.0 and 0.67. Most samples fall in the 2000-3000 meq/L range. Group II samples are found within a very restricted geographical range of about fourteen townships in the southeastern corner of the study area, which corresponds roughly to a zone of >100 000 mg/L TDS

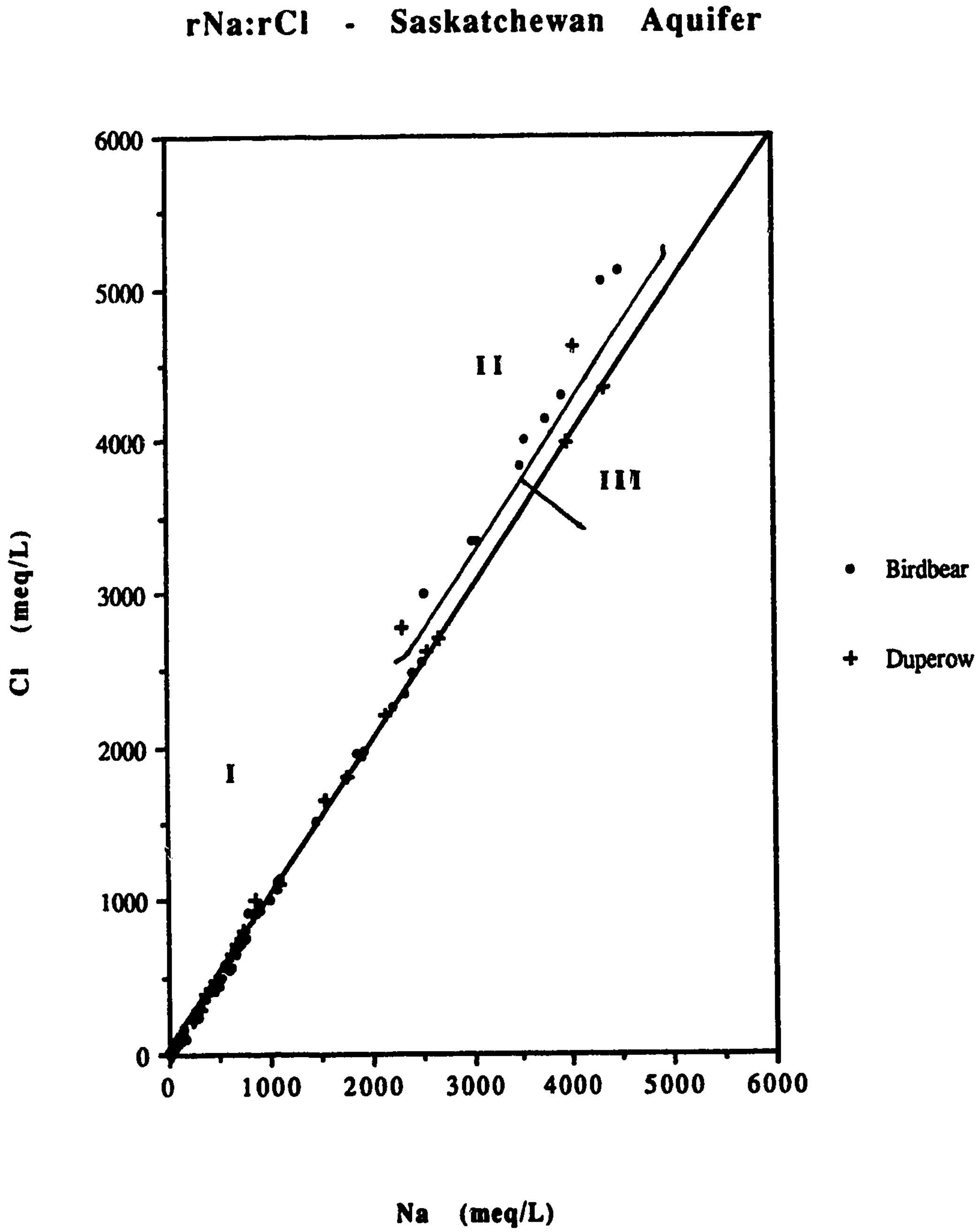


Figure 4.37 Relative concentrations of Na^+ and Cl^- in water samples from the Saskatchewan Aquifer. Samples are divided into three populations: Group I (meteoric water), Group II (basinal water), Group III (water altered by dissolution of evaporite).

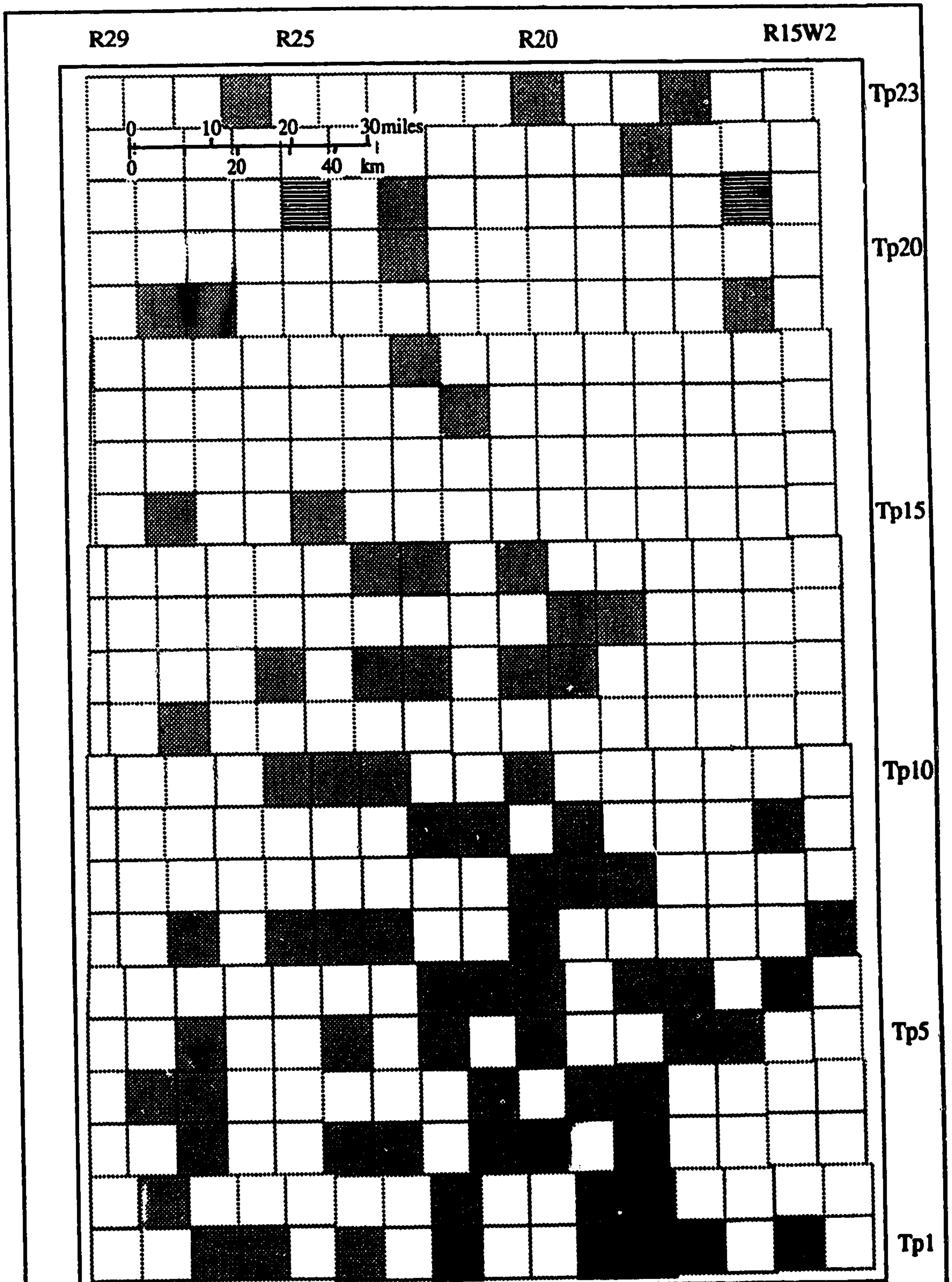


Figure 4.38 Distribution of water groupings in the Saskatchewan Aquifer. Townships containing water analyses classified into one of three groupings, based on relative ionic concentrations of Na^+ and Cl^- are shaded: Group I (meteoric water) Group II (basinal water) Group III (water altered by evaporite dissolution)

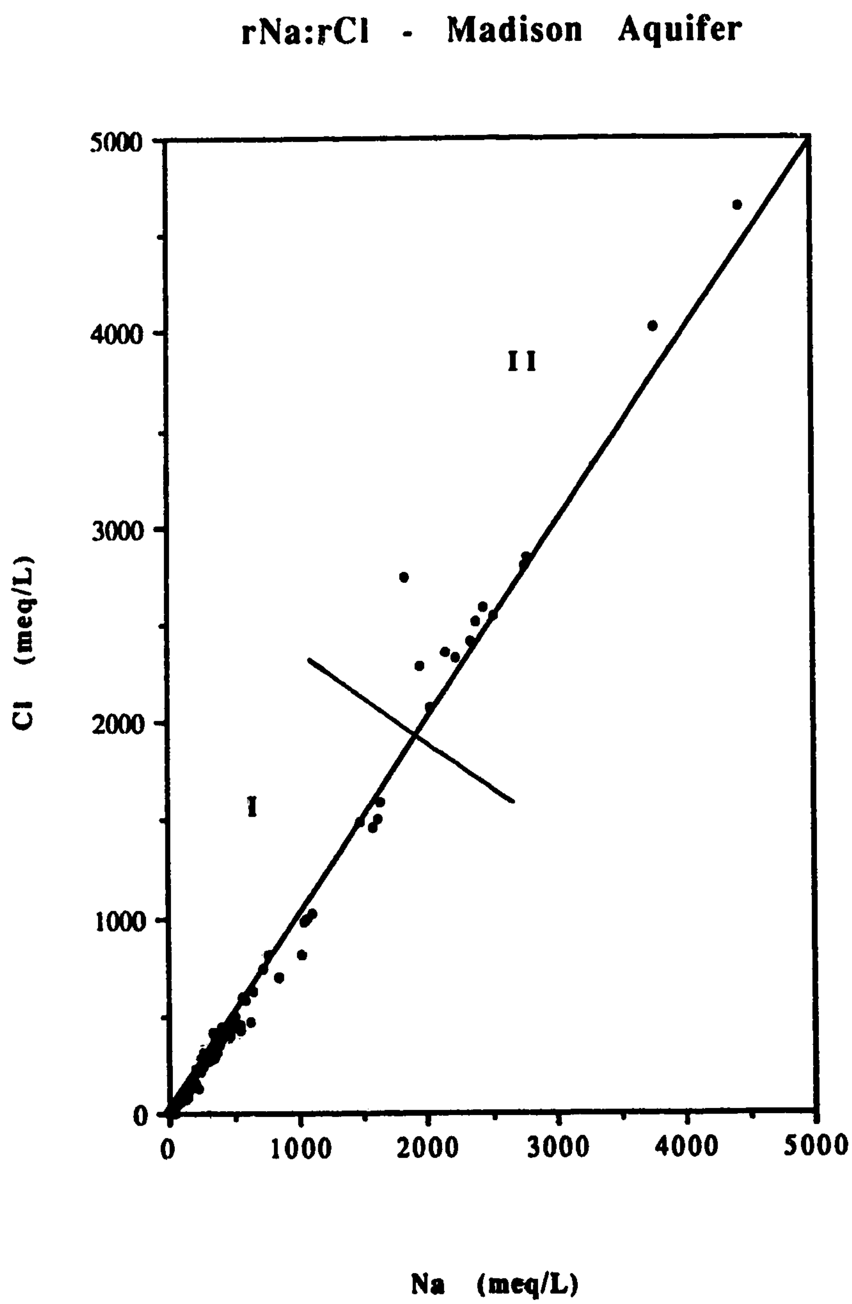


Figure 4.39 Relative concentrations of Na^+ and Cl^- in water samples from the Madison Aquifer. Samples are divided into two populations: Group I (meteoric water), Group II (basinal water).

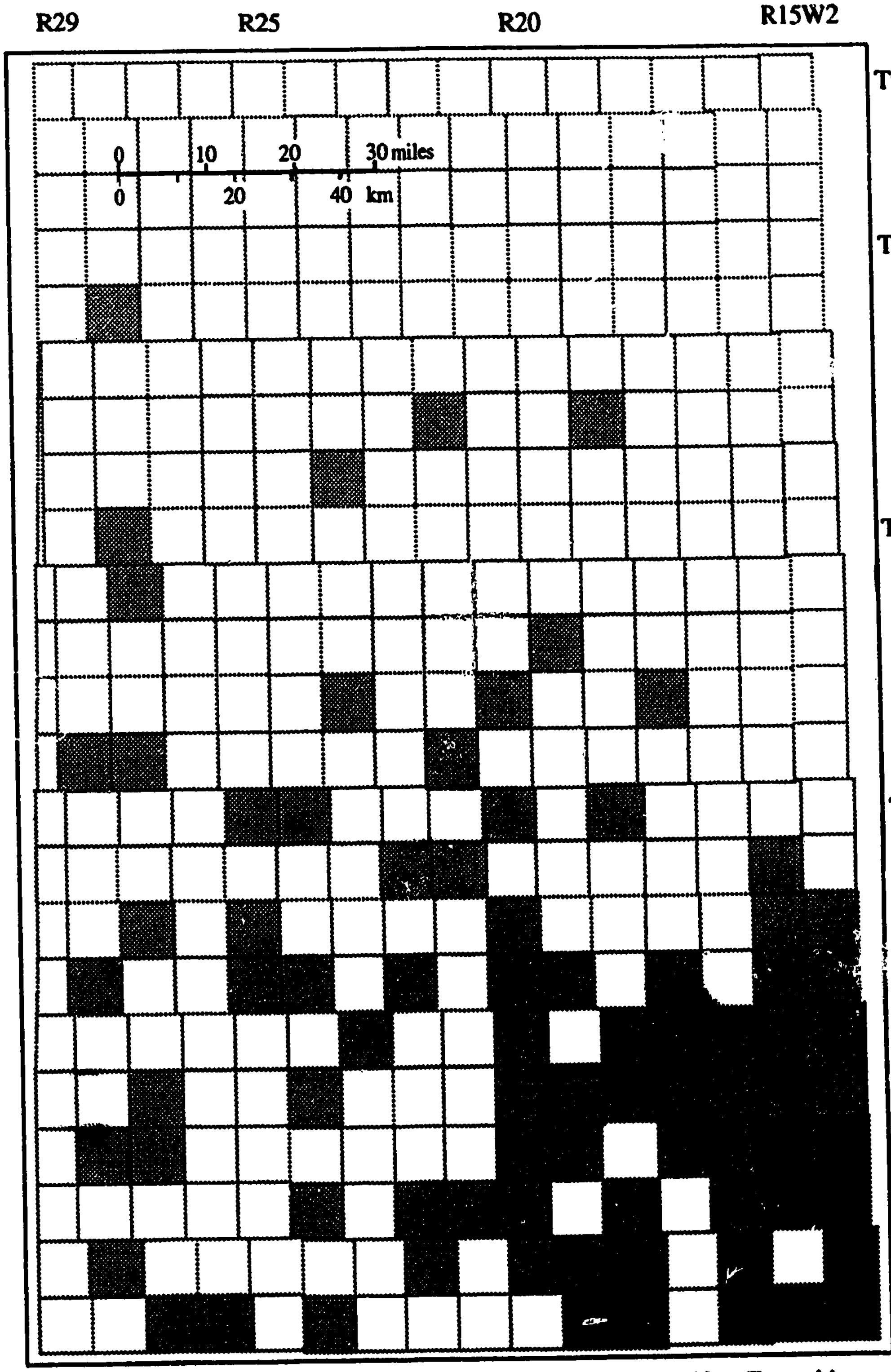


Figure 4.40 Distribution of water groupings in the Madison Aquifer. Townships containing water analyses classified into one of two groupings, based on relative ionic concentrations of Na^+ and Cl^- are shaded: Group I (meteoric water) Group II (basinal water)

concentration (Figure 4.40). The eleven Madison Group oilfields in the study area are found in the area occupied by or adjacent to Group II waters.

The fifteen data points from the Middle Jurassic Aquifer have Na^{+}:Cl^{-} ratios that are markedly higher and more scattered than in any other unit (Figure 4.42). Samples interpreted to belong to Group I have rNa^{+}/rCl^{-} ratios between 1.01 and 11.34 and salinities less than 450 mg/L Na^{+} or Cl^{-}. Group I samples with the greatest variability in rNa^{+}/rCl^{-} ratio and the lowest salinities were taken from the western half of the area. A single sample with an ionic ratio of 0.93 and salinity of greater than 750 mg/L Na^{+} or Cl^{-}, was taken from Tp 1, R 15W2. It is interpreted to belong to, or be strongly influenced by Group II waters (Figure 4.42).

Analyses from the Mannville and Viking aquifers exhibit similar total concentrations to those taken from the Middle Jurassic Aquifer, but their ionic ratios are less variable (Figure 4.41). Only Group I is represented. The data form a linear trend of ionic ratios between 1.03 and 1.09. Variations between Group I data of the Mannville and Middle Jurassic aquifers may be a product of lithology, sampling sites or interference and distribution of intermediate and local flow systems.

rNa:rCl - Mesozoic Aquifers

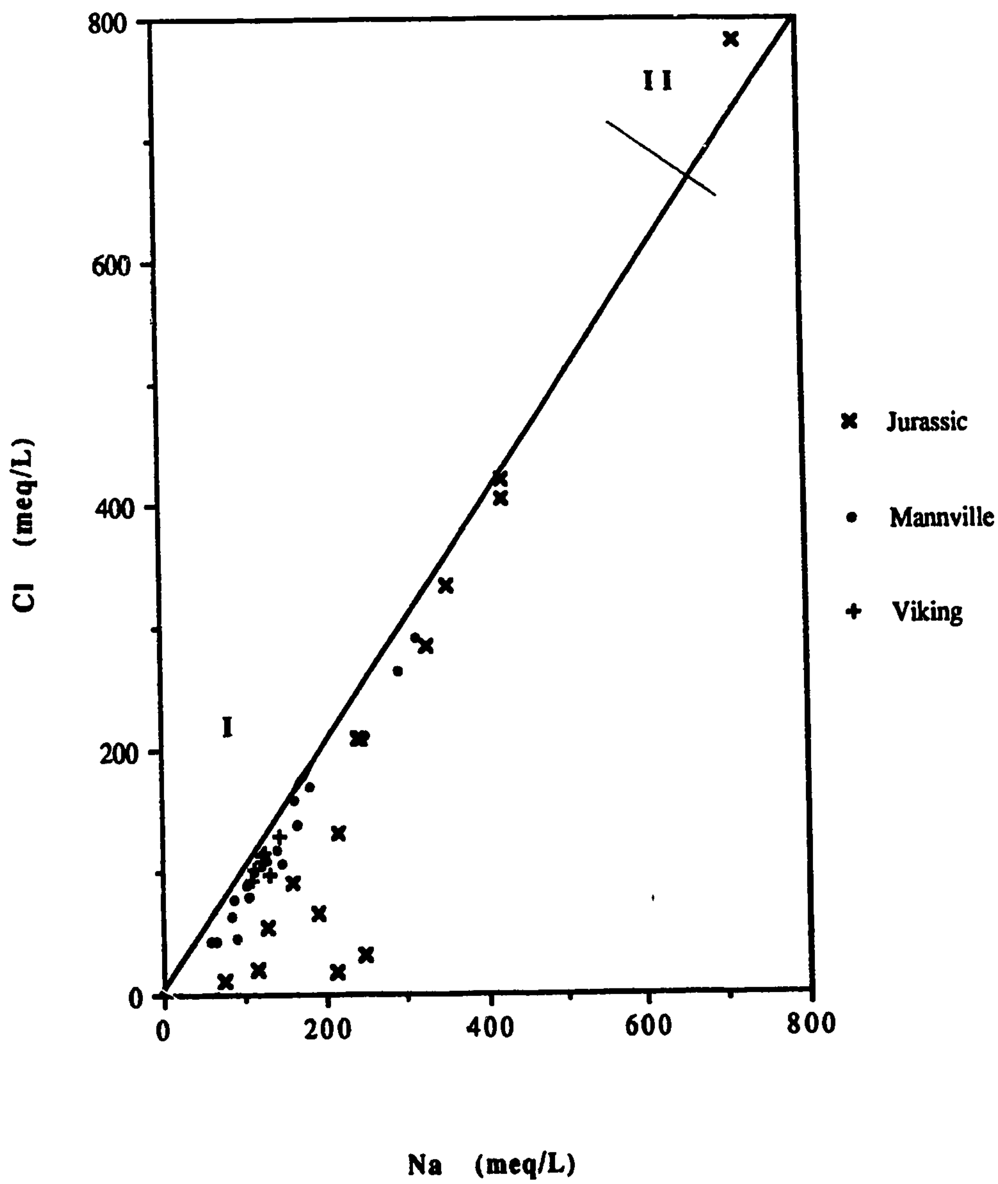


Figure 4.41 Relative concentrations of Na^+ and Cl^- in water samples from the Mesozoic aquifers and V:.king Formation. Samples are divided into two populations: Group I (meteoric water), Group II (basinal water).

