1988

Solution-generated collapse (SGC) structures and formation-fluid hydrodynamics in southern Manitoba.

Ioannis. Bacopoulos
University of Windsor

SOLUTION-GENERATED COLLAPSE (SGC) STRUCTURES AND FORMATION-FLUID HYDRODYNAMICS IN SOUTHERN MANITOBA

by

Ioannis Bacopoulos

A Thesis
submitted to the Faculty of Graduate Studies
through the Department of Geology
in Partial Fulfillment
of the Requirements for the Degree
of Master of Science at
The University of Windsor

Windsor, Ontario, Canada

1988

ISBN 0-315-48139-0

ABSTRACT

Solution-generated collapse (SGC) structures associated with bedded halite of the Prairie Evaporite (Middle Devonian) are a result of localized salt solution by circulating groundwater. They have exerted a major influence on the structural configuration of the Phanerozoic strata in southwestern Manitoba.

These structures are reflected in anomalies on isopach and structure contour maps. Their effect on the hydrogeologic environment and groundwater regime is demonstrated by the presence of pressure cells on maps of potentiometric surfaces. They are also reflected in the continuity of pressure systems across two or more lithostratigraphic units, as evidenced by fluid-pressure profiles. The imprint of solution-generated collapse structures on prevailing hydrogeologic conditions reflects the presence of brecciated strata and fracture systems that permit relatively unrestricted cross-formational flow.

Recognition of localised cross-formational flow carries important implications for oil-exploration and environmental-management strategies in southwestern Manitoba, because solution-generated collapse has influenced both structure and depositional format. A common element is localization of vertical fluid migration, affecting hydrocarbons and formation waters with base metals in solution, as well as injected fluid wastes.

All Paleozoic formations in the outcrop belts are somewhat affected by the regional flow system and appear to be unsuitable for waste injection. This holds true especially for the two lowermost post-Prairie units that have been affected by salt-related tectonics. Of the remaining Paleozoic strata, truncated in the subsurface at the pre-Jurassic unconformity, the Mission Canyon and Lodgepole Formations in the southwestern corner of the province and the northern part of the salt area respectively, provide potential waste-disposal targets. The same appears to be true for the Devonian Nisku Formation to the east of the solution-formed salt edge.

In southwestern Manitoba, the areas where the Lyleton-Bakken interval is characterized by relatively high permeabilities, probably as a result of fracturing related to salt solution, may include additional potential for hydrocarbon discovery within the Mississippian strata. The Devonian Nisku Formation appears to be prospective for hydrocarbons in the southern part of the Birdtail-Waskada axis. The trend of the same axis may be prospective for Mississippi Valley-type (MVT) lead-zinc deposits.

ACKNOWLEDGMENTS

Sacrifices were made, in the form of financial and moral support, from my parents Amalia and Georgios Bacopoulos for the successful completion of my studies in Canada. They deserve to be the first to receive my most sincere thanks.

I would like to acknowledge the Energy, Mines and Resources for the financial contribution through the EMR grant No. 164 and EMR grant No. 67, that defrayed in part the costs of this study.

I am deeply indebted to my supervisor Dr. Frank Simpson under whose supervision I carried out thesis-related research. He provided invaluable criticism throughout my research, and most importantly contributed to the broadening of my geological interests.

Thanks are due to my sister Vicky Bacopoulou for her help in the compilation of my data during her stay in Canada. My gratitudes are also extended to Miss. Marianne Cooper and Mr. Kivuti Nyagah for their assistance in typing, during the final stages of this work.

Finally, worthy of special mention and acknowledgment is my friend and colleague Mr. Gary Lagos, who contributed significantly through invaluable discussions to my thorough understanding of hydrodynamics.

LIST OF CONTENTS

LIST OF FIGURES

Figures | Pages

CHAPTER 1

INTRODUCTION

1.1 Study Area

The study area is in southwestern Manitoba, between latitudes 49 degrees and 50 degrees 30 minutes, and from longitude 90 degrees 30 minutes to the Saskatchewan-Manitoba border (Fig. 1). It comprises Ranges 16 to 29WPM inclusive and Townships 1 to 18 inclusive.

1.2 The Problem

Solution-generated collapse (SGC) structures associated with bedded evaporites may be conduits for the upward migration of fluids in sedimentary strata. This carries far-reaching implications for the injection of fluids into subsurface strata and for exploration strategies aimed at location of a wide variety of mineral resources.

The adoption of different approaches to waste confinement and containment has arisen as a natural consequence of intense industrial growth. Subsurface disposal of wastes is one such practice currently applied in Canada. Several factors, such as degree of isolation of the disposal zone from the biosphere, earthquake frequency and magnitude, the presence of faults and fractures, must be taken into account, because they could result in the failure

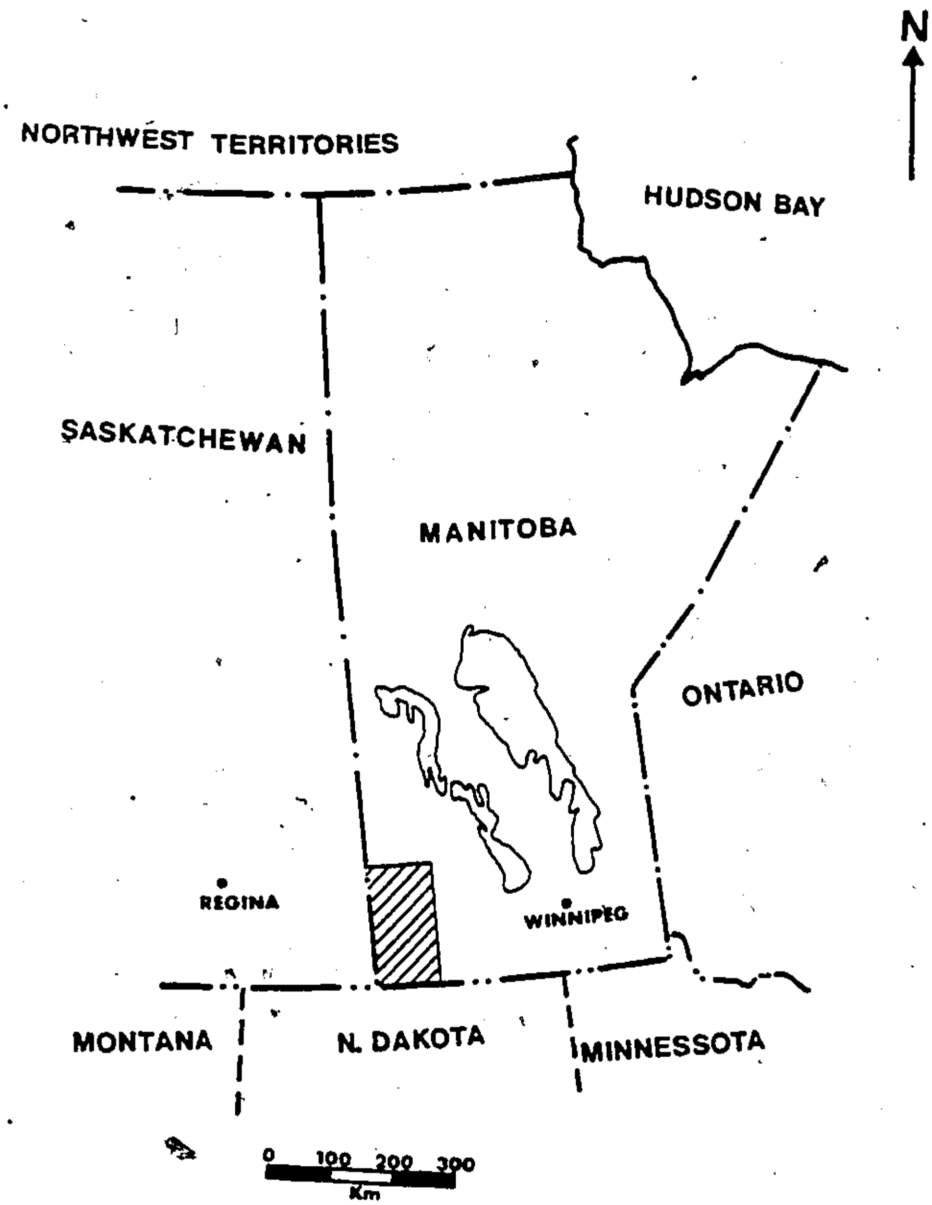

Fig. 1. Location of study area.

of the whole operation with adverse environmental effects. The study area is part of the Williston basin, in which numerous solution-generated collapse structures are associated with the Middle Devonian Prairie Evaporite. The fracture systems and brecciated strata, commonly encountered within these structures, provide potential conduits for upward migration of injected fluid wastes with attendant environmental hazards (Simpson and Dennison, 1975; Simpson et al., 1987).

Solution-generated collapse structures can be of vital importance to exploration for natural resources. The associated fracture systems and breccias can facilitate the upward migration of hydrocarbons and base metals in solution towards the sites of accumulation, provided that certain favourable conditions are obtained (Simpson 1987b, 1988).

The common factor determining the role of solution-generated collapse structures as potential routes of contaminant migration and movement of waters bearing hydrocarbons and base metals, is cross-formational flow.

1.3 Previous Work

Numerous studies have been carried out on the geology and stratigraphy of southwestern Manitoba. Surface geological data are mainly derived from the Paleozoic outcrops in the vicinity of Lakes Winnipegosis, Manitoba and Winnipeg. Within the study area, the widespread occurrence of glacial drift has, to a great extent, precluded surface mapping and the unraveling of the stratigraphy is due to analysis of subsurface data from the numerous wells in and around the oil-producing areas.

Reports by McCabe (1971) and Christopher et al. (1971, 1973) dealt with the general geologic setting of the Phanerozoic succession in southwestern Manitoba and Saskatchewan. McCabe (1959, 1963) described the Mississippian stratigraphy of Manitoba and made reference to the presence of solution-generated collapse structures associated with the Prairie Evaporite (Middle Devonian). McCabe (1967) also included considerations of solution-generated collapse structures in an account of the stratigraphy of the entire Paleozoic succession. Simpson et al. (1987) discussed the occurrence of these structures with regard to the subsurface waste-disposal potential of southwestern Manitoba.

There is relatively little published on the hydrodynamics of deep formation waters in the northern Williston basin region. Regional aspects were considered by Hitchon (1969a, 1969b) for the entire western Canada sedimentary basin. Detailed studies of more local significance include papers by Christopher (1974) on the Jurassic Vanguard Group and the Lower Cretaceous Mannville Group of southwestern Saskatchewan and by Dickey and Cox (1977) on the Viking Sandstone of Alberta. Simpson (1987b, 1988) discussed the significance of hydrodynamics in the exploration for hydrocarbons.