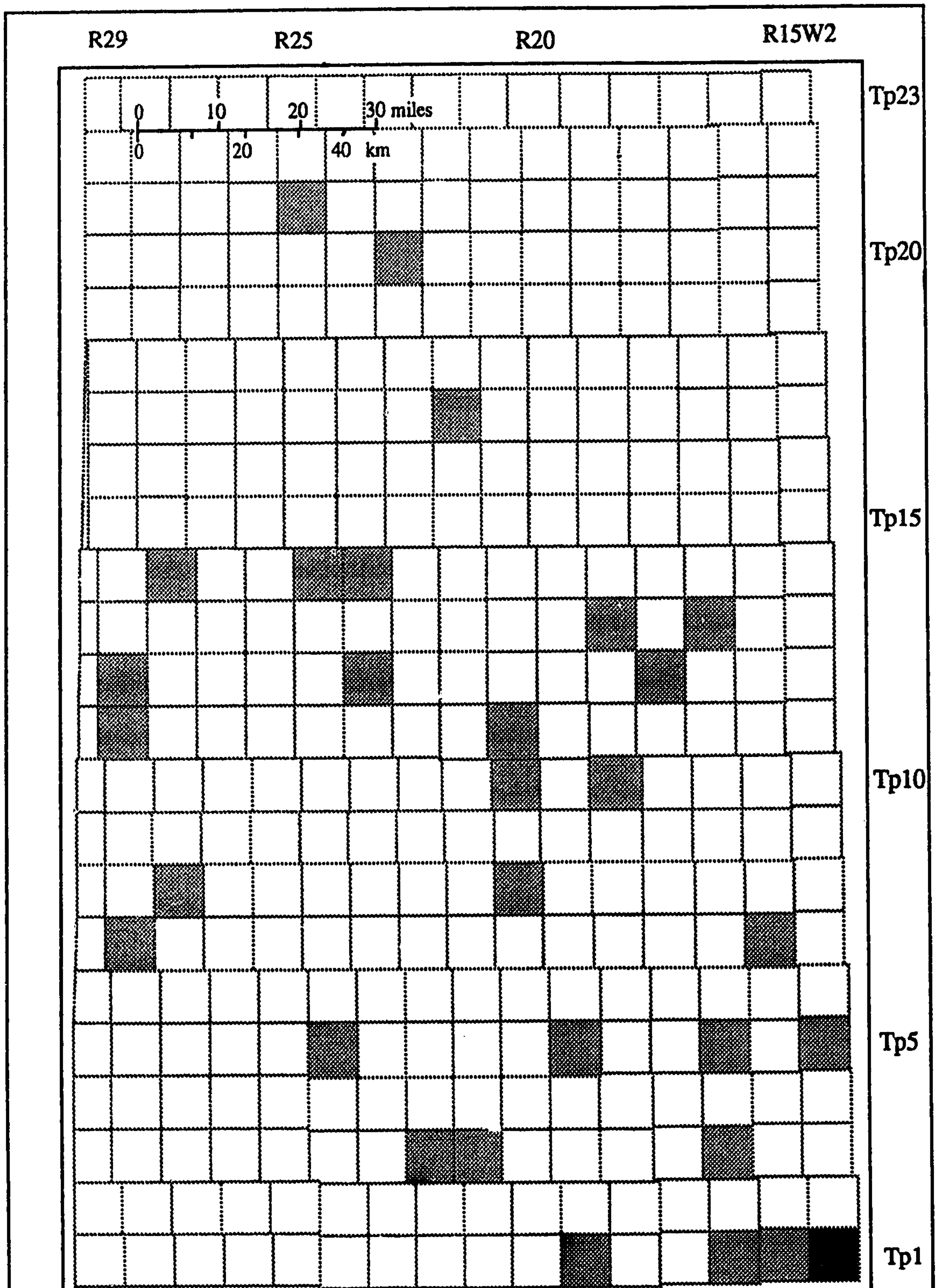


Figure 4.42 Distribution of water groupings in the Mesozoic aquifers. Townships containing water analyses classified into one of two groupings, based on relative ionic concentrations of Na^+ and Cl^- are shaded: Group I (meteoric water)
Group II (basinal water)

5.0 Discussion

5.1 Potentiometric surface, P(Z) and Total Dissolved Solids

Paleozoic

The Paleozoic units from the Precambrian basement up to the SubMesozoic unconformity all exhibit remarkably similar potentiometric surfaces that correspond very closely to topography. Regional flow is from southwest to northeast, from a topographic and potentiometric high at Wood Mountain in the southwest to a low in the northeast plains. Flow throughout the area is mostly lateral, however, upward cross-formational flow is taking place in the southern study area near Wood Mountain along the Coronach, Hummingbird and South Regina troughs, and in the northwest. Downward flow is taking place in the northeast and possibly the southeast and at the southern tip of the Hummingbird Trough.

The Wood Mountain potentiometric high is very similar in form and elevation to the land surface in the area, even in the deepest portions of the subsurface. It is characterized by low salinity waters that extend 2000 metres down to the Precambrian basement. The TDS content, which increases vertically with depth and laterally with decreasing hydraulic head, and the close correlation of the potentiometric surface to the land surface suggest that topographically driven flow is operating in the area.

In a study of the Gravelbourg glacial outwash aquifer west of the Wood Mountain area, Freeze (1969) recorded TDS concentrations of 2500-5500 ppm. In this study, TDS concentrations in the 2500-5500 mg/L range are found continuously through the geological column from the Mannville Aquifer to the Bighorn Aquifer in the area of Wood Mountain.

Recharge to the Paleozoic of the Williston Basin has traditionally been ascribed to western highland Paleozoic outcrop areas (Figure 5.1) of the Rocky Mountains of western Montana and Wyoming and to the Black Hills of South Dakota (Downey et al. 1987; Downey, 1984). A region of low salinity water extends from the western highlands recharge belt through South Dakota, Wyoming, central Montana and into southwestern and central Saskatchewan. Hydrogeological studies of southwestern Saskatchewan indicate that areas of lowest salinity in the province correspond to zones of high hydraulic head along the international border. The lowest salinity and the highest hydraulic head occur around Wood Mountain (Letourneau, pers. comm.; Toop, 1988; Gorrell, 1980; Hitchon, 1969), which is the centre of the zone of salt removal of the Prairie Evaporite Formation in southern Saskatchewan. The potentiometric highs in southern and southwestern Saskatchewan also correlate to the band of highlands extending from Wood Mountain (elevation 1100 m) to Pinto Butte (1100m) to the Cypress Hills (1300m) (Figure 5.1).

Tóth (1963), demonstrated the importance of basin topography on the development of ground water flow systems. Hilly topography will produce intermediate and local subsystems within a regional flow system. As the magnitude of relief increases and as the depth to length ratio of the basin decreases, the more likely it will be that intermediate and local systems will extend to the basal boundary condition. In the region of Wood Mountain in the southwest, a correlation is found between the topographic surface and the potentiometric surfaces of the Basal Clastic to Madison aquifers (Figures

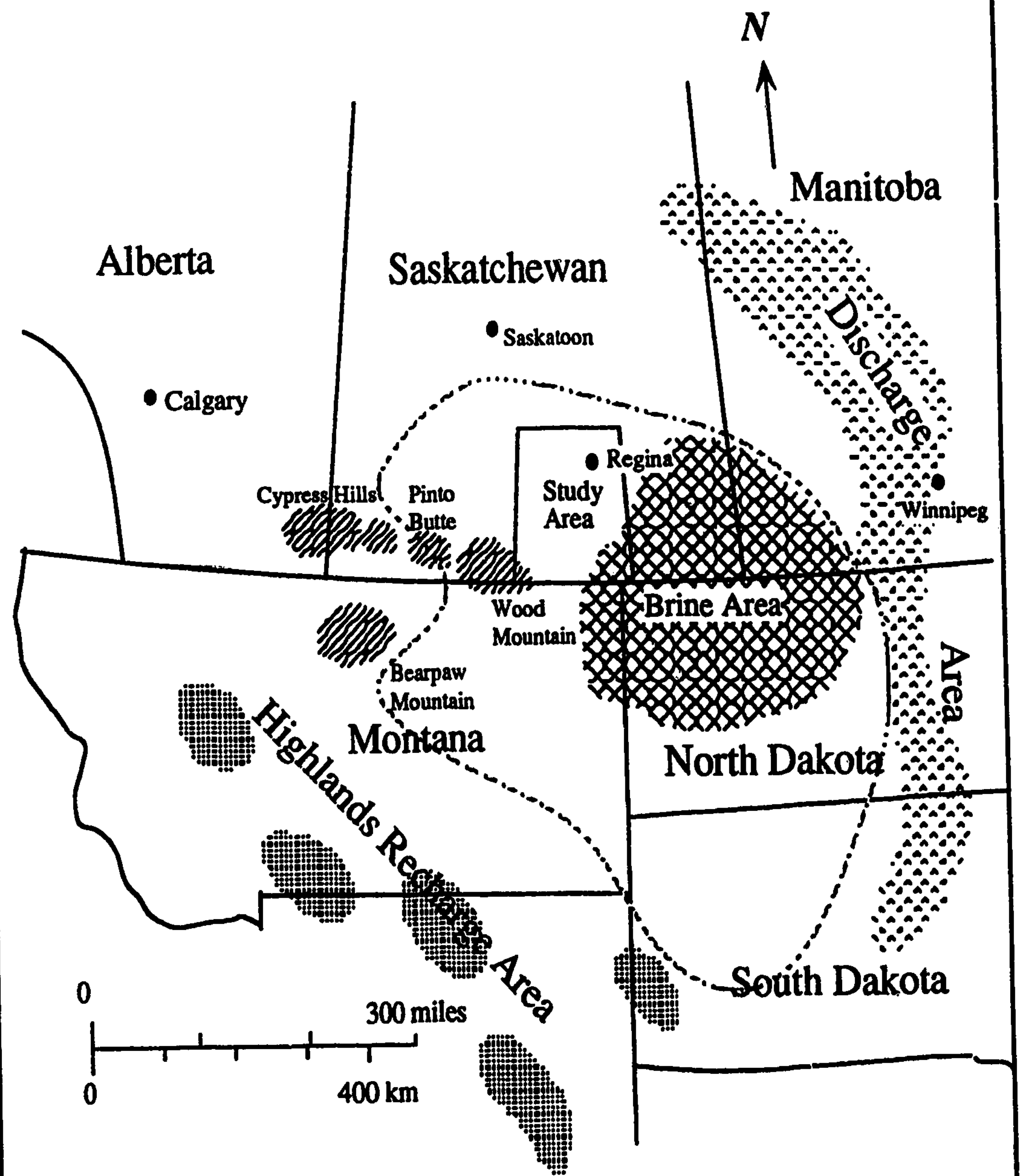


Figure 5.1 Regional Hydrogeology of the Williston Basin (after Downey, 1984). The outline of the Williston Basin is shown as a dashed line. Paleozoic ouctrops of the highlands recharge area are shaded. The Mesozoic outcrops of the Cypress Hills, Bearpaw Mountain, Pinto Butte and Wood Mountain uplifts are indicated by the stripes. The maximum areal extent of the regional brine zone (>100 000 mg/L TDS) in the Paleozoic aquifers is indicated by crosshatching. Regional flow is from the southwest toward the northeast. Discharge from Mesozoic and Paleozoic outcrops occurs in the area shown along the northeastern and eastern margins of the Basin.

1.2, 4.1 to 4.5). The potentiometric surfaces together with the occurrence of low salinity waters from the uppermost to the lowermost aquifers suggest that flow systems generated in the region of Wood Mountain extend to the basal boundary condition.

In the Paleozoic aquifers below the Elk Point Aquitard, regional flow is from southwest to northeast. In the Madison and Saskatchewan aquifers, the regional flow across the area takes on a stronger eastward component. The Madison Aquifer thins dramatically in the north along Township 15 and subcrops along Township 23. It is bounded by the Watrous and Three Forks Aquitards throughout the area. The Madison Aquifer has a transmissivity estimated to be in the order of 10^{-5} m^2/s across the east-central border of the study area. Across the northern border of the area, the transmissivity of the Madison Aquifer is 0 m^2/s, meaning flow will be directed eastwards. The Saskatchewan Aquifer is of fairly constant thickness throughout the region. It subcrops beyond the northern edge of the study area and outcrops in central Manitoba. The outcropping strata may act as a preferred conduit for discharge.

Two other potentiometric highs are found along the southern study area. They do not correspond to topography and are lower in energy than the Wood Mountain high. The highs, which coincide with the Roncott Remnant and the southeastern four townships of the area are most extensive in the aquifers beneath the Prairie Evaporite, becoming weaker in the Saskatchewan and Madison aquifers until disappearing in the Mesozoic. They correlate throughout the section to a zone of elevated salinity of 100 000 to >350 000 mg/L TDS concentrations. The waters appear to have a deep basin origin, as they are several orders of magnitude more saline than the presumably meteoric system coming from Wood Mountain. They are part of a more extensive regional brine area (Figure 5.1) mapped by Downey (1984).

The regional brine area occupies the deepest (Cambrian to Mississippian), most central parts of the Williston Basin and is offset toward the northern and eastern discharge belt. Its distribution and position appear to be determined by basin structure and topography, rather than stratigraphy. Hubbert (1969) suggested that the brine is static and that meteoric flow systems are diverted around and above this zone due to density contrasts. Downey (1984) notes that although some diversion of meteoric flow is taking place, the brine is also in motion as a sluggish segment of the regional flow system across the basin.

The present study indicates that the brine is in motion, although its fluid potential is lower than that of the meteoric regime. The south and southeast potentiometric highs may be part of an ancient regional flow system, or they could indicate more permeable conditions, which would preferentially direct flow into this zone. According to Porter and Fuller (1970), the Ordovician carbonates of the southeastern study area are composed of 40 to 60% fragmental dolomitic limestone and 40 to 60% dense dolomite compared to 20 to 40% fragmental dolomitic limestone and 60 to 80% dense dolomite in the remaining area, suggesting that permeability is in fact greater in the southeast. The south and southeast highs are gradually overwhelmed by the higher energy Wood Mountain regime in the upper units.

The Roncott and southeast potentiometric highs are separated by a low that occupies the length of the Hummingbird Trough, a region where the confining Prairie Evaporite has been removed by dissolution. The potentiometric surfaces of the Basal Clastic (Figure 4.1), Bighorn (Figure 4.2), Winnipegosis (Figure 4.3) and Saskatchewan (Figure 4.4) aquifers, the potentiometric sections "B" (Figure 4.9) and "C" (Figure 4.10) and the pressure versus elevation plots #4 (Figure 4.26) and #5 (Figure 4.27), affirm that the Hummingbird Trough is a conduit for converging and upward directed flow in the area. The Roncott and the southeast highs likely are part of a single regional system that has been split by the pressure sink created by the Trough.

A similar sink along the Coronach Trough separates the Wood Mountain and Roncott highs. It is not as pervasive throughout the Paleozoic section or as obvious as the Hummingbird Trough. The difference in character could be partially attributed to the fact that it is bordered by the Prairie salt on only one side. In the deeper aquifers, the Coronach Trough appears to form an effective boundary between the brines found in the southeast and the lower salinity waters of Wood Mountain.

Changes in salinity are often quite dramatic over short distances, particularly in the Winnipegosis and Duperow aquifers. They are most pronounced where halite beds are distributed within or in contact with an aquifer and where saline and meteoric flow regimes converge along the Coronach Trough.

The brines of the southeast and Roncott flow regimes appear to have buffered the erosive effect of the Wood Mountain meteoric waters, leading to the preservation of the southwestern margins of the Prairie and Davidson salt bodies. The Roncott Remnant is an anomalously westward extension of the southern portion of the Prairie Evaporite, which corresponds to the western edge of the brine within the study area. From Roncott, the salt extends in a southeasterly direction to its southern limit at the centre of the Williston basin (Figure 1.1). As the distributions of the brine area and of the Prairie Evaporite are not coincident (Figure 5.1), and since much of the brine occurs upflow from the salt it may be concluded that the brine is not derived from the Prairie Formation.

The ionic ratios of rNa^{+}:rCl^{-} from samples taken from the brine area were consistently <1, which is characteristic of evolved basin waters. In waters where the Na^{+} and Cl^{-} content are derived from dissolution of halite the TDS content is very high and ionic ratio is very close to one. Although the average rNa^{+}:rCl^{-} ratio is less than one for the Group II samples from the area, it is still higher than expected for basin waters A certain proportion of the salt content could be derived from the evaporite.

Oxygen isotope work on the brine immediately east of the study area found that its chemistry matched the characteristics of a stagnant basin water in equilibrium with the surrounding rock framework (Bailey et al., 1973). Low salinity waters were concluded to be meteoric in origin.

Mesozoic

The potentiometric surfaces of the Mesozoic aquifers of the study area are distinct from those found in the Paleozoic. Hydraulic head decreases upwards, dropping from an 800m average in the Paleozoic aquifers to 700m in the Middle Jurassic Aquifer and 600m in the Mannville Aquifer. The drop in hydraulic head cannot be attributed to differences in fluid density. With the exception of the extreme southeast corner of the area, the total dissolved solids concentrations and corresponding density remain relatively constant between the Madison (Figure 4.16), Middle Jurassic (Figure 4.17), and

Mannville (Figure 4.18) aquifers. The regional flow direction is toward the northeast in the Middle Jurassic, which appears to have a potentiometric surface somewhat transitional between those of the Paleozoic and that of the Mannville. There are no clear patterns that may be correlated to topography.

Pressure versus Elevation plots #4 (Figure 4.26), #5 (Figure 4.27), #6 (Figure 4.28) and #7 (Figure 4.29), indicate that the Middle Jurassic and Mannville aquifers are underpressured with respect to the topography and to the underlying aquifers. The Mannville Aquifer outcrops at an elevation of 300 metres along the Manitoba escarpment over 300 km to the east and northeast of the study area. Much broader Paleozoic outcrops lie immediately east of the escarpment. If underpressuring in the Mesozoic were a result of drawdown due to discharge, a similar effect would be expected in the Paleozoic aquifers. Such an effect is not apparent.

The Mannville and the Middle Jurassic aquifers lie within 800 metres of the land surface and are overlain and underlain by the thick shale sequences of the Colorado Group and the Vanguard and Watrous formations. Underpressuring could result from the elastic rebound of the shales due to glacial erosion and unloading of ice caused by the retreat of the glaciers. Underpressuring is strongest in the near-surface Mannville Aquifer and Viking Formation, which are subjacent to the Colorado shales. Elastic rebound of compressible shales will cause a decrease in fluid pressure and hydraulic head as water is drawn into the expanding shales (Tóth and Corbet, 1986).

Mollard (1988) noted visual evidence of rapid rebound near Eston in southwestern Saskatchewan. Heave and joint fractures were observed in the

Cretaceous Bearpaw shale where it was exposed by dam and spillway excavations. Mollard postulated that unloading and stress relief had caused surface cracks and photolineaments. Subhydrostatic pressures in sands subjacent to Cretaceous shales attributed to elastic rebound have been documented in the Belly River Formation of west-central Alberta by Parks (1989) and in the Cretaceous sands of southeastern Alberta by Tóth and Corbet (1986). In the stated examples, underpressuring was significantly greater than is seen in southeastern Saskatchewan. The difference in magnitude may be related to the degree of unloading. Seven hundred metres of overburden were removed in southeastern Alberta, and 2000 metres of overburden were removed in west-central Alberta. In southeastern Saskatchewan, glacial erosion caused minor alterations in topography, while Wood Mountain escaped the glaciers entirely.

Formation water from the Mesozoic aquifers appears to be of meteoric origin. The water is found within 800 metres of the land surface and has a characteristically low total dissolved solids content (<33,000 mg/L) and $rNa^+:rCl^-$ ionic ratios of greater than one. A single exception is an analysis taken from the Middle Jurassic Aquifer at Tp 1, R 15W2 directly above a zone of high salinity waters in the Madison Aquifer. It has an elevated TDS content (49 000 mg/L) relative to other samples taken from the Middle Jurassic and like the subjacent Madison brines, it has an ionic ratio of less than one.

5.2 Water Characterization

Three populations of waters of differing origins were distinguished by plotting the ratio rNa^{+}:rCl^{-}. Analyses were arbitrarily classified as "Group I", "Group II", or "Group III", based on where the samples plotted relative to each other and relative to the line defined by rNa^{+}:rCl^{-} =1.

Group I is interpreted to be an evolved meteoric water. It has an rNa^{+}:rCl^{-} ratio close to or greater than one that progressively decreases with increasing concentration. Ionic ratios of slightly less than one are characteristic of samples taken from the deep Paleozoic aquifers, while ratios as high as 12.4, but usually less than 1.5 are typical of samples taken near the surface and in the region of Wood Mountain. Maximum ionic concentrations of Group I waters progressively decrease from <3500 mg/L Na^{+} or Cl^{-} in the Basal Clastic Aquifer to <450 mg/L Na^{+} or Cl^{-} in the Mesozoic aquifers.

Samples classified as Group II have rNa^{+}:rCl^{-} ratios between 0.67 and 0.99, similar to waters of marine origin. Excluding a low salinity sample taken from the Middle Jurassic Aquifer, ionic concentrations range between 2000 and 5500 mg/L Na^{+} or Cl^{-}. Group II could represent connate water, or very highly evolved meteoric water that has been resident for a long time.

Group III analyses have rNa^{+}:rCl^{-} ratios between 0.98 and 1.0, and ionic concentrations between 2500 and 5500 mg/L Na^{+} or Cl^{-}. They are interpreted to be Group I or II waters that have been altered due to contact with evaporite salts in the sequence.

All three groupings are associated with particular geographical localities and geological features. Group I may be correlated with the potentiometric high along the western and southwestern margin of the area.

Group II is identified with a brines of the deep basin areas in the southeast. Group III water is found in units in contact with halite or sylvite beds.

With the exception of a single Group II sample in the Middle Jurassic Aquifer, all analyses from the Mesozoic were classified as Group I. Although subpopulations may exist within the Group I samples, they were not regarded as being important in the regional context of this study. A number of analyses from the Middle Jurassic Aquifer had significantly higher ionic ratios than samples taken from the other aquifers. Subpopulations within the Group I waters of the Mesozoic and Upper Paleozoic are difficult to quantify, except as variations possibly caused by lithological differences or by the interference of near surface flow systems. The lack of strong topographic relief in the area decreases the likelihood that a significant number of deeply penetrating, local systems will be generated.

5.3 Tectonic Elements

Major fault zones are often related to deep-seated activity in the Precambrian. Penner and Mollard (1991), in a study of surface and subsurface features in southern Saskatchewan, found that many distinctive surface lineaments could be traced to zones of weakness in the Precambrian basement. Several authors (Wilson et al., 1963; Holter, 1969; Kent, 1974; Worsely and Fuzesy, 1979; McTavish, 1987; and Penner and Mollard, 1991) concluded that removal of evaporite in southeastern and central Saskatchewan was controlled by regional fracturing, likely associated with basement faults.

Fault and fracture zones, depending on geology and flow direction may act as preferred conduits for water or hydrocarbons, or as effective barriers to flow. Conduits to flow may be seen in potentiometric maps as widely spaced, often arcuate isopotentials, while barriers are often indicated by a sudden constriction of contours. Three anomalous regions having the characteristics of fault zones were identified with the Missouri Coteau and the Hummingbird and Coronach troughs.

The Missouri Coteau is an escarpment that divides the Third Prairie Level from the topographically lower Second Prairie Level. It corresponds to the midline of the South Regina Trough (Figure 1.4). Kupsch (1958) suggested that the Coteau is a fault-generated escarpment. More recent work suggests that the Missouri Coteau is largely unrelated to the underlying structure (McTavish, 1991).

Hydrogeological anomalies associated with the Missouri Coteau span the geological sequence, exemplified to varying degrees in both the potentiometric and total dissolved solids maps. Throughout the Paleozoic, potentiometric contours upflow from the Missouri Coteau are lobate. At the Coteau, contours become mildly constricted and straighten out parallel to the escarpment, remaining parallel on the downflow side (Figures 4.1 to 4.5). In the Middle Jurassic Aquifer, a dramatic constriction of flow conforms to the Missouri Coteau (Figure 4.6). Potentiometric contours parallel the Missouri Coteau in parts of the Mannville Aquifer, but do not exhibit a strong correlation.

An anomalously eastward extension of lower salinity water penetrates the brine area from the Basal Clastic Aquifer up to the Middle Jurassic Aquifer along the Missouri Coteau. Salinity contrasts become less distinct toward the top of the section, where meteoric waters have engulfed most of the study area. In the Mannville Aquifer, a sudden increase in total dissolved solids occurs at the Missouri Coteau.

The Hummingbird and Coronach Troughs, which respectively mark the eastern and western boundaries of the Roncott Platform are subsurface features defined by the removal of the Prairie Evaporite along linear trends (Figure 1.4). The Hummingbird and Coronach Troughs may be coincident with an extension of the Precambrian Nemo-Estes gravity-magnetic trend (DeMille et al., 1964). Several workers (Alabi et al., 1975; Camfield and Gough, 1971; Maidens and Paulson, 1988) placed the North America Central Plains (NACP) electroconductivity anomaly, interpreted to be a major basement discontinuity (Camfield and Gough, 1977), coincident with the Hummingbird Trough. Recent studies, (Jones and Savage, 1986; Rankin and Pascal, 1990; Majorowicz et al., 1988 and Price et al., 1986) have relocated the NACP 70 km to the east of the Hummingbird Trough. Jones (personal communication) notes that smaller magnetotelluric anomalies, which may have been mistaken for the NACP zone occur beneath Hummingbird and Coronach Troughs.