1.4 Scope of Study

Partly on the basis of limited data on potentiometric surfaces for strata of the western Canada sedimentary basin, Simpson (1987b, 1988) deduced that some solution-generated collapse structures are the sites of upward cross-formational flow of subsurface waters. The purpose of this study is to examine the validity of this hypothesis, using data from drill stem tests obtained by private companies during the course of oil exploration.

Records of drill-stem tests exist for about 1800 wells out of a total of nearly 3000 wells drilled in southern Manitoba. Six hundred wells with drill stem tests comprise the data set for the present study. Drill-stem test information were derived from the Petrofiche System of International Petrodata Limited. Drill-stem test data were analysed in a systematic study of potentiometric surfaces for selected lithostratigraphic units (Appendix I). They were also used for the calculation of pressure heads (Appendix II).

Patterns of groundwater circulation deduced from potentiometric surfaces and fluid-pressure profiles were examined in relation to the distribution of solution-generated collapse structures in the study area. Sites of cross-formational flow were related to the distribution of known hydrocarbon accumulations and to prospects based on play analysis. The subsurface-disposal potential of the area was re-evaluated in the light of new data on the possible relationships between solution-generated collapse structures and patterns of fluid migration.

CHAPTER 2

REGIONAL GEOLOGY

2.1 General Remarks

The nature of the Phanerozoic sedimentary succession in southwestern Manitoba was, to a large extent, controlled by subsidence of the Williston basin. During Devonian times, the evolution of the Elk Point basin farther west was the dominant controlling factor (McCabe, 1971). The northeastern part of the study area is underlain by the Precambrian basement unconformity which dips gently southwestward (Fig. 2). An increase in the dip is observed from 2.2 m/Km adjacent to the southern perimeter of the Canadian Shield to 9.2 m/Km to the most southwestern corner of the province. The latter coincides with the northeastern flank of the Williston basin.

The Phanerozoic strata comprise a homocline dipping gently southwestward and tapering out to the northeast, and form northwest-trending belts with a slight swing in strike toward the north, close to the Manitoba-Saskatchewan border (Christopher *et al.*, 1973). In the Manitoba part of the Williston Basin, the entire Phanerozoic succession attains a maximum thickness in excess of 2300 m in the southwestern corner of the province.

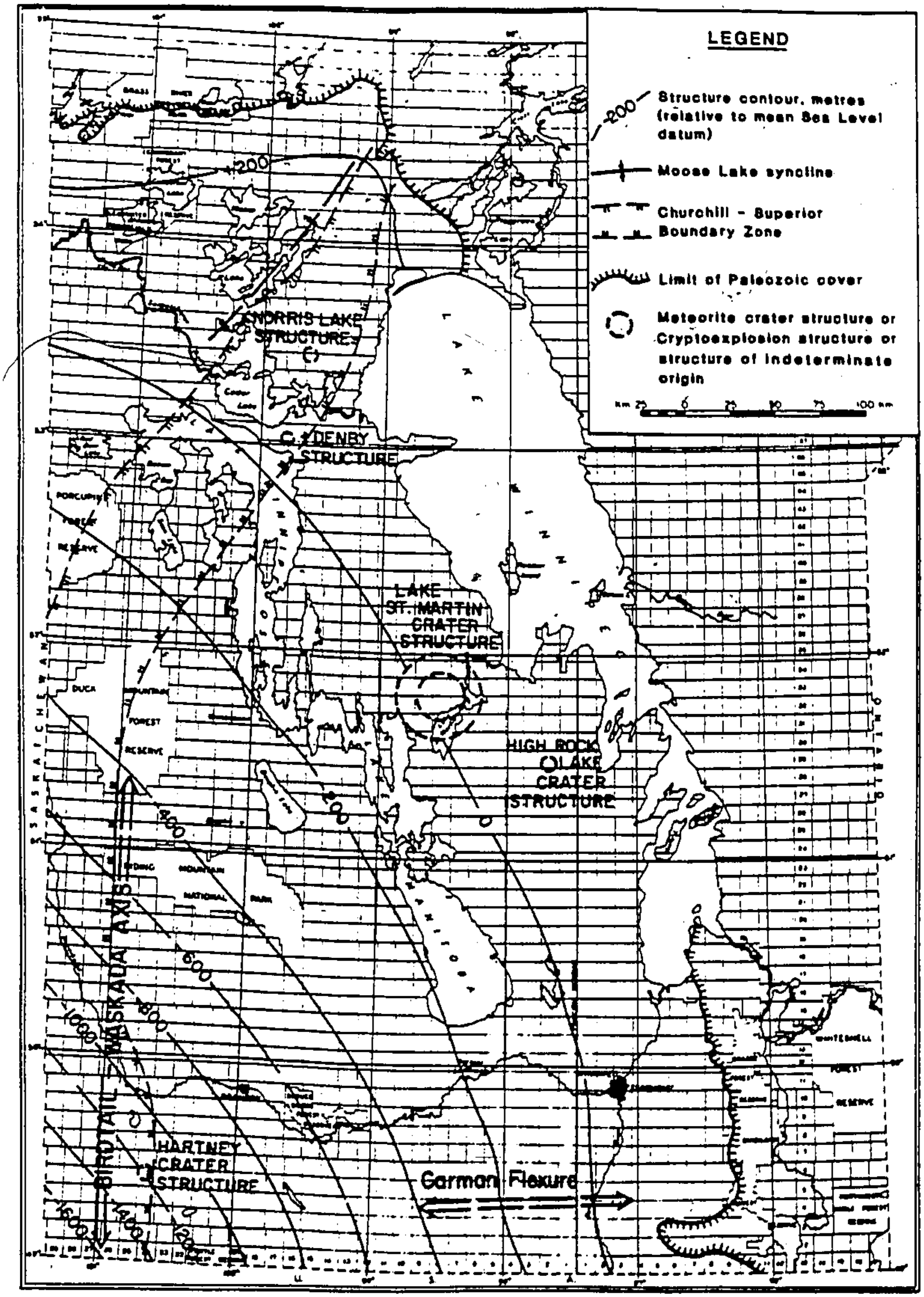

Fig. 2. Structure contour map for Precambrian basement, southwestern Manitoba (after Simpson *et al.*, 1987).

2.2 Outline of Stratigraphy

The Phanerozoic sedimentary strata in southwestern Manitoba and Saskatchewan can be divided into three main parts (Christopher et al., 1971, 1973; Simpson and Dennison, 1975; Simpson et al., 1987) (Fig. 3):

1. the basal clastic division, Middle Cambrian through Middle Ordovician in age;

2. the carbonate-evaporite division, representing the time span from Upper Ordovician through Mississippian; and

3. the upper clastic division, consisting of Mesozoic and Cenozoic strata.

2.2.1 Basal clastic division

The Lower Phanerozoic division consists of the Deadwood Formation (Middle Cambrian) and the overlying Winnipeg Formation (Lower Ordovician) which are separated by a major stratigraphic break. The former comprises mainly mudstones and sandstones and is restricted to the southwestern part of the study area (Fig. 4). It is missing in the rest of southern Manitoba, where the Winnipeg Formation directly overlies the Precambrian basement with an unconformable contact (McCabe, 1978; Simpson et al., 1987).

The Winnipeg Formation along its outcrop belt in Lake Manitoba consists of an upper sandstone and shale unit and a basal sandstone unit (Baillie, 1952). Elsewhere in southern

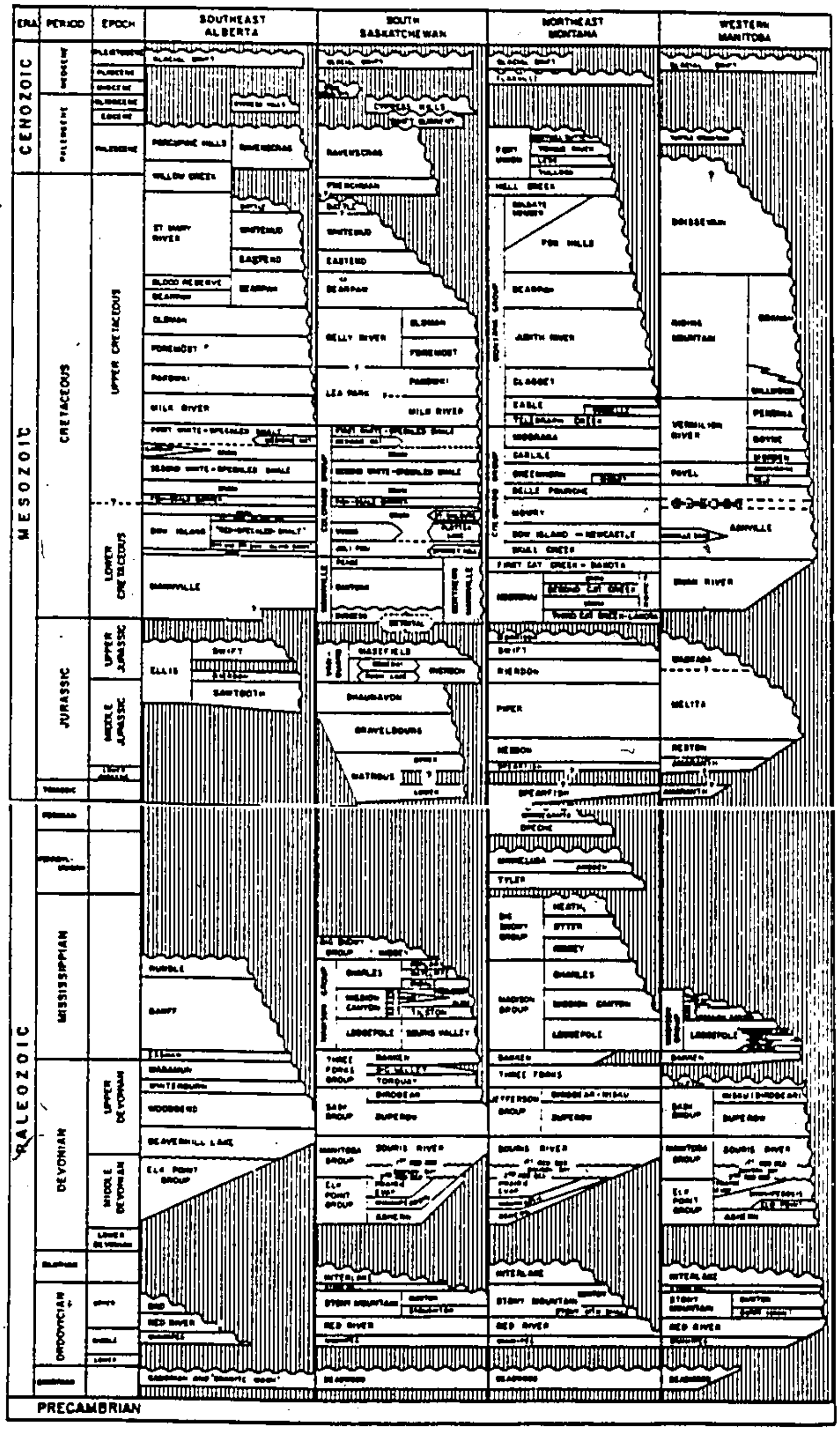

Fig. 3. Stratigraphic correlation and nomenclature chart for the northern Williston basin region (after Simpson and Dennison, 1975).