A study of the geothermics of the Williston Basin by Majorowicz et al. (1986) illustrates an elongate temperature high at 2 km depth that follows the Hummingbird Trough. Majorowicz interpreted the high to be caused in part, by the upward movement of formation waters.

The influence of the Hummingbird and Coronach troughs is evident in chemical and potentiometric maps throughout the Paleozoic, but not in the Mesozoic. In the aquifers below the Elk Point Aquitard, the potentiometric contours constrict to form an elongate low along the centre of the

Hummingbird Trough. In the Saskatchewan and Madison aquifers, the potentiometric contours become very constricted around a low that occurs immediately east of the Hummingbird Trough. In the Bighorn Aquifer, a region of low TDS concentrations occupies the zone of salt removal.

An elongate potentiometric low occupies the Coronach Trough in the Saskatchewan and Madison aquifers. A similar low lies one township to the east of the Coronach Trough in aquifers beneath the Elk Point Aquitard. The Coronach Trough may be a fault zone, which could form a conduit to flow along its length and a barrier across its face. The barrier may act as a buffer to salt removal by preventing mixing of the eastern saline and western meteoric waters. Total dissolved solids concentrations in formation fluids increase rapidly from west to east across the Coronach Trough.

The offset of a potentiometric low along the Coronach Trough in the aquifers below the Aquitard, could be a function of the relative strengths of the converging flow regimes. In the Saskatchewan and Madison aquifers, fracturing and brecciation above the zone of salt removal could create a highly permeable lens. Flow would be directed laterally and vertically into the lens, forming the potentiometric anomaly seen in the Saskatchewan and Madison aquifers.

5.4 Petroleum Hydrogeology

According to the Hydraulic Theory of Petroleum Migration (Tóth, 1980), hydrocarbons will migrate with the formation waters from mature source rocks toward sites of accumulation that are characterized by stagnant conditions, potentiometric lows, upward flow and high salinity. When tracing the migration pathways of oil, it is important to recognize source beds and their relationship to accumulation sites.

Two competing flow regimes exist within the study area. One is beneficial to the generation and entrapment of petroleum, while the other has a destructive influence. The stronger of the two regimes is the Wood Mountain flow regime, which is interpreted to be meteoric in origin and is topographically driven. It dominates the regional flow pattern in the area. Competing with the Wood Mountain regime is the sluggish, saline Southeast flow regime, which is divided into two parts by the Hummingbird Trough. The two regimes converge at the Coronach Trough. The Wood Mountain regime has been instrumental in removing the Prairie Evaporite salt through dissolution, while the Southeast regime appears to have protected the salt from erosion.

The Wood Mountain regime corresponds to an influx of meteoric water. The water originates along shallower western margin of the Williston Basin where petroleum is unlikely to be generated. All oil presently found in the study area is associated with the Southeast flow regime. Osadetz et al. (1991) concluded that oil in the Mississippian Oungre Trend was generated locally from the Lodgepole and Winnipegosis formations. Winnipegosis-sourced Mississippian oil could have migrated upwards along vertical fractures of the Hummingbird Trough.

Based on hydrocarbon pools and source bed characteristics, Osadetz et al. (1991) have identified four families of oil in the northern Williston Basin with the following characteristics:

A: Bighorn Group (Ordovician) Sourced, found in Ordovician to Middle Devonian pools; 24-34° API

B: Bakken Formation (Upper Devonian) Sourced, found in Bakken and Mississippian pools; 36.5-40.5° API

C: Lodgepole Formation (Mississippian) Sourced, found in Mississippian to Cretaceous pools; 17-37°, usually >26° API

D: Winnipegosis Formation (Middle Devonian) Sourced, found in Winnipegosis to Mississipian pools; 24.9-40.5° API

Family A and B oils are found in limited quantities in the study area and in the Canadian Williston Basin as a whole. With the exception of the Minton Winnipegosis Formation pool these oils are confined to the stratigraphic unit that contains their source. Family A pools are essentially locally sourced and are usually characterized by short migration pathways. Family B oils are found far from mature source regions and lie updip of their expulsion thresholds.

Family C oils are interpreted to be both distantly and locally sourced within the Mississippian. Pools near the southeast corner of the study area represent some of the deepest Mississippian production within the Williston Basin. These are medium gravity oils matching local source maturities. They are interpreted to have originated within a several township area surrounding known accumulations (Hartling et al., 1982). Biodegradation and water washing do not appear to have significantly affected oil density.

The Family D oils found in the Hoffer, Flat Lake and Hummingbird Fields all have maturities similar to Winnipegosis Formation sources underlying the pools.

The source beds and gravity of the oil pools within the study area are outlined in Table 5.1:

Table 5.1- Oil Family and API Gravity of Oilfields- Study Area

(After Osadetz et al., 1991)

Field	Zone	Family	API°
Colgate	Midale Beds (Miss.)	N.A.	34.8
Flat Lake	Ratcliffe Beds (Miss.)	D	32.0
Freda Lake	Ratcliffe Beds	C	31.0
Hoffer	Ratcliffe Beds	D	29.0
Lake Alma	Ratcliffe Beds	C	30.4
Lake Alma	Red River Fm.	A	33.3
Lougheed	Midale Beds	C	30.2
Hummingbird	Ratcliffe Beds	C	31.1
Hummingbird	Bakken Fm.	C	N.A.
Hummingbird	Birdbear Fm.	D	39.0
Minton	Winnipegosis/Red R. fms.	A	33.0
Neptune	Ratcliffe Beds	C	24.0
Roncott	Bakken Formation	B	40.5
Skinner Lake	Ratcliffe Beds	C	27.0
Tatagwa	Midale Beds	N.A.	25.0
Tatagwa North	Midale Beds	N.A.	25.7

According to the hydraulic theory of petroleum migration, oil entrapment will occur in and around enclosed potentiometric lows, with smaller accumulations developing between source beds and these lows. The theory is clearly demonstrated within the study area. Lodgepole Formation and Winnipegosis Formation-sourced oil within the Madison Group is found along and downflow of the Hummingbird Trough. The Hummingbird Trough is a fractured zone that has acted as a conduit for upward heat flow and the migration of hydrocarbons. Converging flow directed Winnipegosis Formation-sourced oil into the Hummingbird Trough where it migrated up-section with the formation fluids across the Elk Point Aquitard. Lodgepole-sourced oil was likely generated in the vicinity of the Hummingbird Trough, where fluid-enhanced heat flow acted as an agent of maturation. In the Saskatchewan and Madison aquifers, hydrocarbons migrated with the formation waters toward the northeast, until they were trapped by structural and stratigraphic features within potentiometric lows.

Although the trend across the Mississippian subcrop is for API gravity of the oi to increase toward the east, within the Oungre Trend there is a slight decrease toward the east. The local variation may have resulted from the lower migration angle of denser oils that allowed them to migrate farther before being trapped, or from the increased degradation that would occur along a longer migration path. The variation is within the range of sampling error, however, as the gravities were averaged for each pool they are likely characteristic of the regional trend.

The eleven known Madison Aquifer oil pools in the study area are confined to the southeast, which is the only region occupied by saline, deep-basin waters favourable to oil generation and preservation. Seven of the pools are found where TDS concentrations in formation waters are between 50 000 and 100 000 mg/L; four are found in waters ranging from 20 000 to 50

000 mg/L. The API gravity of the oils is generally lower in the meteoric water zones.

Bailey et al. (1973) studied Mississippian oils in a meteoric water (50 000 mg/L TDS) zone northeast of Weyburn, Saskatchewan. They concluded that water washing and biodegradation had degraded the previously sweet, medium to low density crudes into sour nonproductive tars. Osadetz et al. (1991) studied the effects of water washing and biodegradation in selected fields in southeastern Saskatchewan. They concluded that although water washing and possibly biodegradation had occurred, the controlling effect on oil quality and composition appeared to be migration path length, thermal maturity and source rock characteristics.

Known Madison Aquifer oilfields occur in the southeastern study area where the potentiometric surface is below 825 metres. Pool size and frequency increase with decreasing fluid potential in the productive area. Flow converges from the northwest, west and south and moves eastward to an arcuate low of <650 m on the eastern edge of the area. A similar pattern of converging flow is also seen in the underlying Saskatchewan Aquifer. The Weyburn field, which lies just outside the study area adjacent to the 650m low, is the second largest field in the Canadian Williston Basin. Oil was likely directed toward Weyburn from several sources and directions.

Although a larger potentiometric low occurs in the northeast study area, it is unlikely to contain oil. This low is part of the regional trend dominated by meteoric waters of Wood Mountain flow regime. Unlike the southeast corner, this area does not lie immediately downflow from known mature source beds, and water chemistry is not conducive to oil preservation.

The unusual westward position of the Bakken Roncott pool is in accordance with the hydraulic theory of petroleum migration. Roncott contains Bakken Formation derived oil, which has migrated nearly 200 km from its source near the centre of the Williston Basin, along the Bakken sand body, a fairly thin, but continuous unit found within the Bakken shale (LeFever et al. 1991). The Bakken Formation has, for the purposes of this study, been designated an aquitard unit. It may be concluded that unless it is fractured, the Bakken shale forms an effective barrier to oil migration, but not necessarily to water.

Initially, the high quality, high gravity (40.5° API) crude of the Roncott Bakken oilfield appears to have defied present-day hydrochemistry, by avoiding degradation despite its long migration pathway and accumulation in waters containing less than 4000 mg/L TDS. Roncott oil migrated and accumulated according to present-day hydrogeology. It was carried by saline basin waters in a northwesterly direction from the centre of the basin, then north into the study area. The oil was trapped within an elongate open-ended potentiometric low located along the Coronach Trough. The same waters that buffered the Roncott Remnant from the erosive effects of the Wood Mountain flow regime protected the Bakken-sourced oil along its migration path. Future discoveries of Bakken Formation and deeper Paleozoic oil could be found in the Coronach low.

A smaller Bakken Formation oil pool is located subjacent to the Hummingbird Mississippian oil pool. Both pools contain oils sourced from the Lodgepole Formation. Downward directed flow at the tip of the Hummingbird Trough and fracturing of the Bakken shale in the

Hummingbird structure allowed Lodgepole oil to migrate into the Bakken sand.

Bakken oil shows have been found throughout much of the southern study area east of the Roncott oil pool. Although no potentiometric surface map was created for the Bakken Formation, pervasive potentiometric lows found both in the superjacent Madison and subjacent Saskatchewan aquifers were used to outline hydrogeologically favoured sites for Bakken (and Saskatchewan) oil accumulation. Potentiometric lows around the Coronach Trough and east of the Hummingbird Trough are preferred exploration targets.

Bighorn-sourced oil is found at Minton, as well as in isolated wells at Lake Alma, and West Oungre (Tp 3, R 15W2). At Minton, oil has been structurally trapped, enroute toward potentiometric lows at the eastern edge of the Roncott potentiometric high. The two smaller pools are located in the extreme southeast study area along potentiometric lows of 850-875m in a region of converging flow.

According to Osadetz et al. (1989), significant quantities of Bighorn-sourced oil remain to be discovered. Hydrogeologically favourable zones for accumulation within the Bighorn and Winnipegosis aquifers include the potentiometric low which follows the Coronach Trough (Tp 2-6, R 25W2) and the region east of and including the Hummingbird Trough and south of a zone of the constricted isopotentials that follow Tp 5.

The Hummingbird and Coronach troughs are zones where converging flow is pervasive throughout the Paleozoic aquifers. They represent promising areas that should be investigated further, particularly for traps related to solution-collapse structures.

The Mesozoic aquifers have uncertain hydrocarbon potential. Although there are no known mature source beds in the Mesozoic, significant accumulations of oil could have migrated along permeable pathways formed by fracture zones and interconnected sand bodies in the Watrous Aquitard and in the superjacent Middle Jurassic Aquifer. Exploration in and above the Mesozoic confining layers has resulted in several major discoveries in Manitoba and eastern Saskatchewan (Barchyn, 1984), and may be applicable to the study area as well. The most prospective zones would be above existing Madison Aquifer pools and along regional fault zones.

Hydrogeologically prospective zones are outlined as follows in Table 3 and in Figures 5.2 to 5.5:

<u>Table 5.2 - Areas Recommended for Petroleum Exploration:</u>

Basal Clastic Aquifer :	questionable potential due to lack of source beds-similar to Bighorn.
Bighorn Aquifer:	T2-6, R24-26 W2 T1-5, R15-20 W2, (and possibly north of T5)
WinnipegosisAquifer:	similar to Bighorn
Saskatchewan Aquifer	T3-6, R25-27 W2 T1-8, R15-20 W2, (especially T3-5, R17-19; T5-6, R15-16) T1-3, R21-23 W2

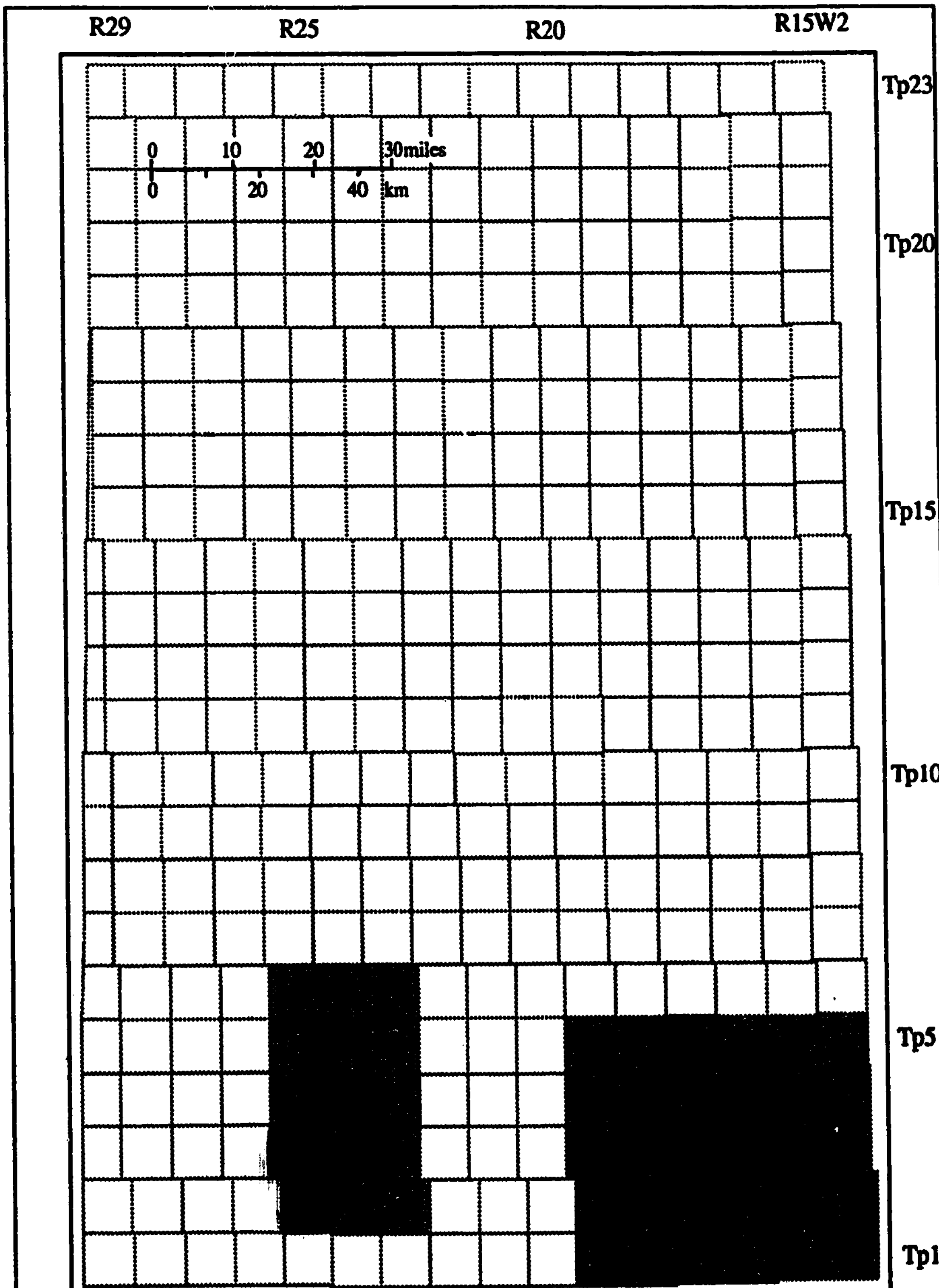


Figure 5.2 Areas recommended for petroleum exploration in the Bighorn and Winnipegosis aquifers in south-central Saskatchewan. Shaded townships are those interpreted to be most favourable to hydrocarbon accumulation, based on the hydrogeology of the area.

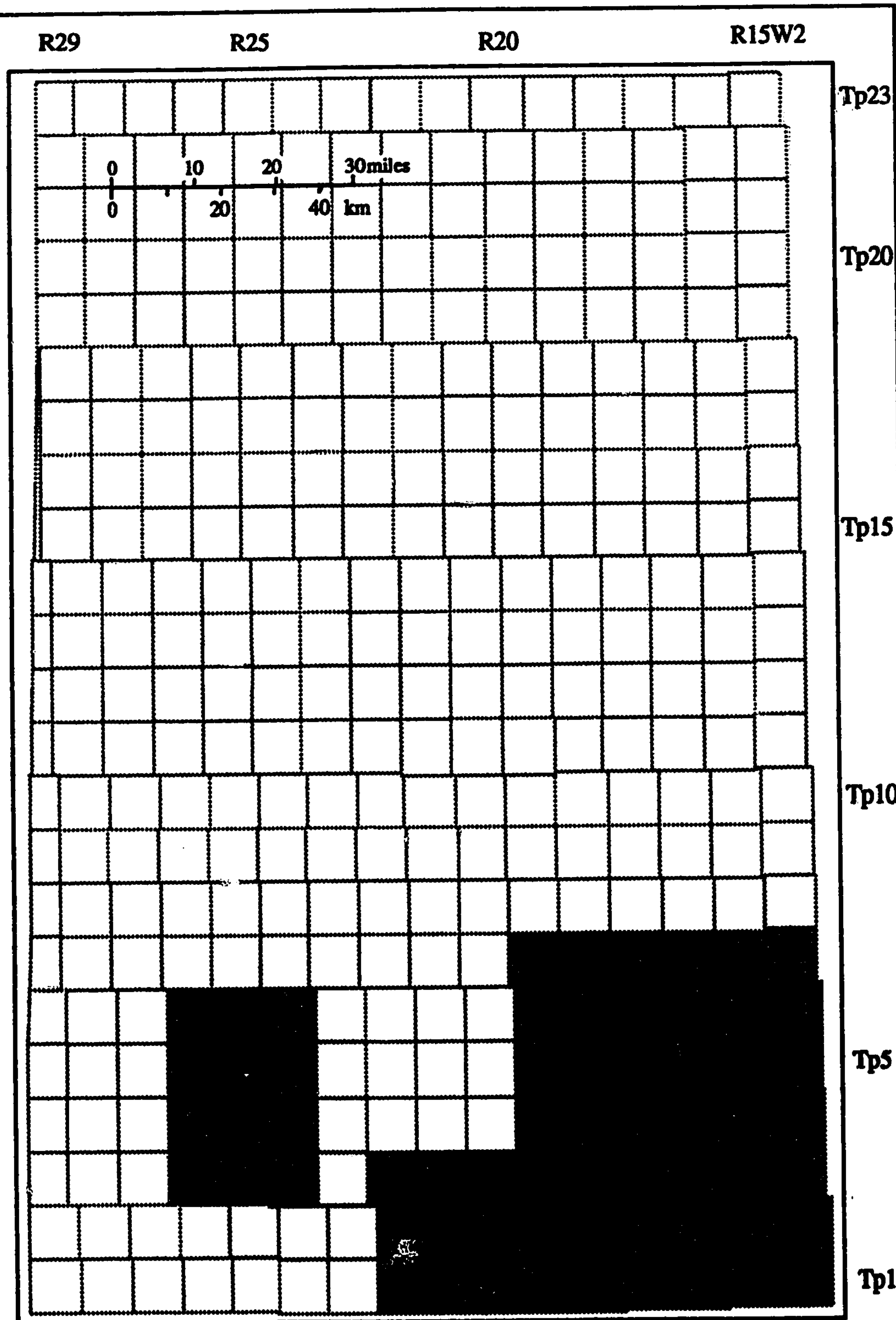


Figure 5.3 Areas recommended for petroleum exploration in the Saskatchewan Aquifer and Bakken Formation in south-central Saskatchewan. Shaded townships are interpreted to be favourable to hydrocarbon accumulation, based on the hydrogeology of the area.

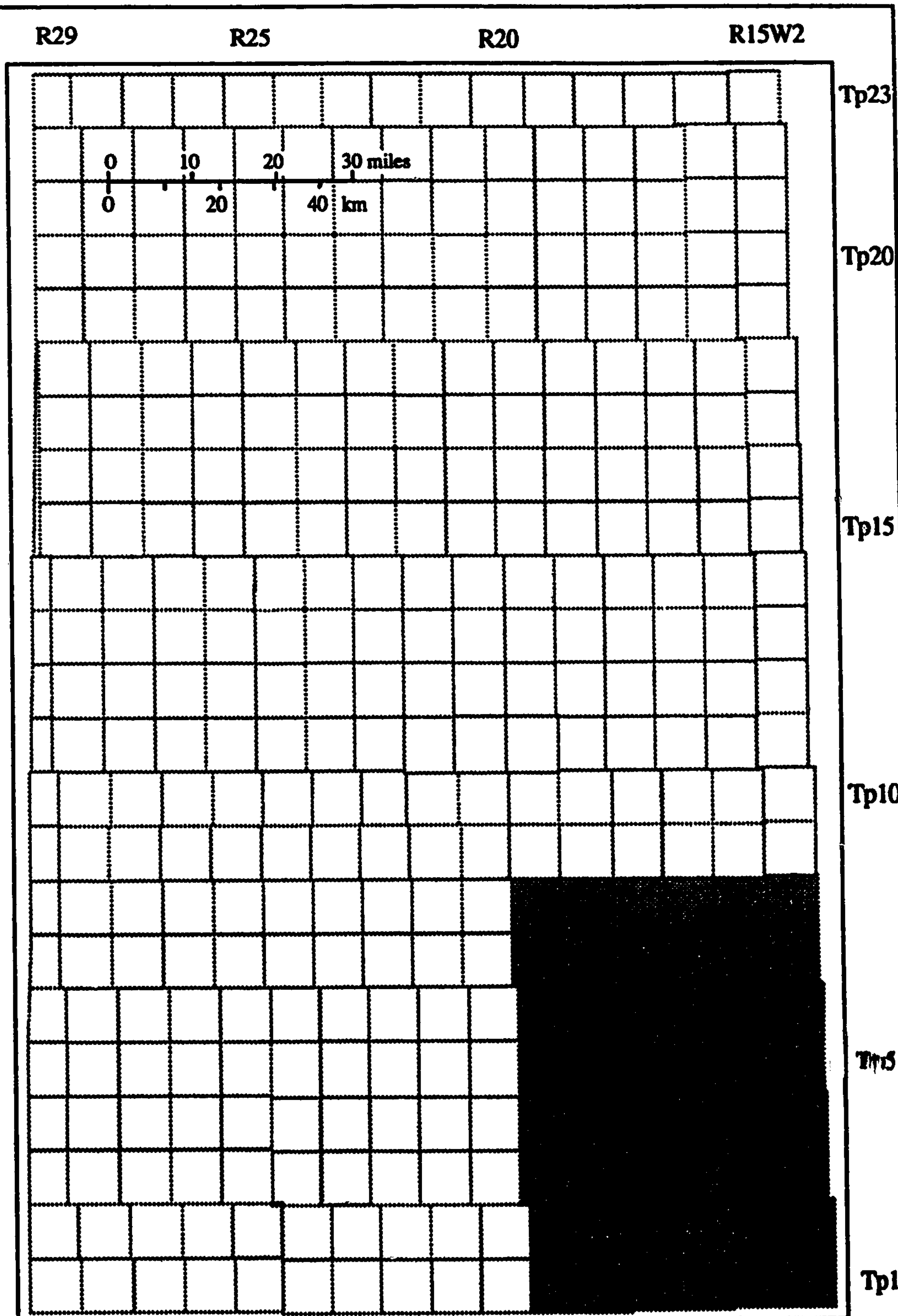


Figure 5.4 Areas recommended for petroleum exploration in the Madison Aquifer in south-central Saskatchewan. Shaded townships are interpreted to be favourable to hydrocarbon accumulation, based on the hydrogeology of the area.

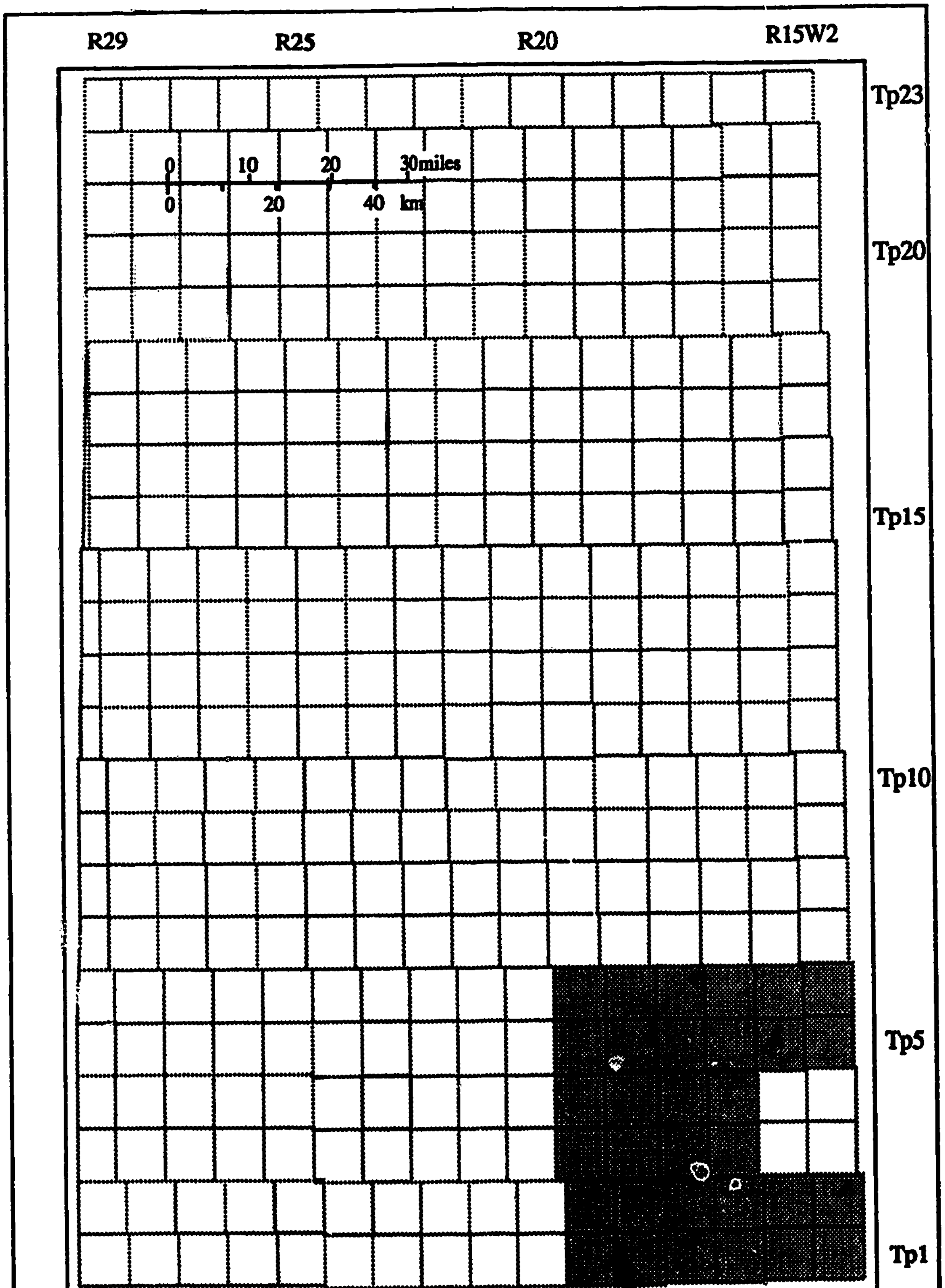


Figure 5.5 Areas recommended for petroleum exploration in the Middle Jurassic Aquifer in south-central Saskatchewan. Shaded townships are interpreted to be somewhat favourable to to hydrocarbon accumulation, based on the hydrogeology of the area.

Bakken Formation	-as Saskatchewan
Madison Aquifer	T1-8, R15-20 W2, (especially T3-7, R16-18)
	T9-11, R15-17W2?
Middle Jurassic Aquifer	T1-6, R17-20 W2?
	T1-2, R15-16 W2?
	T5-6, R15-16 W2?
Mannville Aquifer	-not favourable

6.0 Conclusions

Hydrogeology has been the controlling influence on the migration, accumulation and preservation of hydrocarbons in the Williston Basin of south-central Saskatchewan. It is a useful as an exploration tool for hydrocarbons and for the identification of tectonic features in the subsurface.

Two competing flow regimes are present in the Paleozoic aquifers in the study area. An active fresh, meteoric influx is entering the area along its western and southwestern boundary. It is gravity driven and appears to originate from the Wood Mountain uplands. It is the controlling force in determining the regional flow pattern of the area and has likely been instrumental in removing the Prairie Evaporite in central Saskatchewan.

Sluggish deep-basin brines from the centre of the Williston Basin are entering the study area along its south-central to southeastern margins. The brines were instrumental in the preservation of the Roncott Remnant of the Prairie Evaporite salt, by acting as a buffer against the influx of erosive meteoric waters.

The potentiometric surfaces of the Paleozoic aquifers correspond closely to topography. Pressures are somewhat superhydrostatic in the south, hydrostatic in central areas and somewhat subhydrostatic in the north. Heads associated with the Wood Mountain flow regime closely resemble topography, while those of the Southeast flow regime do not. Populations defined by the ratio $rNa^+:rCl^-$ combined with total Na^+ and Cl^- ionic concentrations may be used to identify the distribution of waters belonging to the two flow regimes, and of waters directly affected by dissolution of the Prairie Evaporite.

Three regional fault zones occur in the area. They are associated with the Missouri Coteau, and the Hummingbird and Coronach troughs and are interpreted to be pervasive through much of the sedimentary column. They were identified through the correlation of several features, including linear trends of congested potentiometric and total dissolved solids contours, elongate or enclosed potentiometric lows, anomalous temperature patterns, surface lineaments and preferential removal of evaporite salts. Features associated with the Missouri Coteau are found throughout the sedimentary column, while features related to the Hummingbird and Coronach troughs are limited to the Paleozoic aquifers.

The Mesozoic aquifers of the study area have very different characteristics from the Paleozoic aquifers. Potentiometric surfaces within the Mesozoic are subhydrostatic, independent of topography and are markedly different from Paleozoic potentiometric trends in magnitude and pattern. Fluid pressures in the Mesozoic have probably been reduced by the elastic rebound of shale units, that occurred as a result of glacial erosion and retreat. The Mesozoic is dominated by water interpreted to be of meteoric origin. Variations in the total dissolved solids content and the $rNa^+:rCl^-$ ratio are probably due to changes in lithology and to the interference of intermediate and local flow systems of various migration lengths and fluid pathways.

The distribution of oilfields in the area may be explained in terms of the hydraulic theory of petroleum migration. Oil was transported from mature trapped along its migration route or in the lows. Oil sourced from the Winnipegosis Aquifer was transported across the Elk Point Aquitard through the fracture zone created by the Hummingbird Trough. It migrated alongside Lodgepole Formation-sourced oil to traps along the Madison Group subcrop. Bakken Formation-sourced oil was trapped in a potentiometric low associated with the Coronach Trough. Hydrogeological evidence suggests that future oil discoveries could be found in the Paleozoic and possibly in the overlying Mesozoic units, east of the Hummingbird Trough and in the district surrounding the Coronach Trough.

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Appendix 1

Pressure Data

L	S	Tp	R	M	QC	DST	Rec	Pressure	Z	Head	Unit
15	15	1	15	2	w	2	w	12065.8	-593	637	Mannville
3	3	1	16	2	r	1	w	12058.2	-649	580	Mannville
2	17	1	16	2	p	3	w	11810.7	-620	584	Mannville
10	20	1	17	2	p	7	w	11238.5	-528	618	Mannville
8	30	1	17	2	p	3	w	11548.7	-594	583	Mannville
8	22	2	17	2	w	1	w	10375.9	-499	558	Mannville
11	26	2	19	2	p	2	w	11555.6	-546	632	Mannville
4	24	5	15	2	p	7	w	9154	-496	438	Mannville
9	27	5	15	2	p	3	w	9230	-485	456	Mannville
6	2	9	23	2	c	7	w	8963.2	-331	583	Mannville
11	7	11	21	2	c	1	w	9176.9	-290	646	Mannville
14	11	11	29	2	c	2	w	9997.4	-368	652	Mannville
10	33	12	29	2	w	1	w	9652.7	-314	670	Mannville
7	2	16	16	2	c	1	w/o	8396	-235	621	Mannville
4	12	17	1	3	p	2	w	9942.2	-343	671	Mannville
11	11	20	22	2	p	1	w	7234	-102	636	Mannville
11	29	20	23	2	c	1	w	7555.3	-92	678	Mannville
13	32	5	17	2	c	4	w	13569.6	-682.8	700	M. Jurassic
10	11	5	25	2	w	2	w	13891.6	-645.6	770	M. Jurassic
9	28	8	21	2	w	4	w	12321.6	-521.5	735	M. Jurassic
4	3	8	23	2	p	4	w/m	13078.7	-580	753	M. Jurassic
11	10	8	28	2	w	4	w	12312	-604.4	651	M. Jurassic
6	14	9	18	2	w	2	w	11296.4	-475.2	676	M. Jurassic
6	15	9	22	2	c	1	w	13753	-667.8	734	M. Jurassic
6	2	9	23	2	w	11	w	13203.5	-579.4	767	M. Jurassic
4	20	10	20	2	c	3	w	11376.3	-488.3	671	M. Jurassic
5	19	10	21	2	w	1	w	11596.3	-524	658	M. Jurassic
15	20	11	14	2	c	1	w	10029.8	-437.4	585	M. Jurassic
11	7	11	21	2	c	2	w	8963.2	-310.3	603	M. Jurassic
4	12	11	22	2	p	1	w	9052.8	-309.4	613	M. Jurassic
10	33	12	29	2	w	2	w	10686.9	-406.6	683	M. Jurassic
13	3	1	15	2	p	3	w	21856	-1468	760	Madison
15	15	1	15	2	c	8	w	20449	-1283	802	Madison
4	20	1	15	2	w	4	w	20100	-1269	780	Madison
7	25	1	15	2	p	3	w	20024	-1221	820	Madison
7	27	1	15	2	c	2	w	19754	-1257	756	Madison
6	28	1	15	2	wr	1	w	19992	-1265	773	Madison
12	28	1	15	2	p	1	w/o	19878	-1263	764	Madison
5	30	1	15	2	w	12	w	21253	-1416	751	Madison
9	30	1	15	2	cr	4	w	19933	-1278	754	Madison
3	36	1	15	2	r	1	w	20144	-1229	825	Madison
7	3	1	16	2	p	1	o/m	19873	-1271	755	Madison

L	S	Tp	R	M	QC	DST	Rec	Pressure	Z	Head	Unit
8	5	1	16	2	p	3	w/m	20055	-1300	745	Madison
10	8	1	16	2	wr	3	w/m	20502	-1311	779	Madison
4	9	1	16	2	pr	1	w/m/o	20130	-1279	773	Madison
12	10	1	16	2	p	1	o/m	19936	-1269	764	Madison
4	11	1	16	2	p	1	o/m/w	20067	-1262	784	Madison
4	19	1	16	2	p	3	w	20689	-1353	800	Madison
16	23	1	16	2	c	2	w	19822	-1266	754	Madison
2	34	1	16	2	c	1	w/m	19869	-1267	758	Madison
7	23	1	17	2	c	4	w	22335	-1441	835	Madison
7	30	1	18	2	c	1	w	20627	-1293	810	Madison
11	1	1	19	2	p	1	w	20657	-1320	786	Madison
13	6	1	19	2	c	3	w	19781	-1230	787	Madison
15	10	1	20	2	p	4	w	21197	-1336	825	Madison
4	11	1	20	2	c	2	w/m	19363	-1187	787	Madison
1	15	1	25	2	c	2	w	18044	-963	876	Madison
4	31	1	27	2	p	1	w	17948	-983	868	Madison
11	15	1	28	2	c	7	w	19305	-1110	858	Madison
2	8	2	15	2	cr	1	w	20073	-1215	831	Madison
5	11	2	15	2	p	1	w/m	19959	-1215	820	Madison
12	17	2	15	2	w	1	w	19194	-1191	766	Madison
16	10	2	16	2	c	2	w	19250	-1227	735	Madison
16	12	2	16	2	p	1	na	19281	-1234	731	Madison
3	20	2	16	2	p	3	w	19837	-1281	742	Madison
7	30	2	16	2	p	1	w	18570	-1137	756	Madison
7	2	2	17	2	c	2	w	20390	-1303	776	Madison
4	19	2	17	2	c	3	w	20036	-1266	776	Madison
8	22	2	17	2	c	5	w	21129	-1400	754	Madison
11	1	2	18	2	c	1	w/m	20167	-1262	794	Madison
11	20	2	18	2	c	6	w	19649	-1254	749	Madison
5	12	2	19	2	c	1	w/m	19759	-1217	797	Madison
12	13	2	19	2	w	2	w	20493	-1336	753	Madison
10	26	2	19	2	p	3	w/m	19599	-1240	758	Madison
11	9	2	20	2	c	3	w	18944	-1141	790	Madison
1	31	2	20	2	p	4	w	18462	-1069	813	Madison
7	14	2	21	2	p	1	w/m	18628	-1083	816	Madison
5	1	2	23	2	w	1	w	18415	-1048	829	Madison
9	17	2	25	2	p	3	w	18885	-1065	860	Madison
3	34	2	27	2	c	1	w	19099	-1054	893	Madison
12	21	2	29	2	c	1	w	18526	-996	892	Madison
3	5	3	15	2	w	1	m	18791	-1179	737	Madison
14	7	3	15	2	p	1	w/o/m	18062	-1116	725	Madison
1	11	3	15	2	c	1	w/m	18773	-1188	726	Madison

L	S	Tp	R	M	QC	DST	Rec	Pressure	Z	Head	Unit
4	30	3	15	2	p	1	w	17872	-1097	725	Madison
8	31	3	15	2	c	1	w	17584	-1074	718	Madison
8	18	3	16	2	c	1	w	16725	-1025	680	Madison
7	21	3	16	2	w	1	w/m	17167	-1068	682	Madison
7	34	3	16	2	p	2	w	17633	-1090	707	Madison
7	7	3	17	2	c	2	w/m	19346	-1220	753	Madison
4	20	3	17	2	c	1	w/m	17987	-1093	740	Madison
4	29	3	17	2	p	2	w/m	17464	-1067	713	Madison
16	35	3	17	2	p	2	w	16991	-1040	692	Madison
9	9	3	18	2	p	1	w	17853	-1091	729	Madison
1	15	3	19	2	c	2	w	18769	-1161	752	Madison
11	28	3	19	2	c	1	w	18446	-1123	757	Madison
12	24	3	20	2	p	1	w/m	18721	-1108	800	Madison
3	24	3	21	2	p	1	w	17265	-936	824	Madison
9	22	3	22	2	p	2	w	17296	-969	794	Madison
15	24	3	22	2	c	6	w	19133	-1142	809	Madison
8	23	3	24	2	c	1	w	17533	-922	865	Madison
16	10	3	25	2	c	9	w	19305	-1098	870	Madison
9	5	3	28	2	p	1	w	18009	-962	873	Madison
2	3	4	15	2	p	1	m	17132	-1051	695	Madison
12	12	4	15	2	c	2	w	16631	-1027	668	Madison
11	30	4	16	2	p	3	w	16703	-997	705	Madison
14	2	4	17	2	w	1	w/m	17123	-1037	709	Madison
13	7	4	17	2	w	1	m/w	16983	-998	733	Madison
15	9	4	17	2	c	1	m/w/o	16571	-1029	661	Madison
5	10	4	17	2	c	1	o/m/w	16682	-1023	677	Madison
13	10	4	17	2	p	1	m/o/w	16534	-1025	660	Madison
7	14	4	17	2	c	3	w	17007	-1032	701	Madison
3	3	4	18	2	c	1	m/w	17236	-1033	724	Madison
3	28	4	18	2	w	1	m/o	16652	-961	736	Madison
9	29	4	18	2	w	1	w/o	16555	-953	734	Madison
11	31	4	18	2	wr	1	o/m/w	16467	-950	728	Madison
14	8	4	19	2	p	1	w	18147	-1095	755	Madison
2	17	4	19	2	p	2	w	18899	-1173	754	Madison
11	3	4	20	2	p	1	w	19154	-1168	784	Madison
3	26	4	20	2	p	2	w	18386	-1154	720	Madison
3	11	4	21	2	w	2	w	17939	-1044	785	Madison
12	20	4	21	2	c	4	w	16423	-842	832	Madison
9	13	4	27	2	p	3	w	17313	-902	863	Madison
11	18	5	14	2	p	2	w	16634	-1011	685	Madison
10	9	5	15	2	w	2	w	15858	-935	681	Madison
5	13	5	15	2	w	1	w/o	15538	-919	665	Madison

L	S	Tp	R	M	QC	DST	Rec	Pressure	Z	Head	Unit
11	16	5	15	2	p	1	w	16246	-964	692	Madison
15	24	5	15	2	cr	1	w/m	15319	-910	652	Madison
1	26	5	15	2	p	1	w	15581	-915	673	Madison
13	27	5	15	2	cr	2	o/w	15572	-885	702	Madison
9	27	5	15	2	c	2	w	15554	-885	700	Madison
7	28	5	15	2	p	1	w/m	15679	-909	689	Madison
15	28	5	15	2	pr	1	w/m	15851	-896	719	Madison
1	29	5	15	2	c	1	w/m/wc	15945	-920	706	Madison
9	30	5	15	2	pr	1	w/m	15687	-888	711	Madison
9	31	5	15	2	cr	1	w	15623	-889	704	Madison
7	33	5	15	2	p	2	o	15663	-883	713	Madison
7	34	5	15	2	c	2	w/m	15593	-885	704	Madison
9	34	5	15	2	p	1	w/m	15681	-896	702	Madison
2	35	5	15	2	c	4	w	15908	-912	710	Madison
1	36	5	15	2	c	1	w	15224	-906	646	Madison
3	14	5	16	2	p	1	w	16291	-948	713	Madison
6	16	5	16	2	c	1	w	16034	-930	705	Madison
14	23	5	16	2	c	4	w/o	15617	-884	708	Madison
7	24	5	16	2	p	1	w/m	16090	-934	706	Madison
1	27	5	16	2	p	2	w	15674	-891	707	Madison
7	27	5	16	2	p	1	w/o	15879	-902	716	Madison
16	28	5	16	2	p	1	w	15800	-895	716	Madison
13	33	5	16	2	p	2	w	15502	-869	711	Madison
14	33	5	16	2	p	2	w	15635	-889	705	Madison
15	35	5	16	2	pr	2	w/m	15567	-881	706	Madison
2	36	5	16	2	p	4	w/o	15443	-873	701	Madison
9	4	5	17	2	p	1	w/m	16345	-967	700	Madison
13	32	5	17	2	c	9	w	16134	-904	741	Madison
16	34	5	17	2	p	1	w	15763	-888	719	Madison
9	35	5	17	2	p	2	w	15830	-889	725	Madison
15	36	5	17	2	p	2	w	15734	-887	717	Madison
13	30	5	18	2	p	1	w	15728	-882	722	Madison
1	14	5	19	2	c	1	w	16052	-916	720	Madison
16	35	5	19	2	w	1	w	15704	-874	727	Madison
2	29	5	20	2	p	1	w	16829	-980	736	Madison
10	34	5	20	2	c	6	w	16720	-986	719	Madison
5	28	5	21	2	c	2	w	17584	-973	820	Madison
11	32	5	23	2	p	5	w/m	15934	-804	820	Madison
3	28	5	25	2	c	2	w	16479	-807	873	Madison
9	36	5	25	2	p	2	w/m	16821	-886	829	Madison
13	6	6	14	2	p	1	w	14924	-869	653	Madison
5	18	6	14	2	p	1	w	14613	-846	644	Madison

L	S	Tp	R	M	QC	DST	Rec	Pressure	Z	Head	Unit
15	1	6	15	2	p	1	w/o/m	15009	-859	671	Madison
1	2	6	15	2	p	1	w	14650	-879	615	Madison
11	5	6	15	2	c	1	m/w	15536	-867	717	Madison
7	6	6	15	2	p	1	w	15487	-869	710	Madison
13	8	6	15	2	cr	1	w	15202	-845	705	Madison
15	8	6	15	2	c	1	w	15359	-855	710	Madison
15	11	6	15	2	p	1	w	14906	-848	671	Madison
11	12	6	15	2	p	1	w	14714	-849	651	Madison
1	13	6	15	2	p	1	w	14708	-861	639	Madison
3	17	6	15	2	c	1	w	15302	-845	715	Madison
13	17	6	15	2	c	2	w/m	15407	-851	719	Madison
9	18	6	15	2	c	2	w/m	15290	-843	716	Madison
13	21	6	15	2	c	1	w	15144	-834	710	Madison
11	24	6	15	2	?	1	na	15255	-855	700	Madison
13	25	6	15	2	c	2	w	15100	-814	725	Madison
1	28	6	15	2	w	1	w/o	14987	-817	711	Madison
9	1	6	16	2	p	1	w	15539	-865	719	Madison
13	1	6	16	2	cr	1	w/m	15492	-867	712	Madison
8	2	6	16	2	c	4	w	15771	-892	715	Madison
7	3	6	16	2	p	3	w	15740	-890	714	Madison
7	13	6	16	2	c	2	w	15340	-852	712	Madison
11	13	6	16	2	c	4	w/m	15162	-838	707	Madison
11	15	6	16	2	p	1	w	15321	-848	714	Madison
9	17	6	16	2	p	1	w	15312	-855	706	Madison
13	21	6	16	2	p	1	w	15250	-850	705	Madison
9	23	6	16	2	cr	2	w/m	14997	-819	710	Madison
11	23	6	16	2	wr	2	w/o	14997	-812	717	Madison
13	24	6	16	2	c	1	w	14996	-810	719	Madison
7	25	6	16	2	c	2	w/m	15148	-824	720	Madison
9	26	6	16	2	p	1	w	15326	-850	714	Madison
13	34	6	16	2	p	1	w	14980	-813	714	Madison
1	11	6	17	2	p	2	w/m	15641	-866	729	Madison
7	21	6	17	2	p	2	w	16539	-952	734	Madison
9	24	6	17	2	p	1	w/m	15375	-854	714	Madison
13	4	6	18	2	c	1	w	15135	-832	711	Madison
5	7	6	18	2	pr	2	w	15586	-875	714	Madison
1	1	6	19	2	c	1	w	15726	-874	729	Madison
3	15	6	19	2	p	2	w	15955	-908	718	Madison
5	15	6	19	2	p	2	w	15927	-901	722	Madison
5	16	6	19	2	p	1	w/m	15621	-878	714	Madison
1	20	6	19	2	p	1	w/o	15739	-881	724	Madison
9	6	6	21	2	w	2	w	16485	-883	798	Madison