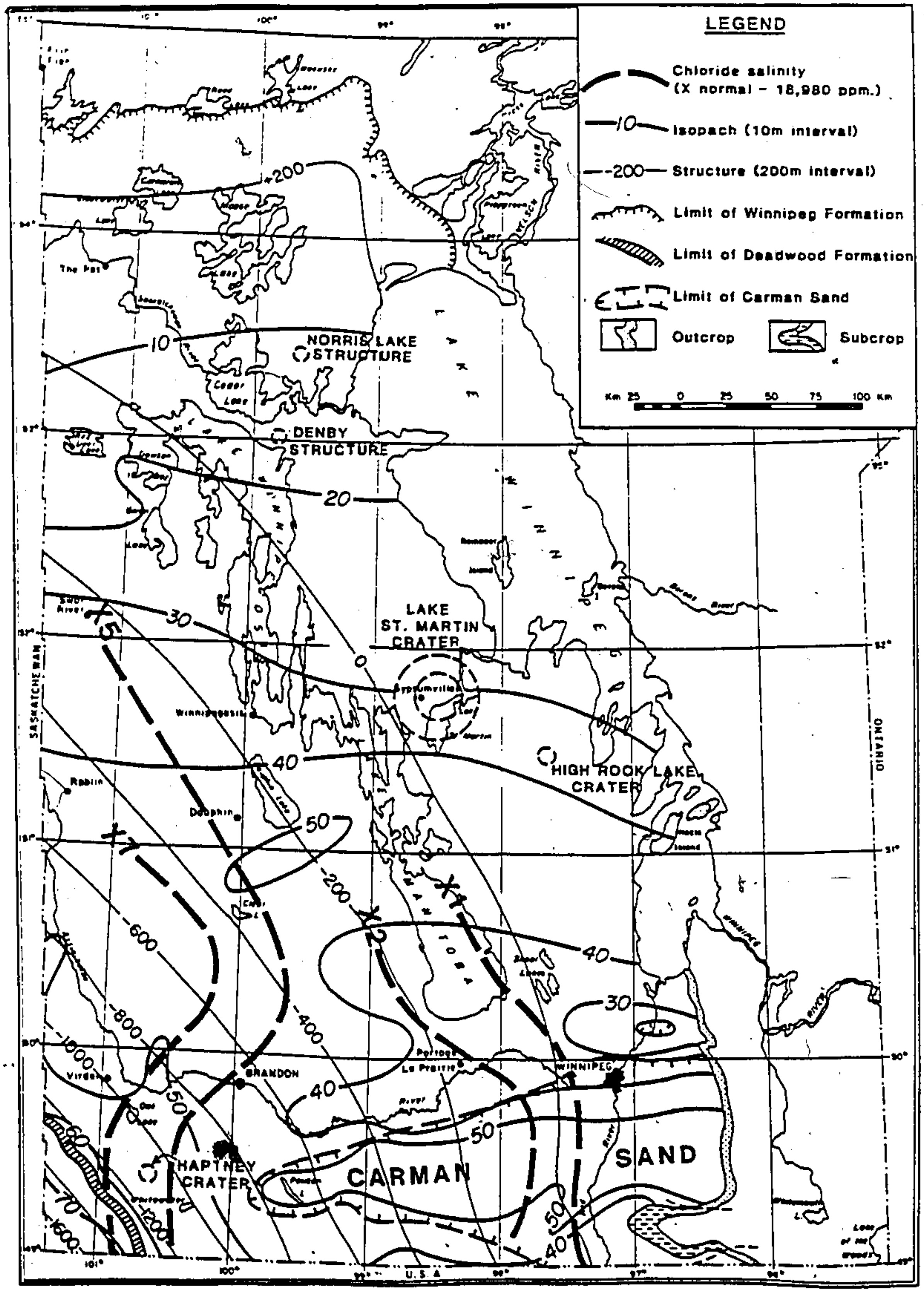

Fig. 4. Isopach-structure contour and salinity map, basal clastic unit, southwestern Manitoba (after Simpson *et al.*, 1987).

Manitoba, the shale occurs at the base of the formation (Christopher et al., 1971, 1973). Considerable lateral variation in lithology also occurs. Differential compaction features are associated with anomalously thick sections of sand. An example of such a feature is the Carman Sand, encountered south of Winnipeg (McCabe, 1967, 1978). Simpson et al. (1987) reported a northward attenuation of the shale intercalations within this unit.

2.2.2 Carbonate-evaporite division

In the study area, the entire carbonate-evaporite division conformably overlies the Winnipeg Formation. Further northeast, in central Manitoba, it rests unconformably on the Precambrian basement (Simpson and Dennison, 1975). Two main subdivisions are distinguished and are separated by an unconformity of regional extent. The first is Middle Ordovician through Silurian in age, whereas the second is Middle Devonian through Mississippian. However, subordinate unconformities followed by deposition of red beds and evaporites are also encountered. Strata of the carbonate-evaporite division from the Middle Ordovician Red River Formation to the Upper Devonian Souris River Formation are exposed along the outcrop belts in the vicinity of the Lakes Winnipeg, Winnipegosis and Manitoba. The rest of the Paleozoic succession, from the Upper Devonian Duperow Formation through the entire Mississippian succession, is truncated at the pre-Mesozoic unconformity (Simpson et al., 1987).

The Ordovician part of the carbonate-evaporite division includes, in ascending order, the Red River, Stony Mountain and Stonewall Formations. The latter straddles the Ordovician-Silurian time boundary. The Red River Formation along its outcrop belt near Lake Winnipeg consists of dolomitic limestone and dolostone. In the same area, the Stony Mountain Formation comprises calcareous shales, argillaceous dolostones and dolostones (Baillie, 1952). In the subsurface, a northward transition in the former is observed from dolomitic limestone to non-calcareous dolomite (McCabe, 1971). The Stonewall Formation, which outcrops in the Interlake area, consists mainly of arenaceous shales and dolostones (Baillie, 1951b). Christopher et al. (1971, 1973) described the Ordovician sequence above the Winnipeg Formation as containing mainly limestone and dolomitic limestone, interrupted by marker beds with high argillaceous or arenaceous content, such as the shaly Gunn and Penitentiary Members of the Stony Mountain Formation. They also referred to the existence of anhydrite at the top of the Gunton Member of the Stony Mountain Formation and in the middle of the Stonewall Formation.

The Silurian succession comprises the Interlake Group, consisting mainly of dolomites. It can be divided into subgroups by the presence of marker beds (Christopher et al., 1971, 1973). It is exposed in the Interlake area, where four units comprising dolostone are distinct. In the upper part of the two younger units biostromal, as well as coral and algal massive reefs, consisting of dolostone, are observed (Baillie, 1951b). The latter, however, represent the Middle Interlake Group, since the entire Upper Interlake has been removed by erosion in the Manitoba part of the Williston basin (McCabe, 1971).

The beginning of Devonian time heralded a landmark in the evolution of the Manitoba part of the Williston basin. The Elk Point basin in the west became the dominant factor controlling subsidence and sedimentation. In southwestern Manitoba, a clear distinction can be made between (1) shelf strata, deposited on a stable shelf and represented by the Manitoba outcrop belt (Manitoba Shelf), and (2) basin strata, laid down on a subsiding basin characterized by thick evaporitic deposits, which occur in the rest of the area. However, the delineation of shelf and basin areas becomes ambiguous during early Upper Devonian times (Baillie, 1953, 1955).

Christopher _et al_. (1971, 1973) divided the entire Devonian sequence into four phases. The first one includes, in ascending order, the Elk Point Group, the Dawson Bay Formation and the Davidson Member of the Souris River Formation. Each one comprises three distinct units, namely from bottom to top, red beds, carbonate rocks and evaporites. By far, the Elk Point Group has been considered as the most significant component since it includes the thickest evaporitic deposits which constitute the Prairie Evaporite. It begins with the red beds of the Ashern Formation, representing most probably the hiatus between Late Silurian-Middle Devonian, followed by the thin-bedded limestones of the Elm Point Formation and the dolostones of the Winnipegosis Formation.

In contrast with Baillie (1953, 1955), who considered the Elm Point Formation underlying the Winnipegosis dolostones, McCabe (1971) ascribed its presence to lateral undolomitized interreef facies of the Winnipegosis Formation. The latter includes biohermal organic reefs (Fig. 5) comprising structureless masses of dolostone and interreef beds consisting of bedded dolomite (Baillie, 1951a, 1953, 1955). Pinnacle reefs are also abundant, punctuating the continuity of the interreef areas. A prominent north-trending fringing reef is encountered within the study area east of the Saskatchewan- Manitoba border (McCabe, 1967, 1971).

The Winnipegosis Formation is succeeded by the Prairie Evaporite, comprising in the central part of the Elk Point basin salt interbedded with anhydrite in the upper beds. Close to the margins of the basin, anhydrite is on top of the salt extending to the shelf area near the Manitoba outcrop belt, where it overlaps Winnipegosis shelf facies, thus indicating an eastward extension of the basin during the final stages of its evolution (Baillie, 1953, 1955). The maximum thickness of the Prairie Evaporite in