L	S	Tp	R	M	QC	DST	Rec	Pressure	Z	Head	Unit
2	6	7	15	2	p	1	w	15156	-834	711	Madison
13	21	7	15	2	w	1	w	14795	-790	718	Madison
5	28	7	15	2	p	3	w	14808	-805	705	Madison
15	29	7	15	2	p	3	w	14982	-808	719	Madison
3	32	7	15	2	p	2	w	14734	-787	715	Madison
9	33	7	15	2	c	1	w	14362	-751	713	Madison
9	35	7	15	2	p	1	w	14210	-748	700	Madison
7	11	7	16	2	p	1	w	15032	-802	731	Madison
9	13	7	16	2	p	2	w/m	15103	-832	708	Madison
13	16	7	18	2	p	1	w	15987	-893	737	Madison
14	22	7	18	2	w	1	w	15720	-882	721	Madison
6	2	7	20	2	p	2	w/o	15914	-880	742	Madison
4	27	7	20	2	c	2	w	16300	-883	779	Madison
10	27	7	21	2	w	1	w/m	15830	-832	782	Madison
7	36	7	21	2	c	6	w/m	14588	-754	733	Madison
4	12	7	24	2	p	1	w	15618	-758	834	Madison
8	29	7	25	2	p	1	w	15787	-766	843	Madison
13	35	7	25	2	c	1	m/w	15540	-759	825	Madison
11	28	7	26	2	p	1	w	15803	-776	835	Madison
14	29	7	29	2	c	3	w	15824	-733	880	Madison
8	4	8	16	2	p	1	w	14404	-752	717	Madison
1	13	8	16	2	p	1	w	14245	-733	719	Madison
7	16	8	16	2	c	1	w	13872	-704	710	Madison
5	24	8	16	2	p	1	w	13995	-717	709	Madison
11	23	8	21	2	c	1	w	14465	-747	728	Madison
9	28	8	21	2	c	7	w	14969	-793	733	Madison
11	10	8	28	2	c	7	w	15318	-715	847	Madison
10	28	9	15	2	w	3	w	12480	-635	638	Madison
16	26	9	16	2	c	1	w	13272	-640	713	Madison
4	2	9	17	2	p	2	w	13971	-724	701	Madison
6	15	9	22	2	c	3	w	15362	-788	778	Madison
3	18	10	25	2	c	1	w	15233	-747	806	Madison
13	13	10	26	2	w	1	w	15169	-731	815	Madison
15	20	11	14	2	p	3	w	11866	-587	623	Madison
3	13	11	21	2	w	1	w	13317	-608	749	Madison
4	12	11	22	2	c	7	w/m	13292	-596	759	Madison
13	27	11	28	2	c	1	w/m	15169	-669	877	Madison
14	11	11	29	2	c	4	w	15208	-693	857	Madison
1	11	12	18	2	w	3	w	12536	-583	695	Madison
9	4	12	23	2	w	2	w	14700	-732	767	Madison
11	9	12	24	2	w	4	w	15161	-732	814	Madison
11	22	13	16	2	c	1	w	11032	-500	625	Madison

L	S	Tp	R	M	QC	DST	Rec	Pressure	Z	Head	Unit
9	20	13	19	2	p	4	w	12549	-584	695	Madison
13	14	13	20	2	p	1	w	12252	-514.5	736	Madison
13	14	13	21	2	c	1	w	12252	-515	734	Madison
2	11	14	28	2	w	3	w	14031	-633	798	Madison
2	1	15	23	2	p	1	w	13859	-667	746	Madison
14	19	15	25	2	p	2	w	14010	-648	780	Madison
12	14	1	16	2	c	3	w	24584.6	-1707.8	798	Saskatchewan
10	15	1	16	2	p	1	w/o/m	24510.1	-1698.3	800	Saskatchewan
2	29	1	17	2	c	8	w	23947.6	-1659.6	782	Saskatchewan
1	35	1	18	2	p	1	w	24338.5	-1693.5	787	Saskatchewan
13	6	1	19	2	c	4	w	24236.4	-1636.2	834	Saskatchewan
15	10	1	20	2	p	3	w/m	23699.2	-1610.5	805	Saskatchewan
3	16	1	20	2	p	1	w	24082.7	-1612.1	843	Saskatchewan
4	30	1	23	2	c	2	w	22494.8	-1465.2	828	Saskatchewan
1	15	1	25	2	c	8	w	22826.5	-1430.1	897	Saskatchewan
11	30	1	27	2	c	1	w	21797.8	-1352.2	870	Saskatchewan
4	31	1	27	2	c	3	w	21684	-1346.3	864	Saskatchewan
11	15	1	28	2	c	9	w	21890.9	-1337.5	894	Saskatchewan
9	34	2	15	2	p	4	w	23109.8	-1603.6	752	Saskatchewan
6	13	2	19	2	p	8	w	23924.8	-1649.9	789	Saskatchewan
10	26	2	19	2	p	9	o	23089.2	-1587.7	766	Saskatchewan
1	35	2	19	2	pr	2	w	23359.4	-1617.3	764	Saskatchewan
12	21	2	29	2	c	4	w	21166.9	-1276.5	881	Saskatchewan
13	18	3	14	2	p	2	w	22625.8	-1560.3	746	Saskatchewan
7	7	3	17	2	p	1	w/m	23349	-1618.5	762	Saskatchewan
9	36	3	17	2	p	7	w	21797.8	-1458.5	763	Saskatchewan
9	9	3	18	2	c	2	w	21977.7	-1490.5	750	Saskatchewan
7	12	3	19	2	p	4	w/wc	23028.5	-1588.6	759	Saskatchewan
15	12	3	21	2	c	18	w	22617.6	-1486.8	819	Saskatchewan
12	3	3	25	2	p	1	w	21680.6	-1320.7	889	Saskatchewan
1	28	3	26	2	p	5	w	21481.3	-1344.5	845	Saskatchewan
9	5	3	28	2	p	4	w	22152.9	-1394.5	864	Saskatchewan
8	36	3	29	2	p	3	w	21697.8	-1327.4	884	Saskatchewan
11	30	4	16	2	c	1	w	20993.8	-1389	751	Saskatchewan
14	2	4	17	2	c	2	w	21587.5	-1450.2	750	Saskatchewan
14	8	4	19	2	p	3	w	22008.1	-1485.9	758	Saskatchewan
12	20	4	21	2	p	1	w	21296.5	-1323.7	847	Saskatchewan
4	21	4	26	2	w	6	w	20362.3	-1258.8	817	Saskatchewan
9	21	4	28	2	c	5	w	20684.3	-1226.2	882	Saskatchewan
10	18	5	19	2	c	2	w/m	21075.2	-1407	741	Saskatchewan
12	33	5	23	2	p	2	w	20058.9	-1235.7	809	Saskatchewan

L	S	Tp	R	M	QC	DST	Rec	Pressure	Z	Head	Unit
3	26	6	16	2	p	1	w	19278.9	-1241	724	Saskatchewan
1	1	6	19	2	c	2	w	19956.9	-1285.3	749	Saskatchewan
7	14	6	19	2	p	1	w	19923.1	-1294.5	736	Saskatchewan
14	16	6	19	2	c	1	w	19991.2	-1277.8	760	Saskatchewan
8	29	6	20	2	p	1	w	20187.2	-1305.2	753	Saskatchewan
9	6	6	21	2	w	3	w	20239.6	-1257.9	805	Saskatchewan
8	10	6	22	2	p	1	w	20252	-1260.3	804	Saskatchewan
16	10	7	15	2	c	4	w	18952.3	-1199.1	733	Saskatchewan
15	29	7	15	2	p	6	w	20181.6	-1337.2	720	Saskatchewan
9	36	7	18	2	p	4	w	20185.1	-1319.2	738	Saskatchewan
16	25	7	21	2	p	1	w	19257.1	-1190.5	773	Saskatchewan
10	27	7	21	2	p	3	w	21477.2	-1382.9	806	Saskatchewan
8	29	7	25	2	c	2	w	20385	-1264.7	813	Saskatchewan
9	9	7	28	2	c	1	w	19925.8	-1138.4	893	Saskatchewan
9	26	8	18	2	p	2	w	18967.5	-1188.1	745	Saskatchewan
2	30	8	19	2	p	1	w	19206.7	-1207	751	Saskatchewan
6	5	8	22	2	p	2	w	19335.7	-1151.5	820	Saskatchewan
14	27	8	26	2	w	4	w	18960.6	-1115.9	817	Saskatchewan
11	18	9	16	2	p	1	w	18402	-1146.4	729	Saskatchewan
8	17	9	20	2	p	2	w/m	18784.8	-1164.9	750	Saskatchewan
6	15	9	22	2	c	4	w	19934.8	-1275.9	756	Saskatchewan
6	2	9	23	2	w	29	w	19594.2	-1199.7	798	Saskatchewan
14	12	9	28	2	p	2	w	19339.8	-1151.5	820	Saskatchewan
5	19	10	21	2	c	6	w	18403.5	-1085.1	791	Saskatchewan
10	34	10	23	2	p	2	m/w	18100.8	-1065.3	780	Saskatchewan
13	13	10	26	2	w	3	w	18286.3	-1038.1	826	Saskatchewan
13	27	11	28	2	c	2	w	17364.4	-922.6	847	Saskatchewan
16	6	12	20	2	p	2	w	17304.5	-1010.1	754	Saskatchewan
15	20	12	22	2	w	7	w	18593.1	-1110.7	785	Saskatchewan
11	9	12	24	2	c	5	w	17236.9	-970.8	786	Saskatchewan
6	24	12	26	2	p	1	w	17099	-948.2	795	Saskatchewan
13	14	13	20	2	p	3	w	16119.9	-905	738	Saskatchewan
4	2	14	21	2	p	1	w	16305.4	-918.1	744	Saskatchewan
13	16	14	23	2	p	1	w	16271.6	-893.4	765	Saskatchewan
14	19	15	25	2	p	1	w	15892.4	-854.4	766	Saskatchewan
8	4	15	28	2	w	2	w	15746.2	-855	750	Saskatchewan
16	22	18	24	2	p	3	w	13182.8	-588.6	755	Saskatchewan
1	29	19	16	2	c	2	w	10332.5	-417.3	636	Saskatchewan
14	9	20	18	2	w	3	w	10677.2	-410.6	678	Saskatchewan
11	29	20	23	2	w	3	w	11583.2	-478.8	702	Saskatchewan
16	10	21	25	2	c	8	w	12238.6	-517.2	730	Saskatchewan
1	14	1	17	2	p	1	w	29206.2	-2103.4	874	Winnipegosis

L	S	Tp	R	M	QC	DST	Rec	Pressure	Z	Head	Unit
10	26	2	19	2	p	13	w	27551.4	-1976	833	Winnipegosis
12	21	2	29	2	c	9	wc/w	24083.4	-1593.2	862	Winnipegosis
11	2	3	21	2	c	2	w	26664.1	-1843.4	875	Winnipegosis
8	23	3	24	2	c	8	w/wc	26085.6	-1768.8	890	Winnipegosis
8	36	3	29	2	c	6	w/wc	24144.1	-1563.6	898	Winnipegosis
3	26	4	20	2	c	5	w	25633.3	-1794.4	819	Winnipegosis
16	10	7	15	2	w	5	w/wc	24012.4	-1675.5	772	Winnipegosis
7	36	7	21	2	c	2	w	23518	-1600.8	797	Winnipegosis
5	23	7	27	2	p	2	w/wc	22663.1	-1478.9	831	Winnipegosis
9	9	7	28	2	w	2	w	22476.9	-1476.8	814	Winnipegosis
6	15	9	22	2	c	6	w	22980.2	-1542.6	800	Winnipegosis
13	14	13	20	2	p	8	w	20522.2	-1321	771	Winnipegosis
16	26	13	27	2	w	1	w	20084.4	-1257	790	Winnipegosis
13	16	14	23	2	p	5	w	20070.6	-1258.8	787	Winnipegosis
8	4	15	28	2	w	5	w	19305.3	-1210.1	758	Winnipegosis
9	27	16	20	2	p	4	w	18508.5	-1152.4	734	Winnipegosis
10	14	17	18	2	c	1	w	17758.8	-1109.8	700	Winnipegosis
16	9	17	20	2	w	1	w	18595.8	-1140	756	Winnipegosis
6	29	18	16	2	p	1	w	16581.9	-1067.4	623	Winnipegosis
16	22	18	24	2	w	2	w	18318	-1100.7	767	Winnipegosis
1	14	1	17	2	p	3	w/wc	30125.9	-2167.1	904	Bighorn
1	31	1	20	2	p	16	wc/w	28599.4	-2014.4	901	Bighorn
6	13	2	19	2	p	12	w/wc	28440.9	-2040	859	Bighorn
12	21	2	29	2	c	10	w/wc	24373	-1609.6	875	Bighorn
12	3	3	25	2	p	2	w	25531.3	-1752.6	850	Bighorn
1	28	3	26	2	p	8	w	25241.7	-1715.1	858	Bighorn
9	5	3	28	2	p	5	w	25135.5	-1690.7	872	Bighorn
3	26	4	20	2	p	6	w	26176.6	-1850.1	818	Bighorn
7	13	5	30	2	p	1	w	23242.2	-1513.3	856	Bighorn
11	34	7	25	2	c	2	w/wc	23902.7	-1578.5	858	Bighorn
6	15	9	22	2	c	5	w	23346.3	-1575.5	804	Bighorn
13	14	13	20	2	c	3	w	21001.4	-1384.1	757	Bighorn
13	12	14	24	2	w	1	w	20202.4	-1279.9	780	Bighorn
8	17	23	20	2	p	2	w	15893	-989.1	631	Bighorn
13	23	1	17	2	c	2	w/o	31793.1	-2377.4	863	Bighorn
16	36	1	18	2	c	5	wc/w	31601.5	-2332.9	888	Bighorn
6	3	1	19	2	w	2	w	31462.2	-2348.8	858	Bighorn
4	30	1	23	2	c	7	w	28683.6	-2046.1	878	Bighorn
1	30	2	18	2	w	2	w/m	30845.1	-2257.7	887	Bighorn
10	26	2	19	2	p	15	w	30734.1	-2269.8	863	Bighorn
11	2	3	21	2	c	4	w	29318.6	-2104.6	884	Bighorn
8	23	3	24	2	p	14	w	28409.8	-2001.6	894	Bighorn

L	S	Tp	R	M	QC	DST	Rec	Pressure	Z	Head	Unit
6	8	4	21	2	c	2	wc/w	29328.2	-2089.4	900	Bighorn
15	16	4	23	2	c	2	w/m	28409.3	-1986.8	909	Bighorn
12	33	5	23	2	p	5	w	27205.3	-1926.6	847	Bighorn
5	31	7	15	2	p	6	w	26348.3	-1925.7	760	Bighorn
7	36	[illegible]	21	2	c	4	w/m	26841.3	-1914.4	822	Bighorn
8	29	7	25	2	c	8	wc/w	25205	-1738.6	831	Bighorn
2	30	8	19	2	c	3	o/w/m	25572.7	-1823.6	783	Bighorn
9	28	8	21	2	w	17	w	25525.1	-1813.3	789	Bighorn
6	5	8	22	2	c	4	w	25834.7	-1817.5	816	Bighorn
4	3	8	23	2	c	3	w/wc	25639.5	-1802.9	811	Bighorn
14	12	9	28	2	c	1	w	23877.2	-1611.5	822	Bighorn
10	34	10	23	2	p	6	w/wc	24969.4	-1731	814	Bighorn
6	24	12	26	2	w	3	w/m	22943	-1538.3	800	Bighorn
1	9	21	16	2	w	7	w	17769.2	-1180.8	631	Bighorn
5	30	23	1	3	w	3	w	19028.1	-1233.2	706	Bighorn
13	16	14	23	2	w	10	w	22317.6	-1494.4	781	Bighorn
13	4	6	18	2	c	7	w/m	27601.8	-2009.9	804	Bighorn
2	22	2	16	2	w	1	w	31682.1	-2347	883	Bighorn
4	31	1	27	2	w	6	w	24869.4	-1669.4	866	Bighorn
14	2	4	17	2	w	4	wc/m	29173.1	-2109.8	864	Bighorn
8	2	12	27	2	p	2	w	17169.3	-956.8	793	Bighorn
8	36	3	29	2	c	9	w/wc	25241.7	-1702.3	871	Bighorn
2	11	15	26	2	p	3	w	21022.1	-1369.8	773	Bighorn
8	2	6	16	2	c	5	w/m	27868.7	-2057	784	Bighorn
2	4	22	15	2	p	2	w	17244.5	-1150.6	607	Bighorn
[illegible]	25	23	16	2	p	2	w	16299.9	-1081.7	580	Bighorn
6	3	1	19	2	c	3	w/wc	32598.4	-2435.7	887	Basal Clastic
11	30	1	27	2	p	2	w/m	28039	-1908.3	950	Basal Clastic
6	13	2	19	2	c	23	w/wc	31813.8	-2359.5	883	Basal Clastic
8	23	3	24	2	c	15	w	29237.2	-2059.5	921	Basal Clastic
8	36	3	29	2	c	12	w/wc	26751	-1823	904	Basal Clastic
14	2	4	17	2	w	6	wc/w	31557.3	-2313.1	904	Basal Clastic
12	20	4	21	2	p	3	w/wc	28992.4	-2080	875	Basal Clastic
9	35	5	17	2	p	3	w	29104.1	-2142.4	824	Basal Clastic
12	33	5	23	2	p	6	w	27596.3	-1966.9	846	Basal Clastic
10	27	7	21	2	c	8	w	27083.3	-1905.3	855	Basal Clastic
8	29	7	25	2	p	3	w	26062	-1796.2	860	Basal Clastic
9	9	7	28	2	w	5	w	25510.6	-1714.5	886	Basal Clastic
13	13	10	26	2	w	12	w/wc	25338.2	-1713.9	869	Basal Clastic
6	24	12	26	2	pr	2	w/m	23493.9	-1594.7	800	Basal Clastic
8	2	12	27	2	p	4	w	23576.6	-1600.2	803	Basal Clastic
16	26	13	27	2	pr	2	w	22891.3	-1516.4	817	Basal Clastic

L	S	Tp	R	M	QC	DST	Rec	Pressure	Z	Head	Unit
4	2	14	21	2	w	4	w	23725.7	-1649	770	Basal Clastic
3	8	17	19	2	p		w	21557	-1488	709	Basal Clastic
12	6	19	1	3	p	2	w	20098.2	-1398.4	650	Basal Clastic
1	3	19	26	2	cr	1	w	20995.9	-1390.5	750	Basal Clastic
4	12	19	27	2	w	2	w	21105.6	-1386.5	765	Basal Clastic
9	32	20	27	2	pr	2	w	19792.8	-1308.8	709	Basal Clastic
1	9	21	16	2	w	11	w	18359.4	-1251.8	620	Basal Clastic
1	25	23	16	2	p	1	w	16850.8	-1146.7	571	Basal Clastic
8	17	23	20	2	w	3	w/m	18347.6	-1225.6	645	Basal Clastic
14	12	23	26	2	w	6	w	18705.5	-1231.1	676	Basal Clastic

Appendix 2

Chemical Data

L	S	Tp	R	M	Source	yr	pH	QC	TDS	rNa+K	rCl	Na:Cl	Group	Unit
3	3	1	16	2	dst2b	68	8	p	8549	130.3	97.7	1.33	I	Viking
15	24	3	22	2	dst1	54	7	c	7535	125.5	116.2	1.08	I	Viking
13	32	5	17	2	dst2	56	8	c	7760	122.0	108.0	1.13	I	Viking
10	34	5	20	2	dst[illegible]b	52	[illegible]	p	6382	107.[illegible]	94.3	1.14	I	Viking
6	2	7	16	2	dst1	54	7.5	p	[illegible]	145.0	129.7	1.12	I	Viking
9	28	8	21	2	dst1	53	7	c	[illegible]	[illegible]	113.1	1.08	I	Viking
1	11	12	18	2	dst1m	55	8	c	6705	111.0	101.5	1.09	I	Viking
15	15	1	15	2	dst2	53	8.1	p	7185	120.0	104.[illegible]	1.15	I	Mannville
3	3	1	16	2	dst1m	67	7.9	c	8891	139.5	118.3	1.18	I	Mannville
8	30	1	17	2	dst3	66	8.4	w	6755	103.8	79.9	1.30	I	Mannville
6	10	3	17	2	dst4	53	7.5	p	7560	127.7	110.0	1.16	I	Mannville
5	18	3	23	2	dst1	54	7.5	p	3841	65.1	42.6	1.53	I	Mannville
9	27	5	15	2	dst3	86	7.8	w	10421	165.2	138.9	1.19	I	Mannville
10	34	5	20	2	dst3m	52	8.2	c	6264	83.0	64.3	1.29	I	Mannville
14	29	7	29	2	dst1	54	7.5	p	3421	58.3	43.7	1.33	I	Mannville
9	28	8	21	2	dst3	53	7	c	6088	102.2	87.8	1.16	I	Mannville
11	10	8	28	2	dst1	54	7.5	p	5131	85.3	76.1	1.12	I	Mannville
11	7	11	21	2	dst1	59	7.6	p	16583	252.3	211.5	1.19	I	Mannville
14	11	11	29	2	dst3	54	7.5	c	5963	89.9	45.1	1.99	I	Mannville
10	33	12	29	2	dst1	54	7.5	p	6592	111.5	99.8	1.12	I	Mannville
14	11	14	24	2	dst1	54	7	p	9931	163.7	159.6	1.03	I	Mannville
14	6	17	22	2	dst1m	51	8.2	c	22999	317.0	291.0	1.09	I	Mannville
15	12	20	23	2	wh	53	6	c	20980	294.3	264.4	1.11	I	Mannville
16	10	21	25	2	wh	62	7.9	c	11437	181.5	171.0	1.06	I	Mannville
12	30	1	15	2	dst4	53	7	p	49002	723.8	781.0	0.93	II	M. Jurassic
1	31	1	20	2	dst1	57	7.2	w	30164	425.3	405.4	1.05	I	M. Jurassic
5	28	3	23	2	dst2	54	7.8	p	16177	246.1	209.5	1.17	I	M. Jurassic
13	32	5	17	2	dst3	56	7.4	c	21323	327.0	285.0	1.15	I	M. Jurassic
10	11	5	25	2	dst2	54	7	c	15524	242.8	209.0	1.16	I	M. Jurassic
9	28	8	21	2	dst4	53	7.5	c	10507	159.3	90.4	1.76	I	M. Jurassic
11	10	8	28	2	dst4	54	7.5	p	8573	126.6	55.3	2.29	I	M. Jurassic
14	32	10	19	2	dst2t	55	6.8	c	19276	248.4	32.0	7.76	I	M. Jurassic
5	19	10	21	2	dst1b	55	7	p	16710	214.2	18.9	11.34	I	M. Jurassic
1	11	12	18	2	dst2	55	7	c	13494	191.9	67.0	2.86	I	M. Jurassic
11	9	12	24	2	dst1	54	7	p	5097	73.3	12.4	5.90	I	M. Jurassic
4	29	13	17	2	dst2	54	8	c	24495	353.8	334.5	1.06	I	M. Jurassic
9	20	13	19	2	dst	55	6	p	32608	424.1	419.5	1.01	I	M. Jurassic
2	11	14	28	2	dst7	54	6.5	c	10378	114.5	21.2	5.42	I	M. Jurassic
16	10	21	25	2	dst4b	62	8.1	c	14832	215.8	132.2	1.63	I	M. Jurassic
13	3	1	15	2	dst1	66	6.5	p	238054	3793.9	4027.0	0.94	II	Madison
15	15	1	15	2	dst6	53	6.5	c	178368					Madison
13	26	1	15	2	dst3	63	7.4	c	156305					Madison
9	27	1	15	2	dst5	64	6.7	p	160152	2446.0	2588.0	0.95	II	Madison
5	30	1	15	2	perf	52	6.8	c	159060					Madison
12	30	1	15	2	dst17	53	6.6	p	152799	2229.8	2329.2	0.96	II	Madison

L	S	Tp	R	M	Source	yr	pH	QC	TDS	rNa+K	rCl	Na:Cl	Group	Unit
9	31	1	15	2	dst3	84	6.3	p	140731	2150.4	2361.8	0.91	II	Madison
3	36	1	15	2	dst1	66	6.6	p	273201	4443.0	4649.8	0.96	II	Madison
16	5	1	16	2	wh	72	5.9	c	265010					Madison
4	9	1	16	2	dst3	65	6.6	c	186619					Madison
8	9	1	16	2	dst2b	81	6.9	c	121587					Madison
16	23	1	16	2	dst2	66	6.6	p	152652	2392.8	2511.9	0.95	II	Madison
14	29	1	17	2	dst2m	69	6.9	c	147199					Madison
2	31	1	17	2	dst2	65	6.9	c	152153	2342.2	2409.9	0.97	II	Madison
6	7	1	19	2	perf	85	7.2	c	126270	2035.2	2072.7	0.98	II	Madison
15	10	1	20	2	dst4b	85	8.3	p	62400	1010.8	811.0	1.25	II	Madison
4	11	1	20	2	dst4	65	7.8	c	100067	1478.3	1485.9	0.99	II	Madison
1	31	1	20	2	dst4	57	6.8	w	44213					Madison
1	15	1	25	2	dst2	55	5.5	p	3512	23.9	12.1	1.97	I	Madison
4	31	1	27	2	dst1	58	6.8	p	4718	2.5	21.2	0.12	I	Madison
11	15	1	28	2	dst2	55	6	p	4730	44.2	10.3	4.29	I	Madison
15	22	2	15	2	dst1	84	6.4	p	149400	1842.2	2740.0	0.67	II	Madison
5	30	2	15	2	dst6	55	6	c	167936					Madison
5	33	2	15	2	dst3	60	6.3	c	271836					Madison
7	2	2	17	2	perf	84	6.8	w	133512	1962.0	2287.0	0.86	II	Madison
8	22	2	17	2	dst5	56	8	w	151576	2762.0	2793.0	0.99	II	Madison
3	12	2	19	2	perf1	69	6.6	c	128663					Madison
15	23	2	19	2	swab	67	6.6	w	116276					Madison
13	26	2	19	2	dst2b	67	7	p	100920	1610.7	1508.7	1.07	I	Madison
11	9	2	20	2	dst2b	67	7.1	c	52788					Madison
4	32	2	20	2	dst1b	78	7.7	c	14890	209.4	206.8	1.01	I	Madison
7	14	2	21	2	dst1b	69	7.2	c	40949	611.5	467.4	1.31	I	Madison
14	15	2	23	2	dst3m	55	6.8	p	11683	139.5	135.4	1.03	I	Madison
12	21	2	29	2	dst1	58	6.7	p	3713	18.7	8.3	2.25	I	Madison
14	7	3	15	2	dst1m	85	7.2	c	199800	3367.1	3228.9	1.04	II	Madison
7	18	3	15	2	dhs	83	6.7	c	218661					Madison
7	21	3	16	2	dst1dhs	81	7.3	c	154972					Madison
7	34	3	16	2	dst2m	67	7.2	p	171715	2778.9	2841.7	0.98	II	Madison
6	10	3	17	2	dst5	53	7	c	100379	1568.0	1463.6	1.07	I	Madison
4	20	3	17	2	dst1	68	6.8	p	103352	1637.3	1593.4	1.03	I	Madison
1	15	3	19	2	swab	67	6.5	c	68565	1054.7	991.7	1.06	I	Madison
9	20	3	19	2	dst4	55	6	c	29377					Madison
15	12	3	21	2	dst7m	51	7.6	c	15626	197.6	154.5	1.28	I	Madison
3	24	3	21	2	dst1b	68	7.2	p	13104	165.0	124.1	1.33	I	Madison
9	22	3	22	2	dst2b	68	8.2	w	14063					Madison
15	24	3	22	2	dst5	54	6.5	w	15973	188.0	186.1	1.01	I	Madison
5	18	3	23	2	dst5	54	7.5	p	13635	157.1	156.5	1.00	I	Madison
16	10	3	25	2	dst7b	52	5.5	p	16717	240.2	278.0	0.86	I	Madison
9	5	3	28	2	dst1	68	7.7	p	4428					Madison
2	3	4	15	2	dst1	86	6.5	p	161396	2535.1	2538.0	1.00	II	Madison
14	30	4	16	2	dst2m	55	6.8	p	18517	235.6	208.0	1.13	I	Madison

L	S	Tp	R	M	Source	yr	pH	QC	TDS	rNa+K	rCl	Na:Cl	Group	Unit
7	18	4	17	2	dst1b	68	7.1	w	57840					Madison
7	19	4	17	2	dst2b	85	7	p	24372	348.9	317.6	1.10	I	Madison
3	21	4	18	2	perf	84	7.3	w	72155					Madison
13	21	4	18	2	perf	85	7.4	w	70367					Madison
15	21	4	18	2	perf	85	7.4	w	73400	1087.0	1019.0	1.07	I	Madison
11	22	4	18	2	wh	85	7.7	w	81660					Madison
7	24	4	18	2	batt	85	7.5	w	91289					Madison
9	28	4	18	2	perf	85	7.3	c	60003					Madison
5	29	4	18	2	perf	85	7.5	c	53524	832.0	698.0	1.19	I	Madison
15	29	4	18	2	perf	85	7.6	c	59178					Madison
1	31	4	18	2	wh	67	7.6	c	47694					Madison
11	32	4	18	2	wh	84	7.7	w	47582					Madison
3	26	4	20	2	dst2	59	7	c	19991	253.0	240.0	1.05	I	Madison
12	20	4	21	2	dst4b	76	8.6	c	14883	199.3	233.1	0.85	I	Madison
6	29	4	21	2	dst3	54	6.5	w	14749	162.3	139.4	1.16	I	Madison
9	18	4	22	2	dst3m	55	6.8	c	14636					Madison
4	21	4	26	2	dst1	54	6.5	p	4952					Madison
9	21	4	28	2	dst1	55	6.8	p	3877	22.9	5.9	3.90	I	Madison
5	7	4	29	2	dst1	53	7	p	3372	16.4	3.9	4.22	I	Madison
5	13	5	15	2	dst1b	83	7.7	c	53923					Madison
5	15	5	15	2	dst1	83	7.5	w	68708	1042.8	975.7	1.07	I	Madison
11	16	5	15	2	dhs	85	7.1	w	72562					Madison
5	24	5	15	2	dhs	84	7.3	w	49987					Madison
4	25	5	15	2	swab39	88	7.5	w	35440					Madison
8	26	5	15	2	dst1	88	7.2	c	36875	523.4	455.7	1.15	I	Madison
13	27	5	15	2	dst2	85	7.3	c	31460					Madison
15	28	5	15	2	dst2	83	7.6	c	34500					Madison
16	28	5	15	2	swab8	85	7.7	w	28526					Madison
9	30	5	15	2	dst1	83	8	w	26367					Madison
9	32	5	15	2	dst1b	82	7.8	w	36863	529.1	447.6	1.18	I	Madison
7	33	5	15	2	dst1b	83	7.8	w	28913					Madison
13	33	5	15	2	swab19	83	7.7	w	34000					Madison
9	34	5	15	2	dst1b	83	7.2	c	25551					Madison
2	35	5	15	2	dst4	57	7.9	w	28743					Madison
5	36	5	15	2	dst1b	83	7.7	c	28221	378.5	389.2	0.97	I	Madison
3	14	5	16	2	dst2b	83	8.1	c	38600					Madison
14	23	5	16	2	dst4b	84	6.7	c	30620					Madison
1	27	5	16	2	perf	83	7.6	c	26983					Madison
7	27	5	16	2	dst1t	83	7.7	c	26900					Madison
10	27	5	16	2	dst1dhs	83	7.4	c	26048					Madison
16	28	5	16	2	dst3b	84	7.5	p	23975	254.4	309.4	0.82	I	Madison
13	33	5	16	2	swab	84	7.9	w	26600					Madison
15	35	5	16	2	dst2b	83	7.9	p	26300	364.0	346.0	1.05	I	Madison
2	36	5	16	2	dst1	84	7.3	c	26841					Madison
13	32	5	17	2	dst9	56	7.2	c	22678					Madison

L	S	Tp	R	M	Source	yr	pH	QC	TDS	rNa+K	rCl	Na:Cl	Group	Unit
1	33	5	17	2	dst4b	87	6.8	c	25775					Madison
15	36	5	17	2	dst2b	84	7.6	c	22721	303.9	297.5	1.02	I	Madison
3	6	5	18	2	perf	85	6.3	c	31593	533.0	432.0	1.23	I	Madison
1	1	5	19	2	perf1	67	6.3	c	43983					Madison
3	1	5	19	2	perf	83	7.4	w	22893					Madison
7	1	5	19	2	dst4	60	7.5	p	24671	343.0	282.0	1.22	I	Madison
16	35	5	19	2	dst1b	69	8.4	w	24614					Madison
2	29	5	20	2	dhs	84	7.3	w	10600					Madison
10	34	5	20	2	dst6m	52	7.7	c	10172	33.6	33.0	1.02	I	Madison
5	28	5	21	2	dst2	53	7	p	14620	167.8	169.2	0.99	I	Madison
10	11	5	25	2	dst4	54	7	c	10973	107.7	99.8	1.08	I	Madison
11	19	5	28	2	dst3	51	7.8	c	2691	4.6	6.3	0.73	I	Madison
15	1	6	15	2	dst1b	85	7.1	p	55529	761.5	815.0	0.93	I	Madison
1	2	6	15	2	dst1b	68	7.5	c	30900					Madison
7	6	6	15	2	dst1b	79	7.5	p	28438	392.8	386.0	1.02	I	Madison
5	7	6	15	2	perf	84	7.1	c	30823					Madison
9	7	6	15	2	perf	84	7.6	c	40789					Madison
11	7	6	15	2	perf3	84	7.1	c	29963					Madison
3	8	6	15	2	perf	79	7.3	c	29362					Madison
7	8	6	15	2	dst1b	79	7.6	c	20111					Madison
13	8	6	15	2	dst1m	79	7.5	c	25256					Madison
15	8	6	15	2	wh	79	7.1	c	28080					Madison
6	10	6	15	2	perf1	85	7.5	c	39960					Madison
15	11	6	15	2	dst1m	85	7.9	c	54429					Madison
15	12	6	15	2	perf1	85	7.6	c	39059					Madison
11	12	6	15	2	dhs	85	7.6	c	50494	722.9	738.8	0.98	I	Madison
1	13	6	15	2	dst1b	85	6.9	c	33818	454.4	463.9	0.98	I	Madison
9	13	6	15	2	wh	86	7.1	c	35407					Madison
5	17	6	15	2	swab4	80	7	w	28413					Madison
5	24	6	15	2	dst1	85	7.6	c	30600					Madison
11	25	6	15	2	dst1	84	7.6	c	51486					Madison
10	32	6	15	2	dst7m	55	8	w	44402	637.4	623.9	1.02	I	Madison
7	33	6	15	2	dst1m	87	8.5	w	32360					Madison
9	1	6	16	2	dst1b	79	7.2	p	22700	322.3	324.5	0.99	I	Madison
8	2	6	16	2	dst4b	78	7.4	p	24775					Madison
7	3	6	16	2	dst1b	79	7.6	c	27773					Madison
3	6	6	16	2	swab	85	6.8	c	22527					Madison
11	6	6	16	2	wh	85	6.8	c	24326					Madison
13	8	6	16	2	dst1b	59	6.8	c	23694					Madison
3	12	6	16	2	perf2	83	7.5	c	28700					Madison
7	13	6	16	2	dst2	79	8.2	c	30930					Madison
11	13	6	16	2	dst4b	80	7.8	c	33383	406.4	444.2	0.92	I	Madison
11	15	6	16	2	dst1m	79	7.7	p	28762	344.6	414.5	0.83	I	Madison
9	17	6	16	2	dst1b	84	7.2	c	24000					Madison
8	21	6	16	2	dst1m	80	7.7	c	31330					Madison

L	S	Tp	R	M	Source	yr	pH	QC	TDS	rNa+K	rCl	Na:Cl	Group	Unit
13	21	6	16	2	perf	84	7	c	33153					Madison
9	23	6	16	2	dst1b	84	8.1	c	27560					Madison
11	23	6	16	2	wh	84	7.8	w	28759					Madison
7	26	6	16	2	perf	85	6.4	c	33265					Madison
9	26	6	16	2	wh	84	6.9	c	27942					Madison
1	11	6	17	2	dst2b	84	7.4	c	21700					Madison
7	21	6	17	2	dhs	85	7.6	w	24022	364.0	334.0	1.09	I	Madison
13	4	6	18	2	dst1b	68	7.3	c	22229					Madison
5	7	6	18	2	dst2b	87	7.8	c	23880	303.1	306.3	0.99	I	Madison
13	7	6	18	2	swab	85	7.4	c	19125					Madison
12	7	6	18	2	perf	84	7.7	w	22184					Madison
15	10	6	19	2	wh	68	7.3	w	20569					Madison
9	12	6	19	2	perf	85	6.9	c	22585					Madison
13	16	6	19	2	dst2b	85	7.4	p	22204	295.4	265.1	1.11	I	Madison
14	16	6	19	2	dst4b	84	7.6	c	21670					Madison
1	20	6	19	2	dst1b	68	7	c	19692					Madison
9	6	6	21	2	dst1	69	8	c	11100	117.9	97.0	1.22	I	Madison
5	4	6	24	2	dst2b	56	6.8	p	6867	61.0	47.9	1.27	I	Madison
16	11	6	25	2	dst3	52	7.9	c	8843					Madison
14	9	7	15	2	dst1	57	8.5	w	29425					Madison
7	29	7	15	2	dhs	85	7.9	c	30779					Madison
5	31	7	15	2	dst8b	76	7.2	w	31935					Madison
3	32	7	15	2	dst1b	68	7	p	31075	430.4	416.2	1.03	I	Madison
6	2	7	16	2	dst2	54	7	p	28199	370.9	361.0	1.03	I	Madison
14	2	7	16	2	dst1	84	7.1	p	24882	345.4	335.4	1.03	I	Madison
9	13	7	16	2	dst1b	84	7.7	w	25379					Madison
13	16	7	18	2	dst1b	86	6.9	p	26116	369.8	363.1	1.02	I	Madison
14	22	7	18	2	dst1	57	6.8	p	31260					Madison
9	36	7	18	2	dst1	67	7.6	w	34275					Madison
6	2	7	20	2	dst2	85	7.2	c	12033	146.9	97.1	1.51	I	Madison
4	27	7	20	2	dst2b	85	8.1	c	10749	127.9	74.0	1.73	I	Madison
10	27	7	21	2	dst1	59	7.8	c	7869	79.8	60.6	1.32	I	Madison
7	36	7	21	2	wh	76	7.8	w	8567					Madison
16	5	7	24	2	dst3	53	7.7	p	10364					Madison
4	12	7	24	2	dst1b	67	7.4	c	9492	88.8	51.9	1.71	I	Madison
8	29	7	25	2	dst1b	81	7.5	p	15284	175.6	172.5	1.02	I	Madison
6	14	7	26	2	dst2b	55	6.4	p	5082	34.0	19.2	1.77	I	Madison
14	29	7	29	2	dst3	54	6	p	4941	34.6	18.5	1.88	I	Madison
2	1	8	15	2	swab3	85	6.6	c	41652	559.7	595.0	0.94	I	Madison
15	4	8	15	2	dst1	57	7.8	w	33028	451.0	404.0	1.12	I	Madison
8	4	8	16	2	dst1b	86	8.1	c	33110	463.0	458.0	1.01	I	Madison
7	16	8	16	2	dst1m	70	7.1	w	26567	365.0	372.0	0.98	I	Madison
13	22	8	16	2	dst1m	61	7.7	w	25026					Madison
11	23	8	21	2	dst1b	63	7.2	w	10670	130.5	79.5	1.64	I	Madison
9	28	8	21	2	dst6	53	7	c	8911					Madison

L	S	Tp	R	M	Source	yr	pH	QC	TDS	rNa+K	rCl	Na:Cl	Group	Unit
14	27	8	26	2	dst1b	56	6.2	p	4428	31.8	13.8	2.30	I	Madison
11	10	8	28	2	dst7	54	6.5	p	4747	37.7	23.0	1.64	I	Madison
16	26	9	16	2	dst1b	69	7.5	c	31880	451.5	432.1	1.04	I	Madison
6	15	9	22	2	dst3m	59	6.8	w	5544	31.6	22.1	1.43	I	Madison
6	2	9	23	2	dst22	51	7.2	c	5033	41.1	19.5	2.11	I	Madison
14	32	10	19	2	dst3t	55	6.8	c	25941	332.5	331.4	1.00	I	Madison
5	19	10	21	2	dst3	55	6	w	11864	138.5	88.8	1.56	I	Madison
3	18	10	25	2	dst3	54	6.5	p	4710	36.9	17.9	2.06	I	Madison
13	13	10	26	2	dst1	54	6.5	p	4266	29.0	12.4	2.34	I	Madison
4	12	11	22	2	dst7b	67	7.7	w	17235	220.6	130.2	1.69	I	Madison
13	27	11	28	2	dst1	53	6.5	p	4681	26.3	4.0	6.67	I	Madison
14	11	11	29	2	dst4	54	6.5	p	4662	29.2	4.8	6.10	I	Madison
1	11	12	18	2	dst4b	55	6.8	p	22832	289.3	275.0	1.05	I	Madison
15	7	12	21	2	dst1	54	7.8	p	35748	498.6	495.0	1.01	I	Madison
11	9	12	24	2	dst4b	54	6	p	5079	37.0	12.8	2.88	I	Madison
13	14	13	20	2	dst1	68	7.3	p	32668	452.8	406.1	1.11	I	Madison
2	11	14	28	2	dst3	54	6	p	5044	29.5	3.1	9.53	I	Madison
8	4	15	28	2	dst1	53	7	p	5105	38.5	3.1	12.43	I	Madison
11	30	16	24	2	dst1	68	7	p	8320	77.1	61.3	1.26	I	Madison
4	32	17	19	2	wh	63	7	w	41519	571.0	579.8	0.98	I	Madison
14	6	17	22	2	dst2m	55	7.9	c	28679	342.2	347.5	0.98	I	Madison
12	28	19	28	2	dst1b	54	6	c	15302	163.9	176.3	0.93	I	Madison
10	15	1	16	2	dst1dhs	84	5.5	p	294490	4315.4	5053.1	0.85	II	Birdbear
1	35	1	18	2	dst1m	67	7.6	p	297718	4497.1	5121.1	0.88	II	Birdbear
13	6	1	19	2	dst4b	63	6.4	p	220421	3021.0	3334.0	0.91	II	Birdbear
15	10	1	20	2	dst6b	85	7.3	p	176000	2533.2	3000.0	0.84	II	Birdbear
3	16	1	20	2	dst1b	68	7	p	119110	1859.1	1966.0	0.95	II	Birdbear
1	15	1	25	2	dst8	55	5.5	p	51765	756.7	757.9	1.00	I	Birdbear
4	31	1	27	2	dst3	53	6.4	p	10180	92.1	116.3	0.79	I	Birdbear
11	15	1	28	2	dst9	55	6.5	p	11929	154.1	160.7	0.96	I	Birdbear
6	13	2	19	2	dst8	57	5.5	w	269652	3541.0	3997.4	0.89	II	Birdbear
3	26	2	19	2	dst2b	66	6.2	c	224003	3489.1	3840.3	0.91	II	Birdbear
1	35	2	19	2	dst2b	67	6.5	p	242292	3743.5	4145.3	0.90	II	Birdbear
4	32	2	20	2	dst2t	78	6.4	w	60602	1074.4	1071.6	1.00	I	Birdbear
11	15	2	23	2	dst9m	55	6.4	p	50870	724.7	729.7	0.99	I	Birdbear
7	12	3	19	2	dst4	67	5.7	p	251752	3909.0	4288.9	0.91	II	Birdbear
15	12	3	21	2	dst21	51	1.77	c	66397	780.9	913.8	0.85	I	Birdbear
15	24	3	22	2	dst13	55	6.5	p	48904	720.2	715.6	1.01	I	Birdbear
9	5	3	28	2	dst7b	68	7.5	w	9413	107.0	70.1	1.53	I	Birdbear
14	8	4	19	2	dst3	68	7.4	p	34815	530.5	497.3	1.07	I	Birdbear
3	26	4	20	2	dst3	59	6.3	p	155580	2499.0	2553.0	0.98	I	Birdbear
9	18	4	22	2	dst7b	55	6	c	45812	666.9	655.7	1.02	I	Birdbear
9	21	4	28	2	dst5	55	6.6	p	3119	13.5	5.3	2.55	I	Birdbear
5	7	4	29	2	dst3	53	7	p	2705	6.0	2.5	2.37	I	Birdbear
13	32	5	17	2	dst8	56	8.1	w	101606	1466.0	1512.0	0.97	I	Birdbear