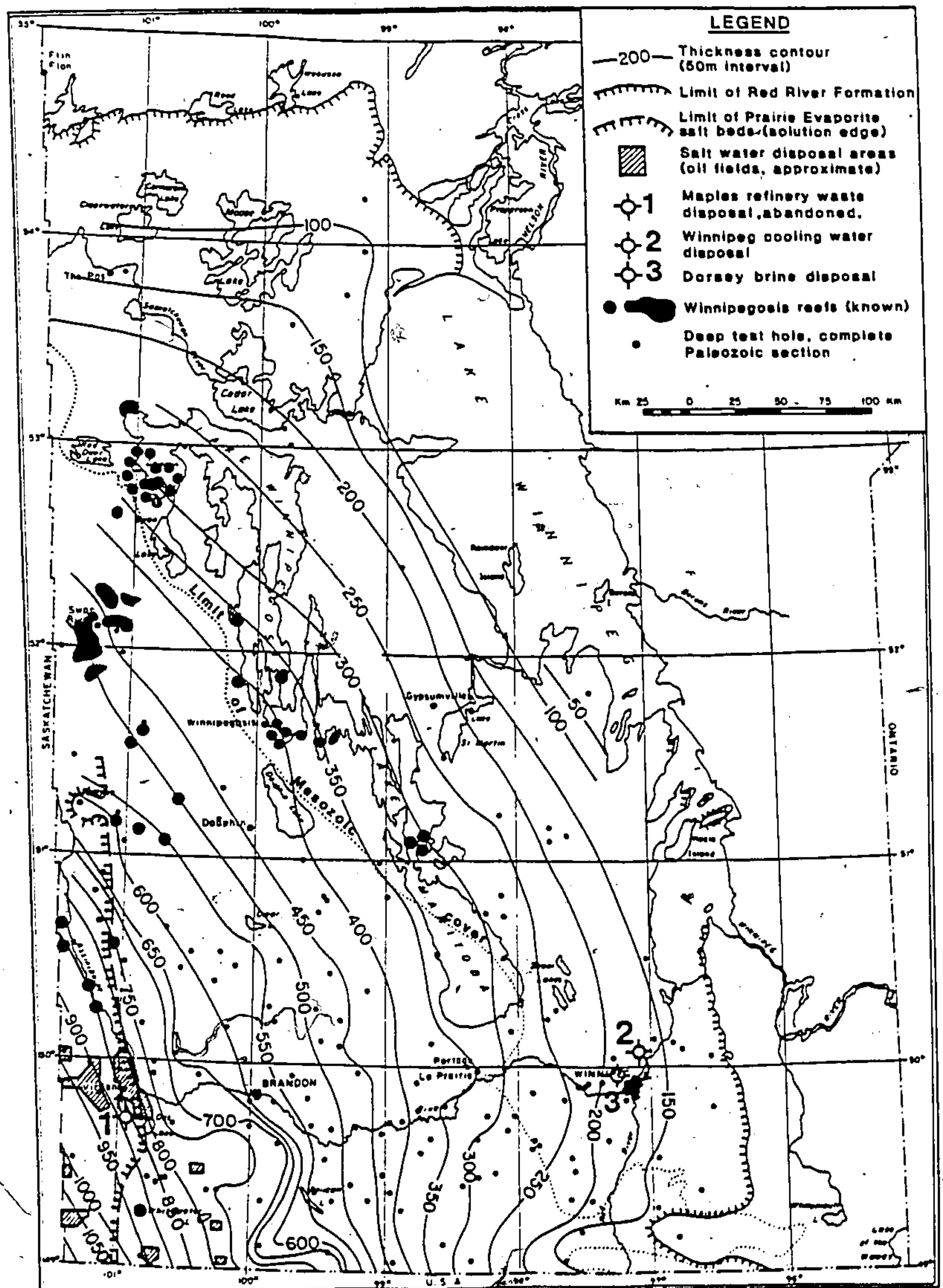

Fig. 5. Isopach map, carbonate-evaporite unit, southwestern Manitoba (after Simpson et al., 1987).

southwestern Manitoba occurs southwest of Virden, where an evaporitic section 150 m thick is encountered. West of Virden the evaporites consist mainly of salt overlain by anhydrite and a veneer of potash beds. Further east, anhydrite becomes the predominant constituent (Bannatyne, 1959). McCabe (1967, 1971) assigned to the present salt limit a solution rather than a depositional nature. The potash horizon at the top of the Prairie Evaporite can be traced in an north-south direction along the Saskatchewan-Manitoba border, extending further west into Saskatchewan. The potash deposits consist mainly of sylvite, as well as sylvinite and carnallite mixed with halite (Bannatyne, 1960).

The younger Dawson Bay Formation and the Davidson Member of the Souris River Formation begin with the Second and First Red Beds respectively, which constitute persistent shale units. The second phase of Devonian strata includes the limestones and the calcareous shales of the higher beds of the Souris River Formation. It is followed by the third phase comprising the Saskatchewan Group, which consists of the Duperow and Nisku (Birdbear) Formations. The former has a lower part of non-argillaceous carbonates, overlain by argillaceous limestones and calcareous shales. The latter consists of non-argillaceous carbonates. Baillie (1953) reported that the carbonates of the Nisku Formation might represent in part a reef complex. The regressive phase of the Devonian was terminated by the deposition of the red shales and siltstones of the Lyleton Formation which represents the fourth and last phase of the Devonian cycle.

During Mississippian times, the subsidence of the Williston basin was again the factor controlling sedimentation in southwestern Manitoba. However, the presence of facies high in shale content which coincide with a depression centered in central North Dakota known as the Mandak Embayment, and its westward shift during Mississippian, indicate that the latter has exerted also a significant control (McCabe, 1959). The Mississippian cycle started with the deposition of the Bakken Formation comprising mainly bituminous shales (Baillie, 1953, 1955). It was followed by the Lodgepole Formation comprising upper and lower parts. Its lower part in Manitoba consists of clean limestone in the east, represented by the Scallion Member, grading westward into argillaceous limestones. The only exception is the presence in the east of two occurrences of Lower Lodgepole characterized by high shale content. The latter represent the Routledge Shale, which overlies the Bakken Formation (McCabe, 1959, 1971).

Further east, in the Saskatchewan shelf, the Lower Lodgepole grades again into clean bioclastic limestone (Porter, 1958). The upper part consists of limestones interbedded with calcareous shales. Lower cyclical sequences at the bottom of the upper part, comprising the Virden and Whitewater Lake Members, are the main oil reservoirs in southwestern Manitoba. Lodgepole and Mission

Canyon strata in the central part of the Williston basin, consisting of bituminous limestones, might constitute the source rock. The youngest strata of the Mississippian are represented, in ascending order, by the Mission Canyon and Charles Evaporite Formations. The MC1 and MC2 Members of the Mission Canyon Formation comprising limestone and evaporites respectively, are correlated with the Tilston Beds of Saskatchewan. The MC3 Limestone and the Charles Evaporite are equivalent to the lower part of the Frobisher-Alida Beds of Saskatchewan. Clastics at the top of the Mississippian are due to the erosion following the emergence of the sedimentary sequence (McCabe, 1959, 1971).

Simpson et al. (1987) treated the entire carbonate-evaporite division as a carbonate sequence interrupted by the presence of persistent shaly or evaporitic facies, such as "the shaly Gunn Member of the Stony Mountain Formation, the shaly Ashern Formation, the Prairie Evaporite-Second Red Beds interval, the Bakken-Lyleton shale interval and the Charles-Mission Canyon Evaporites". They also argued that these units are best developed in the southwestern part of the province, corresponding physiographically to the Manitoba Uplands.

2.2.3 Upper clastic division

The final stages of the evolution of the Cordillera in the west, coinciding with its emergence, gave rise to the provenance for clastic detrital material, laid down to form the upper clastic division (Porter et al., 1982) (Fig. 6). Two main unconformities are present within the uppermost sedimentary division, one separating Jurassic from Cretaceous strata and the other Upper Cretaceous from Tertiary rocks.

The first phase of the upper clastic division includes Triassic(?)-Jurassic strata, comprising in ascending order the Amaranth, Reston, Melita, and Waskada Formations. The first two constitute the Jurassic red beds, deposited on a karstic-trellis topography, reflecting the pre-Mesozoic erosional interval of the Paleozoic rocks and giving rise to considerable thickness variation. In Manitoba they extend to the east beyond 96 degrees longitude (Christopher et al., 1971, 1973).

The contact of the Amaranth Formation with the Mississippian erosional surface is marked by the presence of a basal breccia (Stott, 1955). It consists of an upper and a lower unit. The Lower Amaranth comprises red beds of argillaceous siltstone and shale and is correlative with the oil-producing Spearfish Beds of North Dakota (McCabe, 1971). The Upper Amaranth consists of marine red beds of shale, dolomite and anhydrite. Eastward in Manitoba, this unit is close to the surface and part of the Amaranth Evaporite (anhydrite) has been altered into gypsum (Davies et al., 1962).

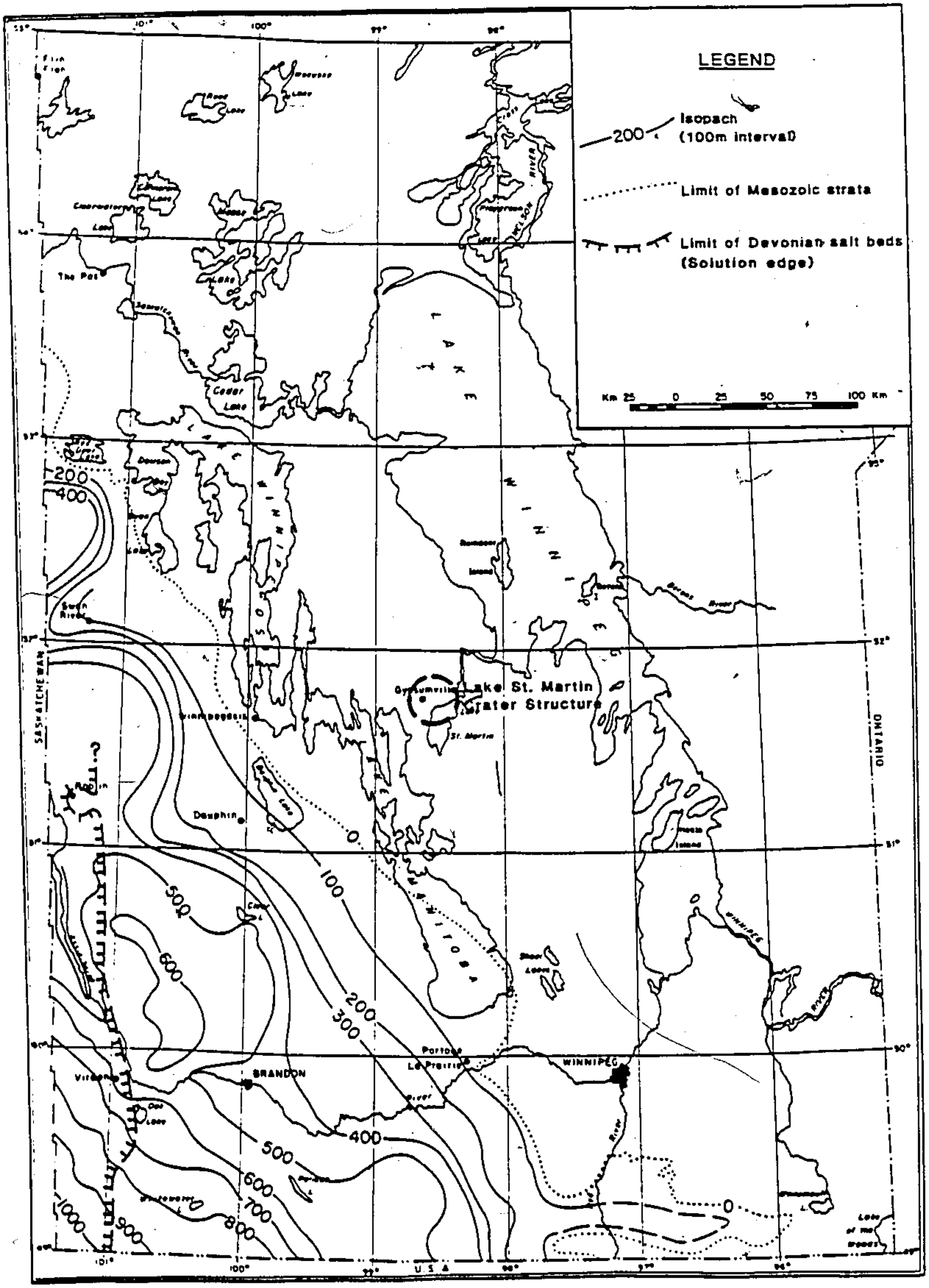

Fig. 6. Isopach map, upper clastic unit, southwestern Manitoba (after Simpson et al., 1987)

The overlying Reston Formation comprises mainly shales which are more abundant in the lower part. However, in the Virden area a sandy oolitic limestone of the Reston overlies the Amaranth Formation. The Middle and Upper Jurassic Melita and Waskada Formations respectively represent the grey beds. The former comprises the most extensive distribution of Jurassic strata in Manitoba (Stott, 1955). It contains a lower part consisting of shales interbedded with sandstones and an upper part including shales, thin beds of limestone and lenses of anhydrite (Davies et al., 1962).