L	S	Tp	R	M	Source	yr	pH	QC	TDS	rNa+K	rCl	Na:Cl	Group	Unit
6	7	5	18	2	dst5	63	7.9	p	72638	1091.0	1121.0	0.97	I	Birdbear
5	28	5	21	2	dst4	53	7	p	30857	413.4	430.1	0.96	I	Birdbear
12	33	5	23	2	dst2b	65	7.6	p	38370	560.3	555.0	1.01	I	Birdbear
10	11	5	25	2	dst2	55	6	c	39821	559.5	583.7	0.96	I	Birdbear
3	9	6	16	2	dst1b	69	6.5	p	195055	3056.0	3334.1	0.92	I	Birdbear
5	25	6	16	2	dst1dhs	84	7.1	c	118865	1904.4	1949.7	0.98	I	Birdbear
13	4	6	18	2	dst4b	68	7.4	c	70777	1089.4	1142.0	0.95	I	Birdbear
7	14	6	19	2	dst1	73	6.6	p	135872	2215.6	2267.5	0.98	I	Birdbear
1	20	6	19	2	dst4	68	6.7	c	30548	448.9	417.4	1.08	I	Birdbear
9	6	6	21	2	dst3	69	7.3	c	25812	356.4	363.8	0.98	I	Birdbear
8	10	6	22	2	dst1b	67	7.7	p	50109	747.1	764.2	0.98	I	Birdbear
6	2	6	23	2	dst6b	53	8.1	c	32626	494.2	438.1	1.13	I	Birdbear
16	10	7	15	2	dst4	66	7.3	p	110458	1769.1	1799.2	0.98	I	Birdbear
16	25	7	21	2	dst1	68	7.7	c	13524	178.4	105.9	1.68	I	Birdbear
9	3	7	24	2	dst6	53	7.4	c	10950	120.7	90.4	1.33	I	Birdbear
6	14	7	26	2	dst6b	55	6	p	13550	153.4	174.8	0.88	I	Birdbear
9	9	7	28	2	dst1	53	6.5	p	3440	9.8	4.0	2.49	I	Birdbear
2	30	8	19	2	dst1b	70	7	c	150614	2415.6	2496.2	0.97	I	Birdbear
3	14	8	20	2	dst2	58	6	p	131397	1931.0	1974.0	0.98	I	Birdbear
9	28	8	21	2	dst9	53	6.5	c	17985	243.0	215.1	1.13	I	Birdbear
11	18	9	16	2	dst1b	68	7.1	p	145509	2350.2	2349.3	1.00	I	Birdbear
8	17	9	20	2	dst1b	68	6.9	p	64270	1003.8	1008.0	1.00	I	Birdbear
5	19	10	21	2	dst6	55	6	p	22253	287.6	286.9	1.00	I	Birdbear
3	18	10	25	2	dst5	54	6.5	p	5592	45.5	31.2	1.46	I	Birdbear
13	13	10	26	2	dst3	54	6.5	p	5071	33.7	11.1	3.02	I	Birdbear
13	27	11	28	2	dst2	53	7	c	4214	15.1	5.4	2.81	I	Birdbear
16	6	12	20	2	dst2b	68	7.4	p	40200	582.1	584.0	1.00	I	Birdbear
11	9	12	24	2	dst7b	54	6	p	11796	133.6	126.3	1.06	I	Birdbear
6	24	12	26	2	dst1b	70	7.5	p	7334	70.1	55.5	1.26	I	Birdbear
9	20	13	19	2	dst5m	55	6	p	76115	1080.0	1113.9	0.97	I	Birdbear
13	14	13	20	2	dst3m	68	7.2	c	41842	604.9	551.5	1.10	I	Birdbear
4	2	14	21	2	dst1	60	8.2	c	60842	895.0	996.0	0.90	I	Birdbear
13	16	14	23	2	dst1	58	8	p	62365	878.5	930.6	0.94	I	Birdbear
14	11	14	24	2	dst3	54	6.5	c	47836	690.3	712.1	0.97	I	Birdbear
14	6	17	22	2	dst3m	51	7.8	p	62284	795.9	924.8	0.86	I	Birdbear
14	10	17	22	2	dst5m	51	7.6	p	71041	903.0	932.2	0.97	I	Birdbear
1	29	19	16	2	dst2	54	6	p	78060	1081.3	1128.0	0.96	I	Birdbear
12	28	19	28	2	dst3	54	6	p	8684	56.3	84.6	0.67	I	Birdbear
15	12	20	23	2	dst3	53	6.5	p	24042	300.6	303.2	0.99	I	Birdbear
1	9	21	16	2	dst2	56	7	w	43547	611.7	560.5	1.09	I	Birdbear
13	5	21	23	2	dst2t	54	7	c	12541	140.5	109.3	1.29	I	Birdbear
4	29	22	18	2	dst1	54	7	p	19534	231.4	218.6	1.06	I	Birdbear
13	29	23	17	2	dst2	53	7	c	21036	282.1	242.5	1.16	I	Birdbear
8	30	23	20	2	dst1	54	6.5	p	32720	41.0	40.8	1.01	I	Birdbear
9	11	23	26	2	dst2	53	6.5	p	50151	688.1	690.9	1.00	I	Birdbear

L	S	Tp	R	M	Source	yr	pH	QC	TDS	rNa+K	rCl	Na:Cl	Group	Unit
4	30	1	23	2	dst3m	60	6.6	p	183061	2309.9	2777.7	0.83	II	Duperow
12	21	2	29	2	dst7	58	7.3	p	5849	46.0	66.0	0.70	I	Duperow
15	12	3	21	2	dst23m	51	6.3	p	348418	4048.4	4615.8	0.88	II	Duperow
8	23	3	24	2	dst6	58	6	c	151376	2145.0	2219.0	0.97	I	Duperow
12	3	3	25	2	dst1m	66	7.4	c	16981	232.0	213.2	1.09	I	Duperow
16	10	3	25	2	dst14m	44	7.3	p	64162	868.0	1006.0	0.86	I	Duperow
9	5	3	28	2	dst3b	68	7.9	c	2703	30.8	7.1	4.35	I	Duperow
12	33	5	23	2	dst3	65	7.5	c	106749	1555.0	1645.0	0.95	I	Duperow
11	19	5	28	2	dst8m	51	7.9	c	4306	18.2	17.1	1.06	I	Duperow
8	10	6	22	2	dst2b	67	7.7	p	49997	748.6	761.4	0.98	I	Duperow
9	36	7	18	2	dst4	67	6.6	p	157555	2552.2	2622.6	0.97	I	Duperow
10	27	7	21	2	dst3b	52	8.4	w	72793	1090.6	1113.9	0.98	I	Duperow
8	29	7	25	2	dst2b	81	8.1	c	21518	282.5	291.2	0.97	I	Duperow
9	28	8	21	2	dst12	53	7	c	45377	628.2	643.9	0.98	I	Duperow
6	15	9	22	2	dst4	59	6.8	c	51748	712.4	754.4	0.94	I	Duperow
6	2	9	23	2	dst40	51	7.4	c	49767	726.2	736.9	0.99	I	Duperow
3	14	10	24	2	dst2	53	8.2	c	50753	749.2	741.8	1.01	I	Duperow
13	13	10	26	2	dst7	54	6.5	p	1252	6.3	1.0	6.37	I	Duperow
13	27	11	28	2	dst3	53	6.5	p	8206	74.2	76.1	0.97	I	Duperow
15	7	12	21	2	dst3b	52	7.7	p	119010	1764.8	1805.3	0.98	I	Duperow
9	4	12	23	2	dst6b	54	6.5	p	33891	449.0	475.3	0.94	I	Duperow
6	24	12	26	2	dst4b	70	7.6	p	27709	389.2	388.8	1.00	I	Duperow
13	16	14	23	2	dst2	58	7.6	p	60091	838.3	909.5	0.92	I	Duperow
7	25	15	25	2	dst2b	70	7.3	c	22233	309.8	287.2	1.08	I	Duperow
8	4	15	28	2	dst3	53	6.5	p	6853	43.0	57.7	0.75	I	Duperow
14	6	17	22	2	dst6m	51	7.6	p	59607	750.6	793.2	0.95	I	Duperow
14	10	17	22	2	dst8m	51	7.4	w	53735	676.5	710.7	0.95	I	Duperow
4	16	18	23	2	dst4m	52	7.6	p	28069	350.5	396.6	0.88	I	Duperow
4	12	19	27	2	dst3b	67	7.9	w	160472	2682.3	2709.9	0.99	I	Duperow
1	9	21	16	2	dst4	56	6	p	244720	3960.0	3990.3	0.99	III	Duperow
16	10	21	25	2	dst8m	62	7.5	c	261570	4341.1	4351.9	1.00	III	Duperow
1	31	1	20	2	dst18	57	5.8	c	306758					Winnipegosis
4	31	1	27	2	dst5	58	6.8	p	124027	1802.7	1917.6	0.94	I	Winnipegosis
12	21	2	29	2	dst9	58	7.6	p	13206	153.3	158.8	0.97	I	Winnipegosis
11	2	3	21	2	dst2b	76	6.7	c	281670	4694.7	4769.3	0.98	III	Winnipegosis
8	23	3	24	2	dst8	58	6	c	182892	2688.7	2721.3	0.99	III	Winnipegosis
3	26	4	20	2	dst5	59	6.8	p	384763	5501.0	5576.0	0.99	III	Winnipegosis
9	35	5	17	2	dst3b	77	5.6	p	284342	4378.8	4861.9	0.90	II	Winnipegosis
15	12	5	21	2	dst36m	51	6.1	p	298373	3712.5	3855.9	0.96	II	Winnipegosis
16	10	7	15	2	dst5	66	6.4	p	324334	5327.5	5544.1	0.96	II	Winnipegosis
10	27	7	21	2	dst4b	59	7.1	c	291510	4167.0	4230.0	0.99	III	Winnipegosis
5	23	7	27	2	dst2	69	7	c	28066	384.1	413.7	0.93	I	Winnipegosis
9	9	7	28	2	dst2m	53	6.5	p	19932	245.7	267.9	0.92	I	Winnipegosis
9	28	8	21	2	dst13	53	5.5	p	247774	3588.7	3617.1	0.99	III	Winnipegosis
6	15	9	22	2	dst6	59	4.5	c	213109	3094.3	3137.3	0.99	III	Winnipegosis

L	S	Tp	R	M	Source	yr	pH	QC	TDS	rNa+K	rCl	Na:Cl	Group	Unit
13	27	11	28	2	dst6	53	6.5	p	24040	311.2	327.8	0.95	I	Winnipegosis
15	7	12	21	2	dst4b	54	7.8	p	135819	2008.0	2061.2	0.97	I	Winnipegosis
13	16	14	23	2	dst5	58	7.4	p	61376	847.9	909.5	0.93	I	Winnipegosis
14	11	14	24	2	dst5	54	6.5	p	54390	790.3	817.8	0.97	I	Winnipegosis
8	4	15	28	2	dst5b	53	6.5	p	11382	127.0	134.0	0.95	I	Winnipegosis
4	16	18	23	2	dst11	52	7.2	w	261088	3696.8	3740.1	0.99	III	Winnipegosis
16	22	18	24	2	dst2b	72	7.4	p	278117	4647.5	4716.6	0.99	III	Winnipegosis
13	13	20	26	2	dst8	54	6.5	p	22045					Winnipegosis
1	9	21	16	2	dst8	56	6	p	175650	2536.3	2594.4	0.98	III	Winnipegosis
10	25	1	15	2	dhs	83	7	w	300154	4737.4	5076.0	0.93	II	Bighorn
6	3	1	19	2	dst2b	77	5.6	p	307284	4075.7	5283.2	0.77	II	Bighorn
1	31	1	20	2	dst16	57	6.1	c	257020	3609.7	3778.8	0.96	II	Bighorn
4	30	1	23	2	dst8b	60	6.1	p	312362	3144.2	4624.8	0.68	II	Bighorn
11	30	1	27	2	dst4b	81	7.2	p	133697	2159.0	2180.2	0.99	I	Bighorn
4	31	1	27	2	dst6	58	6.4	p	123275	1822.5	1896.5	0.96	I	Bighorn
3	20	2	16	2	wh	68	6	w	302046	4010.2	5246.1	0.76	II	Bighorn
6	13	2	19	2	dst12	57	6.6	p	301103	4121.3	4371.0	0.94	II	Bighorn
12	21	2	29	2	dst11	58	7.4	p	3259	12.1	2.3	5.37	I	Bighorn
14	15	3	15	2	dst2	86	6	c	303351	4179.6	5212.3	0.80	II	Bighorn
11	2	3	21	2	dst4b	76	6.5	p	237626	3594.4	4093.2	0.88	II	Bighorn
15	12	3	21	2	dst44	51	7	p	226577	2737.2	3065.0	0.89	IIB	Bighorn
8	23	3	24	2	dst13	58	5	p	287383	3603.4	4230.0	0.85	II	Bighorn
12	3	3	25	2	dst2b	66	7.4	c	180882	2982.2	3023.0	0.99	I	Bighorn
9	5	3	28	2	dst6b	68	7.2	c	51722	793.2	782.3	1.01	I	Bighorn
14	8	4	19	2	dst4		6.1	p	241737	3885.2	4126.1	0.94	II	Bighorn
6	8	4	21	2	dst1	73	7.4	p	275254	4258.7	4723.5	0.90	II	Bighorn
6	11	4	21	2	dst1dhs	73	6.4	c	253270	4074.1	4297.7	0.95	II	Bighorn
12	20	4	21	2	dst2	76	6.2	c	241048	3816.5	4131.1	0.92	II	Bighorn
15	16	4	23	2	dst2dhs	85	5.9	w	252485	4059.1	4117.2	0.99	I	Bighorn
11	32	5	23	2	dst1b	73	6.6	p	236144	3796.0	4014.9	0.95	II	Bighorn
12	33	5	23	2	dst5	65	6.5	c	286864	4006.8	4199.9	0.95	II	Bighorn
7	13	5	30	2	dst1b	72	7.1	p	6364	64.1	71.8	0.89	I	Bighorn
8	2	6	16	2	dst5b	78	6	c	299430	4530.6	5159.2	0.88	II	Bighorn
13	4	6	18	2	dst7b	68	5.9	c	256353	4455.3	4163.0	1.07	I	Bighorn
5	31	7	15	2	dst	76	5.8	w	270460	4275.1	4651.6	0.92	II	Bighorn
10	27	7	21	2	dst7b	59	6.7	c	270564	3831.4	3948.0	0.97	II	Bighorn
5	23	7	27	2	dst1b	69	7.5	c	28861	412.9	387.9	1.06	I	Bighorn
9	9	7	28	2	dst3	53	6.5	c	19682	236.0	278.5	0.85	I	Bighorn
3	14	8	20	2	dst4	58	5.5	p	309437	4024.8	4505.0	0.89	II	Bighorn
9	28	8	21	2	dst17	59	5.5	c	275765	3889.3	4000.7	0.97	II	Bighorn
6	15	9	22	2	dst5	59	5.5	c	186591	2674.5	2721.3	0.98	I	Bighorn
13	13	10	26	2	dst10	54	6	p	137072	2001.2	2037.5	0.98	I	Bighorn
13	29	11	21	2	dst1	58	6.9	p	175070	2582.0	2593.0	1.00	I	Bighorn
15	7	12	21	2	dst6t	52	7.1	c	231434	3201.0	3470.6	0.92	IIB	Bighorn
6	24	12	26	2	dst3b	70	7.2	p	106795	1727.9	1720.7	1.00	I	Bighorn

L	S	Tp	R	M	Source	yr	pH	QC	TDS	rNa+K	rCl	Na:Cl	Group	Unit
4	2	14	21	2	dst3	60	7.8	w	221813	3225.0	3554.0	0.91	IIB	Bighorn
13	16	14	23	2	dst10	58	6.8	w	170272	2163.0	2608.5	0.83	IIB	Bighorn
13	12	14	24	2	dst3	58	5.5	c	135606	1959.5	2016.3	0.97	I	Bighorn
2	11	15	26	2	dst3b	56	7.4	p	198841					Bighorn
10	10	17	29	2	dst4m	68	7.1	p	36461	530.2	544.3	0.97	I	Bighorn
4	16	18	23	2	dst12m	52	7.1	p	117570	1706.8	1751.4	0.97	I	Bighorn
1	9	21	16	2	dst9	56	6	p	157474	2303.2	2333.6	0.99	I	Bighorn
1	25	23	16	2	dst2b	69	7.1	p	140479	2242.3	2259.1	0.99	I	Bighorn
8	17	23	20	2	dst2m	68	7.1	c	133841	2126.0	2166.6	0.98	I	Bighorn
11	30	1	27	2	dst2b	81	7.2	p	138265	2224.0	2220.8	1.00	I	Basal Clastic
6	13	2	19	2	dst23	57	4.5	p	314670	4106.6	4596.6	0.89	II	Basal Clastic
15	12	3	21	2	dst46m	51	5.5	p	306506	3492.7	4050.8	0.86	II	Basal Clastic
8	23	3	24	2	dst15	58	5	p	304900	4065.2	4455.6	0.91	II	Basal Clastic
12	33	5	23	2	dst6	65	6.3	c	258261	3596.2	3839.9	0.94	II	Basal Clastic
8	2	6	16	2	dst6b	78	6.4	p	315285	4853.9	5415.2	0.90	II	Basal Clastic
10	27	7	21	2	dst8	59	6.9	c	285424	4030.7	4173.6	0.97	II	Basal Clastic
8	29	7	25	2	dst3b	81	7.8	c	195028	3177.2	3194.6	0.99	I	Basal Clastic
9	9	7	28	2	dst5b	53	6.5	p	95307	1416.2	1445.3	0.98	I	Basal Clastic
3	14	8	20	2	dst7	58	5.5	c	265519	3620.0	3912.8	0.93	II	Basal Clastic
13	13	10	26	2	dst12	54	6	p	184529	2696.3	2735.4	0.99	I	Basal Clastic
15	7	12	21	2	dst7b	52	7.5	p	184916	2719.5	2759.6	0.99	I	Basal Clastic
6	24	12	26	2	dst2b	70	6.9	p	176405	2890.9	2925.8	0.99	I	Basal Clastic
8	2	12	27	2	dst4b	69	7	p	165101	2714.2	2754.4	0.99	I	Basal Clastic
4	2	14	21	2	dst4	60	7.3	p	200694	2995.0	3091.0	0.97	I	Basal Clastic
13	16	14	23	2	dst12	58	6.6	p	173628	2540.5	2594.4	0.98	I	Basal Clastic
4	12	19	27	2	dst2b	67	6.6	p	241469	4001.2	4039.9	0.99	I	Basal Clastic
9	32	20	27	2	dst2b	68	6.1	p	165462	2691.8	2735.4	0.98	I	Basal Clastic
1	9	21	16	2	dst11	56	6	p	125024	1843.5	1861.2	0.99	I	Basal Clastic
1	25	23	16	2	dst1b	69	7.2	p	112615	1782.7	1777.1	1.00	I	Basal Clastic
8	17	23	20	2	dst3b	69	6.9	p	138948	2243.2	2190.9	1.02	I	Basal Clastic

Appendix 3

Pressure Elevation Data

P(Z)-1 : Southwest

L	S	Tp	R	M	QC	DST	Recovery	Pressure	El
								0.0	
9	5	3	28	2	p	1	w	18009.1	
4	31	1	27	2	p	1	w	17947.7	
12	21	2	29	2	c	1	w	18526.2	
4	31	1	27	2	p	2	w	18326.3	
3	34	2	27	2	c	1	w	19098.5	
11	15	1	28	2	c	6	w	19305.3	
11	15	1	28	2	c	7	w	19305.3	
8	36	3	29	2	w	1	m	21117.9	
12	21	2	29	2	c	4	w	21166.9	
9	5	3	28	2	p	7	w	21129.7	
8	36	3	29	2	p	3	w	21697.8	
11	15	1	28	2	c	9	w	21890.9	
4	31	1	27	2	c	3	w	21684.0	
11	30	1	27	2	c	1	w	21797.8	
12	21	2	29	2	c	5	w	22183.2	
9	5	3	28	2	c	3	w	21770.2	
8	36	3	29	2	p	4	w/wc	22246.6	
9	5	3	28	2	p	4	w	22152.9	
12	21	2	29	2	p	6	w	22497.6	
8	36	3	29	2	c	5	w	23566.3	
12	21	2	29	2	p	7	w	23428.4	
12	21	2	29	2	p	8	w	23724.9	
8	36	3	29	2	c	6	w/wc	24144.1	
8	36	3	29	2	p	7	w/wc	24407.4	
12	21	2	29	2	c	9	wc/w	24083.4	
12	21	2	29	2	c	10	w/wc	24373.0	
4	31	1	27	2	w	4	w	24407.4	
4	31	1	27	2	w	5	w	24635.0	
8	36	3	29	2	c	8	w/wc	25207.2	
4	31	1	27	2	w	6	w	24869.4	
12	21	2	29	2	c	11	w/wc	25054.9	
								24797.0	
								24898.0	
9	5	3	28	2	p	5	w	25135.5	
8	36	3	29	2	c	9	w/wc	25241.7	
8	36	3	29	2	w	10	wc/w	25850.5	
4	31	1	27	2	w	10	w/wc	25873.3	
8	36	3	29	2	c	12	w/wc	26751.0	

ion	Unit
0.0	Nominal
2.3	Madison
2.7	Madison
6.4	Madison
0.0	Madison
3.7	Madison
7.5	Madison
9.5	Madison
37.5	Saskatchewan
76.5	Saskatchewan
31.4	Saskatchewan
27.4	Saskatchewan
37.5	Saskatchewan
46.3	Saskatchewan
52.2	Saskatchewan
57.9	Saskatchewan
67.6	Saskatchewan
85.9	Saskatchewan
94.5	Saskatchewan
09.1	Saskatchewan
27.4	Saskatchewan
29.8	Saskatchewan
40.2	Saskatchewan
63.6	Winnipegosis
91.4	Bighorn
93.2	Winnipegosis
09.6	Bighorn
28.2	Winnipegosis
50.5	Winnipegosis
59.6	Bighorn
69.4	Bighorn
78.2	Bighorn
80.0	Nominal
90.0	Nominal
90.7	Bighorn
02.3	Bighorn
49.6	Bighorn
67.8	Bighorn
23.0	Basal Clastic

L	S	T	R	M	QC	DST	Recovery	Pressure	Elevation	Unit
9	5	3	28	2	p	6	w/wc	26386.2	-1824.5	Bighorn
4	31	1	27	2	w	11	wc/w	26487.6	-1829.7	Bighorn
11	30	1	27	2	w	3	w/m	26996.2	-1860.6	Bighorn
11	30	1	27	2	w	4	w	27057.2	-1862.1	Bighorn
4	31	1	27	2	wr	14	w/wc	27092.3	-1901.0	Basal Clastic
								27450.0	-1925.0	Nominal