Significant sandstone aquifers within the Melita Formation are correlative with the oil-producing lower member of the Saunavon Formation in southwestern Saskatchewan which comprises a lithographic limestone (Christopher et al., 1971). A great part of the Waskada Formation in Manitoba has been removed as a result of the pre-Cretaceous erosion. It consists mainly of sand and shale interbeds, and extends as a tongue from the southwestern corner of Manitoba as far north as Daly oil field (Stott, 1955).

The second phase of the upper clastic division is represented by the Cretaceous Swan River Formation, the Colorado Group and the Montana Group. The Lower Cretaceous Swan River Formation exhibits a considerable thickness variation reflecting to a great extent its deposition on the eroded Jurassic surface. It correlates with the Mannville

Group of Saskatchewan which comprises three distinct units in the Swift Current region grading elsewhere, including southwestern Manitoba, into an interfingering of quartzose sandstones and siltstones (Christopher et al., 1973). An east-west oriented belt is running from Brandon, along which Mannville (Swan River) sediments are thin or completely absent (Davies et al., 1962).

The Mannville Group was followed by the deposition of the Colorado Group, consisting mainly of marine shales interdigitated with regressive-transgressive sandstone units (Simpson and Dennison, 1975). The latter is of Lower through early Upper Cretaceous in age and is divided into two subgroups at the base of the Second Speckled Shale, a widespread marker unit in Saskatchewan equivalent to the calcareous shales of the Favel Formation in Manitoba. The Colorado Group also includes the Fish-Scale Marker, a persistent shale unit which divides the Cretaceous into Lower and Upper Epochs. In Manitoba, the Colorado Group is bounded at the bottom by the Swan River Formation and at the top by the Pembina Member of the Vermilion River Formation (Christopher et al., 1971, 1973).

The Lower Colorado Subgroup is mainly represented by the Ashville Formation consisting along its outcrop in the Manitoba Escarpment of a lower shale unit with minor glauconite and an upper calcareous shale. In the subsurface a sand unit known as the Ashville Sand occurs between the lower and the upper shale (Davies et al, 1962). It is coeval to the oil-producing Viking Sand of west-central Saskatchewan and extends from northeast of Virden in a southward direction, pinching out to the Ashville Shale southwest of a line drawn through Township 12, Range 29WPM and Township 2, Range 12WPM (McCabe, 1971).

The Upper Colorado Subgroup is represented, in ascending stratigraphic order, by the Morden and Boyne members of the Vermilion River Formation, consisting mainly of argillaceous sediments with extensive sandstones in eastern Saskatchewan. Generally the Morden Member comprises a non-calcareous shale unit while the Boyne Member consists of calcareous shale and is correlated with the First Speckled Shale of Saskatchewan.

The Montana Group includes from bottom to top the Pembina Member of the Vermilion River Formation, and the Riding Mountain and Boissevain formations. The former consists of grey and black shale with bentonite becoming abundant in the upper part (Christopher et al., 1973). The presence of bentonite can be attributed to the alteration of volcanic ash derived from a westward source, probably associated with orogenic activity (Davies et al., 1962). The overlying shales represent the Upper Cretaceous Riding Mountain Formation comprising three members. The lower Millwood Member consists of soft bentonitic silty clay overlain by the hard siliceous clayey shales of the middle Odanah Member which is in turn succeeded by the soft clayey silt of the upper Coulter Member. It is followed by the

Boissevain Formation which is composed of sand with minor clay and silt (Bamburak, 1978).

The Cretaceous-Tertiary unconformity represents an interval of erosion which was followed by the deposition of the Turtle Mountain Formation (Paleocene). The latter is limited to the Turtle Mountain area of southern Manitoba which is the site of a paleo-depression at the northeastern flank of the Williston basin. It comprises sand, silt and clay with occurrences of lignite seams (Bamburak, 1978).

Mesozoic strata in southwestern Manitoba are unconformably overlain by Quaternary sand and gravel aquifers, interbedded with till, representing glacial and non-glacial sediments reflecting at least three glacial and non-glacial intervals (Klassen, 1969).

2.3 Structure

In the general Williston basin area two main types of structure are distinguished (Kent, 1968):

1. Deep-seated structures of orogenic or epeirogenic origin. The former are associated with igneous intrusions accompanying the Laramide orogeny and are restricted to the southern part of the Williston Basin. The latter were formed by the rejuvenation of structural highs present in the Precambrian basement. Many of those features, involving folding and draping of the overlying strata, subsequent to reactivation of highs and differential compaction above

them, have been reported from Saskatchewan (Sawatzky et al., 1960). Upward movement and deformation of sediments upon rejuvenation of basement highs (monadnocks) might have occurred during the Laramide orogenic event (Simpson, 1978).

2. Solution-generated collapse structures which resulted from the local removal of salt from the Prairie Evaporite followed by downward displacement of the overlying strata. They are exemplified by the presence of fracture-bounded sinks, elongated depressions, as well as linear trends along which salt solution has taken place. In many instances, sites of salt removal comprise the locales of brecciated strata.

In contrast to Saskatchewan, basement highs do not appear to constitute any major attribute of the structural pattern in Manitoba. It is noteworthy that one basement feature evident in the vicinity of Township 29, Range 2WPM, might represent a unique paleotopographic high in Manitoba (McCabe, 1971). However, basement lineaments are also important features to be added to those noted above. Their significance is manifested by the influence of the boundary zone between the Superior and Churchill crustal blocks on the present structural framework of southern Manitoba (McCabe, 1967).

A genetic relationship also appears to exist between solution-generated collapse structures and basement lineaments, as evidenced by the location of the present salt solution edge relative to the boundary zone. It has been postulated by McCabe (1967) that "true" (epeirogenic) tectonic movements and salt tectonics were linked in giving rise to the present structural configuration of strata. The continuity of the strata is interrupted in some places also, by the presence of more or less circular structures of cryptovolcanic or meteoritic origin, which appear to affect the Precambrian basement (Simpson *et al.*, 1987).

2.3.1 Basement linear features

The moderately uniform pattern of the Precambrian basement, as well as the relatively undisturbed configuration of the strata comprising the Williston basin as evidenced by their gentle southwestward dip, might lead to the inference that Precambrian blocks did not exert any major influence on the structural evolution of the Phanerozoic sequence. A deeper insight, however, reveals anomalous patterns commonly found to be associated with weakness zones of the basement. Geophysical methods have permitted the delineation of basement features accounting, to a major extent, for geological structures within the overlying sedimentary strata. Basement lineaments have been considered the most significant components as indicated by prominent gravity and magnetic trends.

Kent (1974) in a general account of the northern Williston basin, interpreted weakness zones at the surface as counterparts of lineaments present on the Precambrian basement. The latter delimit discrete structural blocks, which underwent differential movement in response to the forces inducing regional uplift or subsidence. In many instances coincidence of these features with oil field trends has been observed. Wilson et al. (1963) ascribed the presence of gravity gradients, south of Regina and parallel to the present salt edge, to basement features which might represent lineaments or highs, thus indicating possible interrelationships between these features.

In southwestern Manitoba, the most conspicuous feature of the Precambrian basement, other than the Moose Lake syncline discussed below, is a slight flexure south of Winnipeg. It is known as the Carman flexure (Fig. 2) and was important in localizing accumulation of the Carman Sand during Middle Ordovician time. Its effect, however, appears to have been lost after the deposition of the overlying Red River Formation (McCabe, 1971, 1978).

The prominent lineament in southern Manitoba is the boundary zone between the Superior and Churchill structural provinces. The boundary zone between the two Precambrian blocks comprises mainly gneisses and is a southern extension of a major structural feature of the Precambrian Shield in northern Manitoba. It is bounded to the west by a northwestward-trending fault zone, coinciding with the gravity low of the Thompson Nickel belt. A gravity trend, the Nelson River gravity high, runs through the middle of the gneissic belt, marking the boundary between the two

Precambrian provinces. However, the truncation of the east-west oriented structural grain of the Superior province at the fault zone, indicates probably the latter as the main boundary (Wilson and Brisbin, 1962).

Kornik (1969) on the basis of magnetic trends, extended the boundary beneath the Phanerozoic cover as far south as Swan River. On an overall aeromagnetic study of Manitoba, exclusive of the southwestern part, Kornik (1971) distinguished the position of the boundary as related to a western and eastern area of low- and high-magnitude anomalies, coinciding with the Churchill and Superior provinces respectively. Truncation of the east-west-oriented magnetic highs of the Superior province at the boundary zone was also observed.

Bell (1971), reported the difficulty in extrapolating the boundary in the rest of southwestern Manitoba because of different geophysical responses of the basement rocks beneath the Phanerozoic cover, from those of their exposed part in the Shield. Magnetic and gravity data were used for further extrapolation of the boundary up to the southwesternmost corner of the province. Green _et al._, (1979) considered the boundary zone to comprise the transitional gneissic zone and the Thompson Nickel belt. Its extension up to the southern boundary of Manitoba is a low-relief magnetic zone and its eastern limit marks the western edge of the east-west-trending structural grain of the Superior block.

The boundary zone was the site of recurrent tectonic activity during Phanerozoic times. A slight flexure of the Precambrian basement northwest of Lake Winnipeg (Fig. 2) lies close to the Nelson River gravity high and is known as the Moose Lake syncline. From the deformation pattern of the overlying strata, a post-Middle Silurian age of this feature has been inferred (McCabe, 1967), suggesting tectonic activity along the boundary during Early Paleozoic times.

A great part of structural and isopach anomalies in southwestern Manitoba is generally oriented along a northward-trending axis, designated the Birdtail-Waskada axis. It coincides approximately with the eastern limit of the belt of low magnetic relief, which represents the extension of the boundary zone in southern Manitoba (Fig. 7). All the area to the east of that trend is underlain by the Superior structural block and has undergone more subsidence and uplift during periods of deposition and erosion respectively.

This is in contrast to the western area, corresponding to the Saskatchewan part of the Williston basin, which is underlain by the Churchill structural block (McCabe, 1967, 1971). This is best exemplified by the thinning of the Devonian formations in the vicinity of the Birdtail-Waskada axis and abnormal thickening eastward, which might reflect also salt removal in depth (Norris et al., 1982). It may be argued that the extension of the Prairie Evaporite anhydrite

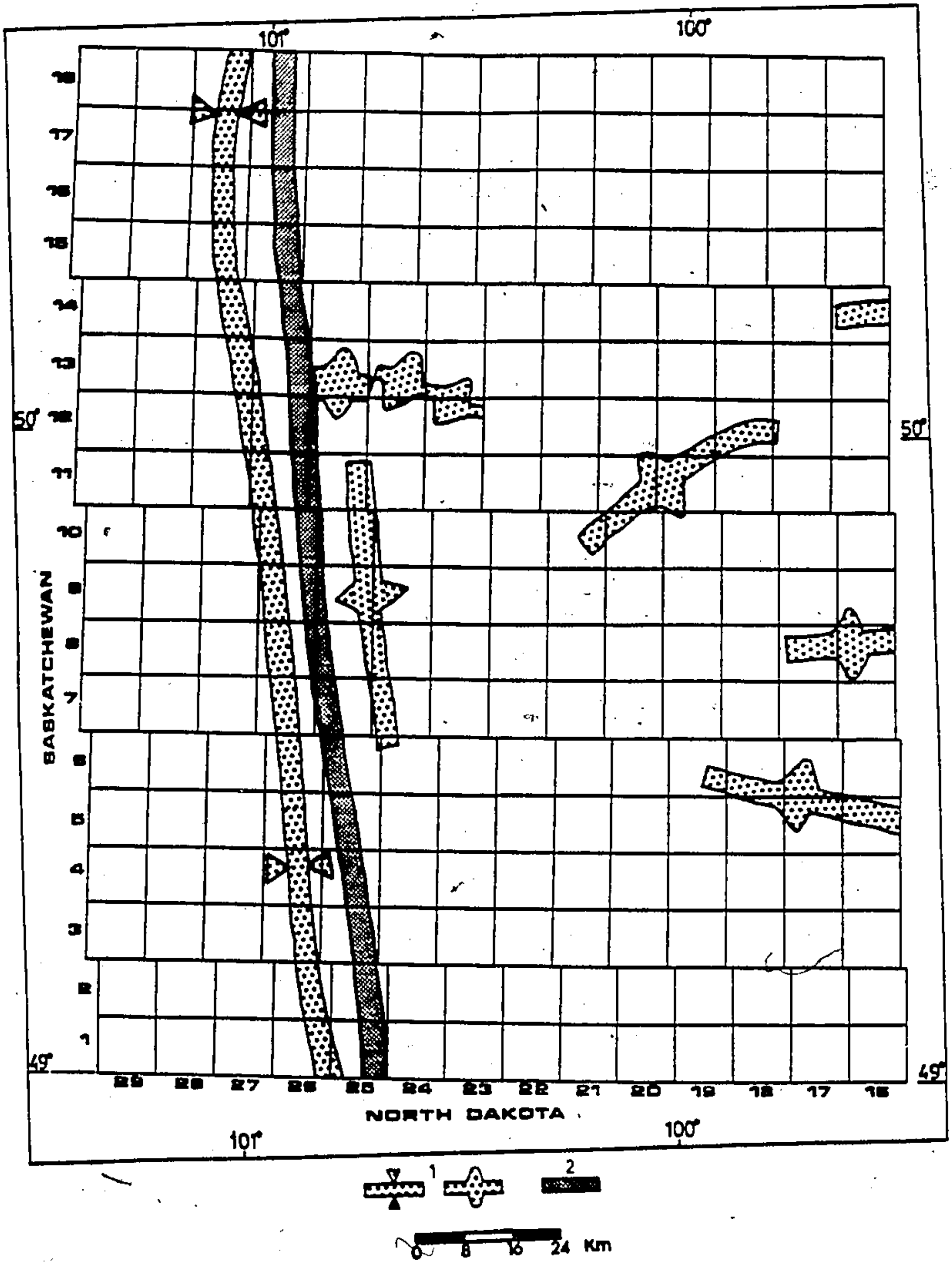

Fig. 7. Map showing main tectonic features of the study area. 1) magnetic anomaly; 2) Birdtail-Waskada axis (adapted from Simpson, 1983).

zone to the previously stable Manitoba shelf provides concrete evidence of the differential subsidence of the correspondingly underlying crustal block. Reactivation of the boundary zone should extend at least up to Late Cretaceous times, as evidenced by the presence of a fault zone. This latter was revealed by an east-west seismic survey across the Nelson River gravity high in southeastern Saskatchewan, where structural disturbance of the Second White-Speckled Shale was observed. Salt-solution features were also reported (Hajnal and McClure, 1977).

In southwestern Manitoba, salt-solution structures and Winnipegosis fringing reefs are the most significant features encountered along the Birdtail-Waskada axis. The economic implications of this relationship are evidenced by the position of the eastern limit of the Prairie Evaporite potash beds, relative to the location of Winnipegosis fringing reefs (Bannatyne, 1960), as well as by the hydrocarbon potential of structures along the Birdtail-Waskada axis (McCabe, 1967).

2.3.2 Solution-generated collapse structures

Solution-generated collapse structures, resulting from salt solution by groundwater in depth, are superimposed on the overall structural pattern of the Williston basin. The initial observations leading to this significant discovery were probably made at the beginning of the century, when

Cole (1915) reported the presence of brine springs in the Manitoba Devonian outcrop belt and linked their occurrence to salt removal by meteoric waters. Since then significant studies have been carried out on the location of these structures in the Canadian part of the Williston basin.

2.3.2.1 Recognition of solution-generated collapse structures

Simpson (1978, 1987a, 1988) summarized the features commonly arising as a result of salt removal by solution. Structural downwarping of strata, as well as anomalous thickening of formations overlying the disturbed rocks are the most conspicuous features observed on structural and isopach maps leading to the recognition of these structures. The age of the strata exhibiting anomalous increases in thickness is the best indicator for the time of salt solution. Repetition of those anomalous patterns in particular sections has been ascribed to recurrent leaching of salt beds by circulating groundwater. Linear trends defined by solution-generated collapse structures, along which age contrasts occur, is a commonly encountered case. They are indicative in many instances of progressive salt removal with time, along a distinct trend.

Direct evidencc of salt solution is provided by the frequent occurrence of collapse breccias. Stratigraphic cross-sections have proved to be the most effective tool for demonstration of relationships between missing salt beds and solution-collapse breccias. The latter are mainly the result of downward displacement of overlying strata in the cavities formed by the retreating salt and are very prominent along a belt in Michigan, Ontario and Ohio which marks the solution limit of the Salina salt (Landes, 1948). Solution-generated collapse breccias are generally characterized by the presence of angular fragments, an upward increase in grain size and grain support and a microporosity grading commonly upward through intergranular porosity into fracture porosity. Fracture systems surround discrete, brecciated sections (Simpson, 1988).

Indistinct development of breccias or their absence is a commonly encountered case in places where documented salt solution has occurred. This appears to be the case for some locales in the Manitoba Devonian outcrop belt. The earliest explanation of this was the absence within the salt of limestone interbeds (Middleton, 1961), while Norris et al. (1982) ascribed the same phenomenon to penecontamporaneous salt solution and collapse of the overlying strata.

2.3.2.2 Location of solution-generated collapse structures

Several places exist within the Williston Basin where salt-collapse features occur. On a basinwide scale, Baillie (1953, 1955) referred to their existence on the basis of presence of brecciated sections coincident with missing sections of the Prairie Evaporite. Simpson and Dennison (1975, Fig. 7) delineated salt-solution structures in Saskatchewan beyond, as well as within the present limit of the salt. A major effect of salt removal is the large, salt-free area in southern Saskatchewan, known as the Swift Current Platform. This area constitutes a prominent feature on isopach and lithofacies maps of the Devonian System (Baillie 1953, 1955).

Solution-generated collapse structures in Manitoba are much less distinct by comparison with adjacent Saskatchewan, where their exact locations have been demarcated. This can be ascribed in part to the lesser number of wells in Manitoba penetrating below the Mississippian formations, since most oil-exploration drilling has been focused on the oil-producing horizons. Clusters of wells exist mainly within the oil fields, with relatively sparse well control in the intervening areas.

On a regional scale, discoveries along the Devonian outcrop belt were of major importance in the evolution of ideas on salt solution. Baillie (1951) attributed draping features in the Manitoba Devonian belt to considerable relief, resulting from the presence of the Winnipegosis reefs, and differential compaction of the overlying formations. In contrast, Holter (1969) ascribed the same features, found also in other parts of the Williston basin, to salt solution followed by collapse and draping of younger strata above the reefs. McCabe (1967, 1971) argued that all the Devonian Winnipegosis outcrop belt was initially overlain by salt, which was later dissolved, thus giving an indication of the probable original extent of the Prairie

Evaporite salt basin. He explained the gentle flexure of structure contours of the Prairie Evaporite along the present salt edge (Bannatyne 1960, Fig. 1), as evidence that the salt limit is solution-formed, rather than depositional-formed. Simpson et al. (1987) designated the entire area extending from the present salt edge as far east as Lake Winnipegosis and Lake Manitoba as a "known" area of salt solution and collapse.

Walker (1957, Fig. 4) indicated an area of salt solution in southern Manitoba, later found by McCabe (1959) to reflect the extension of the Mandak embayment, representing a progressive westward salt solution. Stott (1955, Plate 9) ascribed a prominent ridge with adjacent troughs on the pre-Jurassic unconformity, along the Saskatchewan-Manitoba border, to tectonism or pre-Jurassic erosion. The same feature was later reported by McCabe (1967) as coinciding approximately with the Birdtail-Waskada axis and reflecting probably the combined effect of epeirogenic and salt-related tectonics. Structural and isopach anomalies, oriented parallel to the Birdtail-Waskada axis, were attributed by the same author to salt removal in depth during discrete time intervals.

Local aspects related to solution-generated collapse structures, are mainly restricted within the present salt limit. McCabe (1959) considered the Waskada area (Township 1, Range 26 and 27WPM) to be the only one with direct evidence of salt solution and collapse. McCabe (1963) explained differences in age along structural lows, close to the Daly and Virden oil fields, with reference to collapse of strata subsequent to progressive salt solution. Norris et al. (1982) referred to a number of places close to the Saskatchewan-Manitoba border, specifically along Townships 12, 17 and 19, Range 29WPM, where salt removal has been followed by collapse of the overlying strata.