P(Z)-2: Northwest

L	S	Tp	R	M	QC	DST	Recovery	Pressure	Elevation	Unit
								0.0	570.0	Nominal
1	17	20	23	2	w	1	m	2184.9	289.3	Belly River
11	29	20	23	2	c	1	w	7555.3	-92.0	Mannville
11	11	20	22	2	p	1	w	7234.0	-102.0	Mannville
11	11	20	22	2	c	2	w	7595.3	-131.0	Mannville
								7183.0	-160.0	Nominal
								8477.0	-315.0	Nominal
15	12	20	23	2	w	3	w	11672.8	-423.1	Saskatchewan
11	29	20	23	2	w	3	w	11583.2	-478.8	Saskatchewan
16	10	21	25	2	c	8	w	12238.6	-517.2	Saskatchewan
16	22	18	24	2	p	3	w	13182.8	-588.6	Saskatchewan
16	22	17	24	2	p	5	w	13438.6	-620.6	Saskatchewan
14	6	17	22	2	w	3	w	14607.2	-684.9	Saskatchewan
14	6	17	22	2	w	4	w	14479.0	-705.3	Saskatchewan
								16705.0	-980.0	Nominal
16	22	17	24	2	w	4	w	18471.1	-1023.2	Saskatchewan
16	22	18	24	2	w	2	w	18318.0	-1100.7	Winnipegosis
								19254.0	-1210.0	Nominal
14	12	23	26	2	w	6	w	18705.5	-1231.1	Basal Clastic
4	12	19	27	2	w	2	w	21105.6	-1386.5	Basal Clastic
1	3	19	26	2	c	1	w	20995.9	-1390.5	Basal Clastic

P(Z)-3: Northeast

L	S	Tp	R	M	QC	DST	Recovery	Pressure	Elevation	Unit
								0.0	630.0	Nominal
								9053.0	-290.0	Nominal
1	29	19	16	2	c	2	w	10332.5	-417.3	Saskatchewan
								10768.0	-460.0	Nominal
								15202.0	-860.0	Nominal
6	29	18	16	2	p	1	w	16581.9	-1067.4	Winnipegosis
1	25	23	16	2	p	2	w	16299.9	-1081.7	Bighorn
1	25	23	16	2	p	1	w	16850.8	-1146.7	Basal Clastic
2	4	22	15	2	p	2	w	17244.5	-1150.6	Bighorn
1	9	21	16	2	w	7	w	17769.2	-1180.8	Bighorn
								19111.0	-1220.0	Nominal
1	9	21	16	2	w	11	w	18359.4	-1251.8	Basal Clastic

P(Z)-4: South Regina

L	S	Tp	R	M	QC	DST	Recovery	Pressure	Elevation	Unit
								0.0	740.0	Nominal
9	28	8	21	2	c	1	w	7563.5	-202.4	Viking
9	28	8	21	2	w	4	w	12321.6	-521.5	M. Jurassic
6	15	9	22	2	c	1	w	13753.0	-667.8	M. Jurassic
11	23	8	21	2	c	1	w	14464.5	-746.5	Madison
7	36	7	21	2	c	6	w/o	14587.9	-754.4	Madison
6	15	9	22	2	w	2	w	15662.1	-755.6	Madison
6	15	9	22	2	c	3	w	15362.2	-788.2	Madison
9	28	8	21	2	c	7	w	14968.5	-792.8	Madison
10	27	7	21	2	w	1	w/m	15830.4	-832.1	Madison
6	5	8	22	2	p	2	w	19335.7	-1151.5	Saskatchewan
16	25	7	21	2	w	3	w	19257.1	-1190.5	Saskatchewan
6	5	8	22	2	c	3	w	19628.7	-1203.7	Saskatchewan
								19188.0	-1210.0	Nominal
10	27	7	21	2	p	2	w	19787.9	-1250.6	Saskatchewan
6	15	9	22	2	c	4	w	19934.8	-1275.9	Saskatchewan
10	27	7	21	2	p	3	w	21477.2	-1382.9	Saskatchewan
6	15	9	22	2	c	6	w	22980.2	-1542.6	Winnipegosis
9	28	8	21	2	w	13	w	22752.7	-1551.1	Winnipegosis
								22719.0	-1560.0	Nominal
6	15	9	22	2	c	5	w	23346.3	-1575.5	Winnipegosis
10	27	7	21	2	w	4	wc/w	23777.9	-1582.2	Winnipegosis
7	36	7	21	2	c	2	w	23518.0	-1600.8	Winnipegosis
10	27	7	21	2	w	5	w	24406.7	-1634.3	Bighorn
10	27	7	21	2	w	6	wc/m	25770.5	-1747.1	Bighorn
9	28	8	21	2	w	17	w	25525.1	-1813.3	Bighorn
6	5	8	22	2	c	4	w	25834.7	-1817.5	Bighorn
10	27	7	21	2	w	7	wc.w	26556.5	-1838.6	Bighorn
10	27	7	21	2	c	8	w	27083.3	-1905.3	Basal Clastic
								26598.0	-1910.0	Nominal
7	36	7	21	2	c	4	w/m	26841.3	-1914.4	Basal Clastic

P(Z)-5: Hummingbird

L	S	Tp	R	M	QC	DST	Recovery	Pressure	Elevation	Unit
								740	0	Nominal
								10200	-300	Nominal
10	34	5	20	2	w	1	w	8204.8	-302.7	Viking
10	34	5	20	2	w	3	w	8664.6	-400	Mannville
12	20	4	21	2	c	4	w	16422.6	-[illegible]1.6	Madison
9	6	6	21	2	w	1	w	16184.1	-[illegible]3.7	Madison
15	10	6	19	2	c	1	w	15851	-867.5	Madison
1	1	6	19	2	c	1	w	15726.2	-873.6	Madison
16	35	5	19	2	w	1	w	15704.2	-874.2	Madison
5	16	6	19	2	p	1	w	15621	-878.3	Madison
7	1	5	19	2	p	1	w	16855.6	-881.8	Madison
9	6	6	21	2	w	2	w	16485.4	-882.7	Madison
5	15	6	19	2	p	2	w	15926.9	-901.3	Madison
3	15	6	19	2	p	2	w	15954.5	-908	Madison
1	14	5	19	2	c	1	w	16052.1	-915.9	Madison
3	24	3	21	2	p	1	w	17264.5	-936	Madison
5	28	5	21	2	c	2	w	17583.7	-972.9	Madison
2	29	5	20	2	p	1	w	16828.9	-979.6	Madison
10	34	5	20	2	c	6	w	16719.8	-985.7	Madison
3	11	4	21	2	w	2	w	17938.8	-1043.6	Madison
7	1	5	19	2	c	5	w	17574.7	-1087.5	Madison
14	8	4	19	2	p	1	w	18147	-1094.5	Madison
12	24	3	20	2	p	1	w	18721.3	-1108.3	Madison
11	28	3	19	2	c	1	w	18446.2	-1122.9	Madison
1	15	3	19	2	c	1	w	19028.1	-1143.9	Madison
3	26	4	20	2	p	2	w	18385.6	-1154	Madison
1	15	3	19	2	c	2	w	18768.9	-1161	Madison
11	3	4	20	2	p	1	w	19153.6	-1168.3	Madison
2	17	4	19	2	p	2	w	18899	-1172.6	Madison
7	24	6	21	2	w	4	w	19572.8	-1199.7	Madison
9	6	6	21	2	c	3	w	20239.6	-1257.9	Saskatchewan
14	16	6	19	2	c	1	w	19991.2	-1277.8	Saskatchewan
3	15	6	19	2	w	4	w	19348.8	-1282.6	Saskatchewan
1	1	6	19	2	c	2	w	19956.9	-1285.3	Saskatchewan
7	14	6	19	2	p	1	w	19923.1	-1294.5	Saskatchewan
8	29	6	20	2	p	1	w	20187.2	-1305.2	Saskatchewan
12	20	4	21	2	p	1	w	21296.5	-1323.7	Saskatchewan
10	18	5	19	2	c	2	w	21075.2	-1407	Saskatchewan
14	8	4	19	2	p	3	w	22008.1	-1485.9	Saskatchewan

L	S	Tp	R	M	QC	DST	Recovery	Pressure	Elevation	Unit
15	12	3	21	2	w	18	w	22617.6	-1486.8	Saskatchewan
15	12	3	21	2	c	19	w	23097.4	-1514.2	Saskatchewan
7	12	3	19	2	p	4	w	23028.5	-1588.6	Saskatchewan
								23050	-1600	Nominal
14	8	4	19	2	p	2	w	23947.6	-1641	Saskatchewan
3	26	4	20	2	c	5	w	25633.3	-1794.4	Winnipegosis
11	2	3	21	2	c	2	w	26664.1	-1843.4	Winnipegosis
								26135	-1850	Nominal
3	26	4	20	2	p	6	w	26176.6	-1850.1	Bighorn
6	8	4	21	2	c	1	wc/w	28557.4	-2035.5	Bighorn
12	20	4	21	2	p	3	w/wc	28992.4	-2080	Basal Clastic
6	8	4	21	2	c	2	wc/w	29328.2	-2089.4	Bighorn
								28976	-2100	Nominal
11	2	3	21	2	c	4	w	29318.6	-2104.6	Bighorn
14	8	4	19	2	c	4	w	29080	-2115.3	Bighorn

P(Z)-6: South Hummingbird

L	S	Tp	R	M	QC	DST	Recovery	Pressure	Elevation	Unit
								0.0	735.0	Nominal
11	26	2	19	2	p	1	w	9796.8	-415.7	Viking
11	26	2	19	2	p	2	w	11555.6	-546.0	Mannville
								15744.0	-865.0	Nominal
								17257.0	-1015.0	Nominal
15	23	2	19	2	cr	1	w/m	18604.8	-1149.7	Madison
5	25	2	19	2	cr	1	w	18935.8	-1186.9	Madison
11	1	2	19	2	cr	1	m/w	19113.6	-1195.2	Madison
13	6	1	19	2	p	2	w/m	19934.8	-1208.5	Madison
11	20	2	18	2	c	2	w	19189.0	-1217.0	Madison
5	12	2	19	2	c	1	w/m	19759.0	-1217.1	Madison
13	6	1	19	2	c	3	w	19781.1	-1229.6	Madison
10	26	2	19	2	p	3	w/m	19599.0	-1239.6	Madison
16	36	1	18	2	w	6	m	20249.8	-1244.9	Madison
11	20	2	18	2	c	6	w	19152.9	-1254.0	Madison
11	1	2	18	2	c	1	w/m	20167.2	-1261.9	Madison
7	30	1	18	2	c	1	w	20627.0	-1292.7	Madison
11	1	1	19	2	p	1	w	20656.7	-1319.5	Madison
12	13	2	19	2	w	2	w	20493.1	-1336.1	Madison
3	26	2	19	2	pr	2	w	22841.6	-1600.8	Saskatchewan
3	12	2	19	2	c	4	w	23249.1	-1616.0	Saskatchewan
1	35	2	19	2	pr	2	w	23359.4	-1617.3	Saskatchewan
13	6	1	19	2	c	4	w	24236.4	-1636.2	Saskatchewan
6	13	2	19	2	p	8	w	23924.8	-1649.9	Saskatchewan
								24152.0	-1650.0	Nominal
10	26	2	19	2	w	10	w	23649.0	-1659.6	Saskatchewan
10	26	2	19	2	p	11	w	24326.8	-1687.7	Saskatchewan
1	35	1	18	2	p	1	w	24338.5	-1693.5	Saskatchewan
10	26	2	19	2	p	13	w	27551.4	-1976.0	Winnipegosis
6	13	2	19	2	p	12	w/wc	28440.9	-2040.0	Bighorn
6	13	2	19	2	w	14	w	29999.1	-2169.3	Bighorn
1	30	2	18	2	w	2	w/m	30845.1	-2257.7	Bighorn
6	13	2	19	2	c	17	o/w/m	30804.4	-2260.4	Bighorn
6	13	2	19	2	w	19	w/g/wc	30773.4	-2262.5	Bighorn
10	26	2	19	2	p	15	w	30734.1	-2269.8	Bighorn
6	13	2	19	2	w	21	w	30524.0	-2278.7	Bighorn
16	36	1	18	2	c	5	wc/w	31601.5	-2332.9	Bighorn
6	3	1	19	2	w	2	w	31462.2	-2348.8	Bighorn
6	13	2	19	2	c	23	w/wc	31813.8	-2359.5	Basal Clastic
								32937.0	-2360.0	Nominal
6	3	1	19	2	c	3	w/wc	32598.4	-2435.7	Basal Clastic

P(Z)-7: Southeast

L	S	Tp	R	M	QC	DST	Recovery	Pressure	Elevation	Unit
2	17	1	16	2	c	1	w	1613.4	495.9	Belly R.
								700.0	0.0	Nominal
15	15	1	15	2	c	1	w	11393.6	-495.9	Viking
2	17	1	16	2	p	2	w	10782.0	-496.8	Viking
3	3	1	16	2	p	2	w	10840.6	-504.7	Viking
15	15	1	15	2	w	2	w	12065.8	-593.0	Mannville
2	17	1	16	2	p	3	w	11810.7	-620.0	Mannville
12	9	1	16	2	p	3	w	12365.7	-623.0	Mannville
3	3	1	16	2	cr	1	w	12058.2	-649.0	Mannville
								14975.0	-800.0	Nominal
								15984.0	-900.0	Nominal
								17025.0	-1000.0	Nominal
7	30	2	16	2	p	1	w	18570.0	-1136.8	Madison
3	20	2	16	2	c	2	w	18833.7	-1190.5	Madison
12	17	2	15	2	w	1	w	19193.6	-1190.5	Madison
5	33	2	[illegible]	[illegible]	[illegible]	3	w	18819.2	-1202.7	Madison
5	11	2	15	2	p	[illegible]	w/m	19958.9	-1214.9	Madison
2	8	2	15	2	cr	[illegible]		20072.7	-1214.9	Madison
7	30	2	16	[illegible]	[illegible]	2	w	19387.1	-1216.3	Madison
16	10	2	16	2	c	2	w	19249.5	-1227.1	Madison
16	12	2	16	2	p	1	w	19281.2	-1234.1	Madison
11	35	1	15	2	cr	1	w/m	19175.7	-1234.7	Madison
11	25	1	15	2	p	3	w	19302.6	-1235.4	Madison
13	26	1	15	2	p	2	w/o	19436.3	-1248.8	Madison
11	35	1	15	2	cr	2	w/m	19588.7	-1249.1	Madison
7	27	1	15	2	c	2	w	19753.5	-1257.3	Madison
12	28	1	15	2	p	1	w/o	19878.3	-1262.8	Madison
6	28	1	15	2	wr	1	w	19991.5	-1264.7	Madison
15	23	1	15	2	p	1	w	19122.6	-1264.9	Madison
16	23	1	16	2	c	2	w	19822.4	-1266.4	Madison
2	34	1	16	2	c	1	w	19868.6	-1267.4	Madison
9	15	1	15	2	p	1	w/o	19896.4	-1267.9	Madison
11	25	1	15	2	w	4	w	19634.2	-1268.9	Madison
16	24	1	16	2	c	3	w	19795.5	-1273.8	Madison
9	30	1	15	2	wr	4	w	19933.2	-1277.9	Madison
4	9	1	16	2	pr	1	w/m/o	20129.9	-1278.6	Madison
3	20	2	16	2	p	3	w	19836.9	-1280.5	Madison
15	15	1	15	2	c	8	w	20449.2	-1282.6	Madison
2	10	1	16	2	c	3	w	19925.2	-1283.5	Madison

L	S	T	R	M	QC	DST	Recovery	Pressure	Elevation	Unit
13	3	1	15	2	p	2	w	19962.4	-1290.8	Madison
2	4	1	16	2	cr	3	w	20032.0	-1293.6	Madison
8	5	1	16	2	c	3	w/m	20054.8	-1299.7	Madison
								20282.0	-1300.0	Nominal
4	4	1	16	2	p	3	w	20244.4	-1300.3	Madison
16	24	1	16	2	c	4	w	20091.3	-1306.4	Madison
10	8	1	16	2	wr	3	w/m	20502.3	-1310.6	Madison
4	19	1	16	2	p	2	w	20793.9	-1320.1	Madison
4	19	1	16	2	p	3	w	20689.1	-1353.0	Madison
5	30	1	15	2	w	12	w	21253.1	-1415.8	Madison
12	14	1	16	2	cr	2	w	21332.4	-1428.9	Madison
13	3	1	15	2	c	7	w	21939.7	-1466.1	Madison
13	3	1	15	2	p	3	w	21855.7	-1467.6	Madison
9	34	2	15	2	p	4	w	23109.8	-1603.6	Saskatchewan
								24161.0	-1650.0	Nominal
2	14	1	16	2	c	4	w	24131.5	-1698.2	Saskatchewan
10	15	1	16	2	p	1	w	24510.1	-1698.3	Saskatchewan
12	14	1	16	2	c	3	w	24584.6	-1707.8	Saskatchewan
								32204.0	-2300.0	Nominal
3	20	2	16	2	w	5	o/wc	31325.6	-2341.8	Bighorn
2	22	2	16	2	w	1	w	31682.1	-2347.0	Bighorn
10	25	1	15	2	w	1	w	32453.5	-2470.0	Bighorn

Appendix 4

Formation Tops

Cross Section A

L	11	12	12	6	6	11	15	4	9	3	1	1
S	30	3	33	5	15	7	7	2	27	8	9	25
Tp	1	3	5	8	9	11	12	14	16	17	21	23
R	27	25	23	22	22	21	21	21	20	19	16	16
M	2	2	2	2	2	2	2	2	2	2	2	2
KB	857.7	906.8	710.2	713.5	740.4	631.2	591.9	577.3	577	580.9	608.1	611.1
Mannville	-413.6	-361.5	-335.3	-322.5	-371.8	-201.8	-196.9	-165.2	-196	-124.1	-35.6	9.4
Vanguard	-509.6	-463.9	-427.9	-415.2	-460.2	-296	-294.5	-252.4	-281	-206.4	-111.1	
M. Jurassic	-690.4	-670.8	-569.7	-537.4	-660.5	-395.7	-377.3	-329.2	-328.2	-246	-129.8	-27.6
Watrous	-811.7	-768.4	-704.7	-671.8	-693.4		-495.6	-453.5	-426.7	-351.2	-175.8	-79.5
Madison	-968.4	-930.5	-793.1	-718.8	-731.8		-566	-546.8	-484.3	-409.1	-242.6	-146.9
Three Forks	-1291.4	-1248.7	-1147.3	-1072.3	-1077.4		-886.4	-837.3	-602.9	-516.7	-299	-202.1
Birdbear	-1338.4	-1307.9	-1215.8	-1133.9	-1140.2		-947.3	-903.1	-609.6	-584	-370	-271.6
Duperow	-1362.8	-1333.5	-1240.2	-1164.7	-1173.1		-983.3	-942	-709	-623.1	-409.3	-307
Elk Point	-1625.2	-1616	-1546.8	-1448.4	-1458.7		-1312.5	-1228.3	-991.8	-957.7	-748.3	-625.2
Prairie Salt		-1646.8	-1580.1	-1483.8			-1355.2	-1275.3	-1044.5	-1004.7	-799.2	-681.6
Winnipegosis	-1661.5	-1720.9	-1653.8	-1561.2	-1504.5		-1358.8	-1281.7	-1147.6	-1117.8	-901.3	-853.2
Ashern	-1669.4	-1746.2	-1687.7	-1602.7	-1549.3		-1405.1	-1331.1		-1170.2	-969.2	-867.2
Bighorn	-1673.4	-1751.7	-1698.9	-1614.6	-1556.9		-1415.8	-1341.4		-1182.1	-975.9	-873.6
Basal Clastic	-1907.8	-1996.4	-1961.7	-1874.3	-1808.6		-1674.6	-1608.4		-1453	-1238.1	-1139.7
Precambrian								-1825.1		-1628	-1392	
Total Depth	-1937.9	-1998.2	-2104.6	-1965.4	-1854.1	-428	-1707.2	-1834.9	-1153.7	-1644.7	-1399	-1178.4

Cross Section B

L	10	2	7	11	10	8	10	6
S	25	22	23	29	18	29	27	5
Tp	1	2	3	4	5	6	7	8
R	15	16	17	18	19	20	21	22
M	2	2	2	2	2	2	2	2
KB	687	700.4	741.3	727.3	726.9	727.3	737	713.5
Mannville	-553.5	-522.2	-477	-406.6	-416.1	-370.6	-357.8	-322.5
Vanguard	-636.4	-616.3	-556.2	-495.6	-505.1	-464.8	-455.7	-415.2
M. Jurassic	-852.2	-810.8	-861.2	-696.7	-675.2	-635.2	-596.8	-537.4
Watrous	-960.4	-924.8	-860.7	-790	-799.2	-737.9	-735.2	-671.8
Madison	-1213.1	-1174.7	-1043.6	-940.3	-970.8	-879.9	-820.5	-718.8
Three Forks	-1588.3	-1545.4	-1408.1	-1305.1	-1330.5	-1246.6	-1167.1	-1072.3
Birdbear	-1666.7	-1620.3	-1481.9	-1376.4	-1396.6	-1310.9	-1230.2	-1133.9
Duperow	-1699	-1652	-1512.7		-1424.1	-1343.8	-1261	-1164.7
Elk Point	-1969.6	-1930.6	-1795.9		-1708.1		-1534.4	-1448.4
Prairie Salt	-2010.2	-1974.8	-1837.8				-1575.8	-1483.8
Winnipegosis	-2102.2	-2025.4	-1932.1		-1753		-1579.8	-1561.2
Ashern	-2147.3	-2069.9	-1975.1		-1793.2		-1621.8	-1602.7
Bighorn	-2165	-2083.3	-1987		-1805.4		-1633.4	-1614.6
Basal Clastic	-2537.8	-2436	-2316.1		-2098		-1898.3	-1874.3
Precambrian								
Total Depth	-2585	-2469.2	-2358.8	-1413.9	-2191	-1360.6	-1926	2678.9

Cross Section C

L	1	14	9	10	1	4
S	36	2	9	26	31	18
Tp	5	4	3	2	1	1
R	15	17	18	19	20	21
M	2	2	2	2	2	2
KB	609	723	722.4	742.2	693.7	742.2
Mannville	-361.2	-445.6	-437.4	-450.8	-460.9	-448.3
Vanguard	-449.3	-521.5	-529.1	-526.7	-550.6	-523.3
M. Jurassic	-612.6	-701.9	-745.2	-800.2	781.2	753.4
Watrous	-721.1	-828.4	-854.9	-892.1	-892.9	-892.1
Madison	-863.2	-1003.4	-1063.7	-1107	-1137.1	-1113.7
Three Forks	-1266.4	-1357.9	-1420.6	-1465.2	-1483.2	-1478.6
Birdbear	-1368.5	-1431.9	-1492	-1557.8	-1548.7	-1544.4
Duperow	-1395.7	-1462.1	-1521.8	-1588	-1577.7	-1575.5
Elk Point		-1750.5	-1790.1	-1920.2	-1838.3	-1838.2
Prairie Salt		-1792.5	-1833.7		-1874.8	-1872.4
Winnipegosis		-1889.4	-1915	-1964.7	-1959.6	-1949.8
Ashern		-1929.1	-1944.6	-2002.8	-1991.3	-1978.4
Bighorn		-1939.1	-1950.1	-2019.3	-2002.3	-1990.6
Basal Clastic		-2261		-2324.1	-2310.7	-2284.5
Precambrian						
Total Depth	-1421	-2318.3	-1962.3	-2343.3	-2336.3	-3030

Appendix 5

Table of Densities versus Total Dissolved Solids

Total Dissolved Solids (mg/L)	Relative Density g/cm^3
11 000	1.008
40 000	1.028
86 000	1.060
152 000	1.105
190 000	1.130
320 000	1.260

Total dissolved solids content of formation water with its corresponding relative density used in the calculation of P(Z) curves (after Tóth, 1978):