Adjacent to the present salt limit and along the Birdtail-Waskada axis, a special type of solution-generated collapse structure known as a "sombrero" structure is encountered. These are mainly the result of recurrent salt solution around a site of initial salt removal, leading to the formation of structural highs in areas characterized by structural depressions at the onset of salt retreat (Swenson, 1967). They are manifested in the Waskada area in the presence of a window of the MC1 Member of the Mission Canyon Formation within the subcrop belt of the MC3 Member, in the vicinity of Township 1, Range 25WPM. The latter comprises a structural high and is truncated at the pre-Mesozoic unconformity. The window of the Lodgepole Formation in Township 4, Range 25WPM, probably represents a similar case (McCabe, 1967, 1971). The evidence of salt solution in the same area during late Middle Devonian time (Norris et al., 1982) and the truncation of this feature at the pre-Mesozoic unconformity, lend credence to its "sombrero" origin.

2.3.2.3 Mechanisms of salt solution

It appears that no single mechanism can account for the localized leaching of the salt beds by circulating groundwater in depth. In contrast, there is considerable evidence of particular mechanisms for several individual cases. The presence beneath the salt beds of an aquifer with the necessary hydraulic head and the existence of fractures acting as conduits for the water in the otherwise impermeable salt, constitute, according to Parker (1967), the main prerequisites for formation of solution-generated collapse structures. Within the Williston basin the most prominent aquifer is the Winnipegosis Formation, which underlies the Prairie Evaporite and is characterized in many instances by flowing artesian conditions. Fractures were probably formed in response to differential compaction of the salt above individual reefs (Holter, 1969). It is noteworthy that fringe reefs also can comprise the necessary aquifers, as exemplified by the "Rosetown low" in western Saskatchewan (DeMille et al., 1964).

Basement features also have been invoked to account for the initiation of salt solution. Swenson (1967) argued that generation of fractures necessary for the upward flow of water might be localized above basement zones of weakness and minor movements. Such a case is represented by the location of the Regina-Hummingbird trough relative to a basement feature known as Nemo-Estes zone of southern Saskatchewan (DeMille et al., 1964). It is possible that reactivation of basement linear features initiated salt solution by deflecting the flow of water upward through the fractures formed either by tectonic movements or differential compaction (Sawatzky et al., 1960; Wilson et al., 1963).

In Manitoba, there is evidence of salt removal by solution at both the top and the bottom of the Prairie Evaporite Formation. Norris et al. (1982) referred to a case, in the vicinity of Township 17, Range 29WPM, of solution at the salt subface, above a Winnipegosis reef mound, as well as to removal at the salt superface in the area adjacent to Township 12, Range 29WPM, as manifested by the missing potash horizon.

Simpson (1988) ascribed the individual sites of salt removal to specific groundwater-flow regimes. Salt solution at the superface is probably related to lateral flow from recharge areas and drawdown associated with major river systems, involving downward infiltration of water. The former is dealing mainly with water flowing from upland areas and discharging in lowlands, as discussed by Toth (1962, 1963) and exemplified by the overall groundwater flow pattern of the entire western Canada sedimentary basin (Hitchon, 1969a). The latter is not likely to have been of major importance in Manitoba, since the fine grained Second Red Beds of the overlying Dawson Bay Formation have undoubdedly formed a permeability barrier to migrating fluids (Simpson et al., 1987).

Solution along the eastern margin of the salt, which most probably is the case for the present salt edge in Manitoba, might be in part explained by lateral flow of groundwater from recharge areas. Carbonate mounds of the Winnipegosis Formation and associated compaction-formed fractures provided easy access to the salt subface for circulating groundwater. The contribution of the Birdtail-Waskada axis in the initiation of salt removal is likely to have been of major importance. Tectonic movements along this axis may have induced fracturing of the overlying strata. Its coincidence with the prominent Winnipegosis fringing-reef trend and the present salt edge (McCabe, 1967), evidence a significant role in both control of facies and initiation of salt solution.

2.3.2.4 Timing of solution

Considerable evidence exists on salt solution during discrete time intervals for local, as well as regional scale aspects. Walker (1957, Fig. 4) proposed Mississippian through Jurassic salt removal in order to explain the presence of an anomalously thick Mississippian section in southern Manitoba. The same area was shown by McCabe (1959) to indicate salt solution mainly during Lodgepole times, as evidenced by the lack of major anomalies for the Madison Group as a whole. Studies in the Devonian outcrop belt (Norris *et al.*, 1982) and in the subsurface (McCabe, 1967) have revealed evidence for the solution-removal of salt beds during deposition of the Dawson Bay, Souris River and Duperow successions.

Truncation of structural highs at the pre-Mesozoic unconformity indicates solution extending into Bakken and pre-Jurassic times. It seems, however, that the time span represented by the sub-Mesozoic unconformity involves the most significant episodes of accelerated salt removal. Christopher (1961) argued that periods of cratonic emergence are the most favourable for the salt solution process; so that long hiatuses namely, Late Mississippian-Middle Jurassic, Late Jurassic-Early Cretaceous and Cenozoic-Quaternary are those most likely linked to accelerated salt removal. The latter appears to comprise a plausible hypothesis, since epeirogenic movements associated with cratonic emergence can cause abnormally high fluid pressures (Bradley, 1975), which in turn may give rise to high hydraulic heads, thus promoting leaching of salt in the subsurface. This case seems to be valid to a great extent for Manitoba.

McCabe (1963, Fig. 12) invoked salt solution to account for age contrasts in strata along structural disturbances and indicated the pre-Mesozoic hiatus as the interval involving the most pronounced structural deformation. Should most of the structures in the vicinity of the Daly and Virden oil fields be the result of salt solution, this process should extend at least up to early Upper Cretaceous. There is however an additional evidence concerning the pre-Mesozoic erosional interval as the time span of the most extensive salt removal. Most of the fractures encountered in the Virden field reflecting collapse following salt solution are anhydrite-impregnated. The anhydrite was formed within the fractured Mississippian carbonates probably during the deposition of the Jurassic Amaranth Evaporite. The latter is indicative of post-Mississippian and pre-Jurassic salt removal and collapse (Young and Greggs, 1975).

For the Jurassic generally there is evidence in the form of anomalous increase in thickness, indicative of salt solution. Isopach anomalies well developed in the Upper Jurassic formations are not present in Lower Jurassic units (Stott, 1955, Plates 4-8), thus reflecting salt removal during Upper Jurassic. Isopach anomalies are also conspicuous in the Lower Cretaceous Lower and Upper Ashville formations, as well as in the early Upper Cretaceous Favel Formation (Bannatyne, 1970, Figs. 19, 20, 24) which can be accounted for by salt removal during Cretaceous times.

Anomalous increases in thickness for strata of the upper clastic division might also be attributed to differential compaction features as a result of lateral variations from sand to shale. The latter is likely to be the case for the Lower Cretaceous Ashville Sand (McCabe, 1963). It is noteworthy that Simpson (1983, Fig. GS-23-3, 4) on the basis of the position of the anomalously thick Ashville sand relative to basement magnetic anomalies and the salt solution edge, ascribed the same feature, at least in part, to basement- and salt-related tectonics.

It is generally accepted that salt removal by solution in depth is a process active up to recent times. Bamburak (1978) referred to the likelihood of salt removal in order to explain minor structural disturbances within the Upper Cretaceous- Paleocene sequence in the Turtle Mountain area of southern Manitoba. Christiansen (1967) reported collapse features ranging in age from Late Cretaceous through Pleistocene in the Saskatoon area of Saskatchewan. However, the most direct evidence during present days that salt solution is a continuous and still active process, is provided by the discharge of brine springs in the Devonian outcrop belt.

2.3.2.5 Implications: a brief discussion

The collapse of the overlying strata, upon the removal of a discrete salt section, heralds a landmark in the groundwater flow regime which coincides with the onset of the cross-formational flow. The latter will exert a major influence on possible environmental hazards related to waste disposal practices, as well as the existence of potential fluid migration paths associated with commercial hydrocarbon and other mineral-resources accumulations. The interrelationships between the location of the Daly and Virden oil fields and the episodes of accelerated salt removal is a case in point.

There have been significant hydrocarbon discoveries in the structural highs associated with sombrero structures, as in the window of the MC1 Member of the Mission Canyon Formation in Manitoba (McCabe, 1971) and in the upper part of the Mannville Group in the Beacon Hill gas field of Saskatchewan, where two townships are underlain by a sombrero anticline (Rowland, 1970).

2.3.3 Circular structures of uncertain origin

There has been some controversy with regard to the origin of some more or less circular features present in the Williston basin and in adjacent areas. They appear to disrupt a great portion of the Phanerozoic sedimentary sequence and in some instances to affect the Precambrian basement. The characteristics most commonly associated with these structures are their circular outline (Fig. 2), the presence of an uplifted rim and a topographically lower central core, the existence of brecciated sections and intense faulting. Two main theories have been proposed to account for their origin: crypto-volcanic and meteorite-impact origin. It is possible that a better insight into the genesis of these structures can be achieved through an examination of geophysical responses.

Short (1970) and Trueman (1976) ascribed a meteorite impact origin to the West Hawk Lake crater and Poplar Bay crater of southeastern Manitoba respectively, because they each exhibited a mass deficiency, as evidenced by a negative gravity anomaly. In contrast, DeMille (1960) attributed a crypto-volcanic origin to the Elbow structure of south-central Saskatchewan which was shown to be outlined by a pronounced positive gravity anomaly.

The most prominent and probably the best described of these structures is the Lake St. Martin crater, which forms a structural high on the Precambrian basement, and is exposed northeast from the northern part of Lake Manitoba. A structural uplift of the rim of at least 210 m is observed and the diameter of the structural disturbance is approximately 26 to 28 miles. Intense faulting and brecciation comprising carbonate and basement igneous rocks are also encountered. The presence of carbonate (Elm Point) fragments within the brecciated section of the St. Martin series, as well as red beds and evaporites probably correlative with the Lower Amaranth Formation, are indicative of the probable original extent of Devonian and younger units. The problem of the origin of the crater revolves around the presence of shock metamorphism which can not be fully explained with reference to any of the proposed mechanisms. A combination of crypto-volcanic and meteorite-impact origin, with the meteorite triggering volcanic emissions, alleviates probably the problem related to its genesis (McCabe and Bannatyne, 1970). Another similar structure is represented by the High Rock Lake crater, southeast from the Lake St. Martin crater, and a meteorite impact origin has been proposed (McCabe et al., 1981).

Within the study area, the Hartney structure, located in the vicinity of Township 5, Range 24WPM, has been attributed to several different causes. It is probably associated with crypto-explosion phenomena accompanied by major faulting and is characterized by an uplifted rim and the presence of breccias in the central hole. The Hartney structure is represented by a structural disturbance 6 to 8 miles in diameter and comprises a structural high on the pre-Mesozoic unconformity. In its central part, which represents a structural low, the entire Mississippian section and part of the Devonian are missing and are replaced by an anomalously thick section of brecciated sandstones and shales probably correlative with the Lower Jurassic Amaranth Formation (McCabe, 1959, 1971). An apparent thickening of the Ordovician Red River Formation in the vicinity of the structure is associated with the faulting accompanying this feature (McCabe, 1978), or infilling of an ancient channel (Haites and Van Hees, 1962). Synsedimentary slump faulting accounts probably for the anomalous thickness and nature of the brecciated section. Lack of mixing of Paleozoic carbonates and Jurassic sediments in the breccias is probably indicative of a post-Mississippian to pre-Jurassic age for the Hartney structure (McCabe, 1971). The absence of the Amaranth Evaporite in the Hartney area (Bannatyne, 1959), is an additional evidence for a pre-Upper Amaranth age of this structure. Other theories on the origin of this feature are major faulting (Hartney fault) accompanied by thrust faults (Haites and Van Hees, 1962), as well as meteorite impact phenomena (Sawatzky, 1974).

Evidence concerning the possible interrelationships between these structures and commercial hydrocarbon accumulations is inconclusive. Sawatzky (1974) referred to the possible relationship between meteorite impact phenomena and oil-producing sombrero structures, to propose that the former can provide sites for localized salt solution. The intense fracturing commonly associated with these structures should rule out subsurface waste disposal practices near areas where their occurrence is suspected.

2.3.4 Sub-Mesozoic unconformity

Relatively large-scale flexures, topographic-structural highs, and solution cavities and channels are associated with the sub-Mesozoic unconformity (Fig. 8). Circular structures of uncertain origin, specifically the Lake St. Martin crater and the Hartney structure, as well as the truncated sombrero structures, are also prominent features at the pre-Mesozoic unconformity and are excluded from the following discussion, since they have been already considered in previous sections.

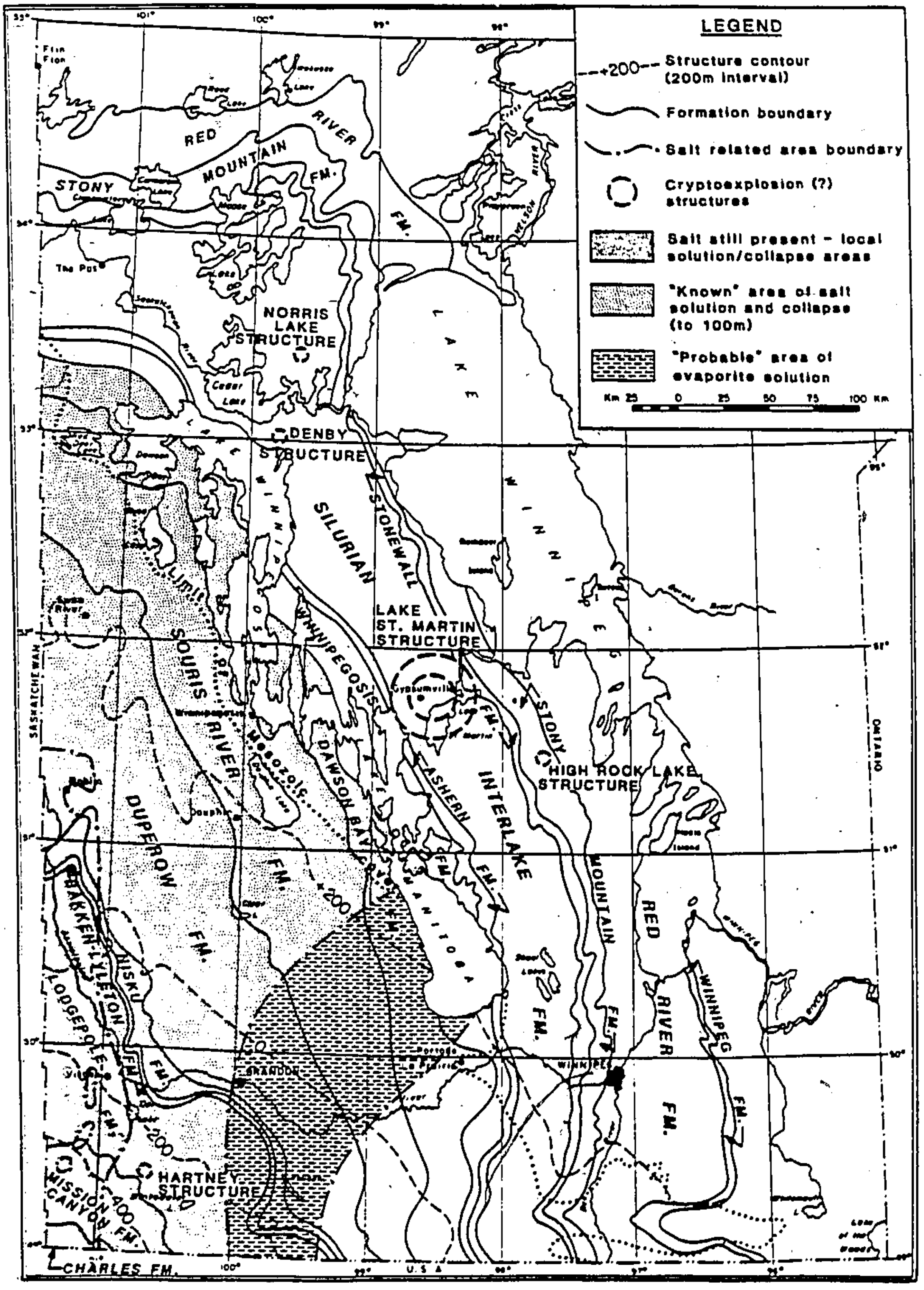

Fig. 8. Structure contour map of sub-Mesozoic unconformity showing outcrop-subcrop belts and areas affected by salt solution and collapse (after Simpson *et al.*, 1987).

2.3.4.1 Large-scale flexures

Large-scale synclinal-anticlinal flexures might reflect tectonic activity or salt solution or even their combined effect. They are manifested especially by the presence of structural depressions and adjacent ridges along the Birdtail-Waskada axis which might represent epeirogenic or salt-related tectonism. However, regardless of the cause-effect relationship, the importance of the boundary zone in controlling the structural integrity during pre-Mesozoic times is highlighted. Within the area of salt occurrence the Daly-Madeline trend is a prominent ridge on the pre-Jurassic erosional surface, extending northward from the Daly and Virden oil fields (McCabe, 1959). The above feature localized the deposition only of the upper part of the Amaranth Formation. The latter is of major importance in controlling the entrapment of hydrocarbons in these areas.

2.3.4.2 Paleotopographic highs

Paleotopographic highs present at the pre-Mesozoic unconformity might represent erosional remnants, tectonic activity during pre-Jurassic times or differential resistance to erosion (McCabe, 1959). The most prominent highs are those encountered along the Mississippian erosional limit. This marks the position of a pronounced escarpment, above which the Lower Jurassic Lower Amaranth Formation is almost absent (Davies *et al.*, 1962). The escarpment is more or less coincident with the subcrop Mississippian-Devonian boundary. One of those paleotopographic highs is represented by a scarp of relatively large areal extent, located along the Mississippian Escarpment in the vicinity of Township 9, Range 19WPM, resulting from the differential erosion between the soft shales of the Lyleton Formation and the hard shales of the overlying Bakken Formation (McCabe, 1978). The entire Amaranth Formation is missing in the adjacent area, more specifically around Township 8, Range 18WPM (Stott, 1955).

Two paleotopographic highs of unknown origin exist also, one in the Duperow Formation south of the Riding Mountain National Park and the other in the Dawson Bay Formation at Portage la Prairie. Irregularities encountered north of the Riding Mountain National Park are probably the result of Winnipegosis reefs and associated salt removal (McCabe, 1971). Four oil fields (Whitewater, Lulu Lake, Tilston and Pierson), located in Townships 3-21, 1-21, 5-29 and 3-29WPM respectively are also associated with local paleotopographic highs of the pre-Jurassic erosional surface. Those highs have exerted a significant control on the entrapment mechanisms for the hydrocarbon accumulations encountered there (Davies et al., 1962).

2.3.4.3 Channels and cavities

Pre-Mesozoic erosion is evidenced by the presence of channels deeply incised into Paleozoic carbonates at the sub-Mesozoic unconformity. Generally the Lower Jurassic sediments, as already mentioned, were deposited on a highly irregular karstic-trellis topography. The most pronounced feature is encountered south of Winnipeg where an east-west-trending channel contains an anomalously large thickness of Amaranth sediments. Far eastward from the limit of the Mesozoic cover in the vicinity of Arborg, close to the contact between the Red River and Stony Mountain Formations, a pre-Jurassic or pre-Cretaceous channel exists, representing a deep dissection of the Paleozoic erosional surface (McCabe, 1971; Simpson et al, 1987). Mesozoic infillings within the channel are probably indicative of the minimum original extent of the Mesozoic units.

Intense subsurface karstification also has resulted in the formation of solution caverns within the Paleozoic carbonates, associated probably in some instances with brecciation. The latter can be even of higher magnitude than that corresponding to collapse subsequent to salt solution (Norris et al., 1982). In the Dawson Bay area, a 2.5 m core from the Souris River carbonates was followed by silica sand and clay representing infillings within a solution-formed cavity (Bannatyne, 1975). In some cases, the formation of large solution cavities has enhanced to a major extent the permeability of carbonate rocks, as exemplified by the upper carbonate aquifer in the Metropolitan Winnipeg area, where high water yields are observed in the vicinity of the areas where these features occur (Render, 1970). The fact that a great many solution-generated collapse structures are probably truncated at the pre-Mesozoic unconformity indicates that frequent occurrence of solution caverns is likely to be expected, as a result of the relatively unrestricted downward seepage of water (Norris et al., 1982).

2.3.4.4 Sub-Mesozoic unconformity and hydrocarbon accumulations

The pre-Mesozoic unconformity has exerted both structural and stratigraphic control on the prolific hydrocarbon accumulations encountered within the study area. The location of the major oil fields in southwestern Manitoba is shown in Figure 9.

Differential subsidence of this erosional surface, affected probably by the Superior-Churchill boundary zone, resulted in a discordance between the general trend of the subcrop belts and their structural contour pattern. As a consequence, a general rise of the Paleozoic belts to the northwest occurred. This accounts in part for the commercial oil accumulations of the Lodgepole Formation in the Daly and Virden oil fields. The Mission Canyon Formation exhibits a structural rise to the southeast and appears to be the only exception. This reasoning can be invoked to explain the lack of any major oil fields in the Manitoba part of the Mission Canyon Formation and their abundance in North Dakota (McCabe, 1959).

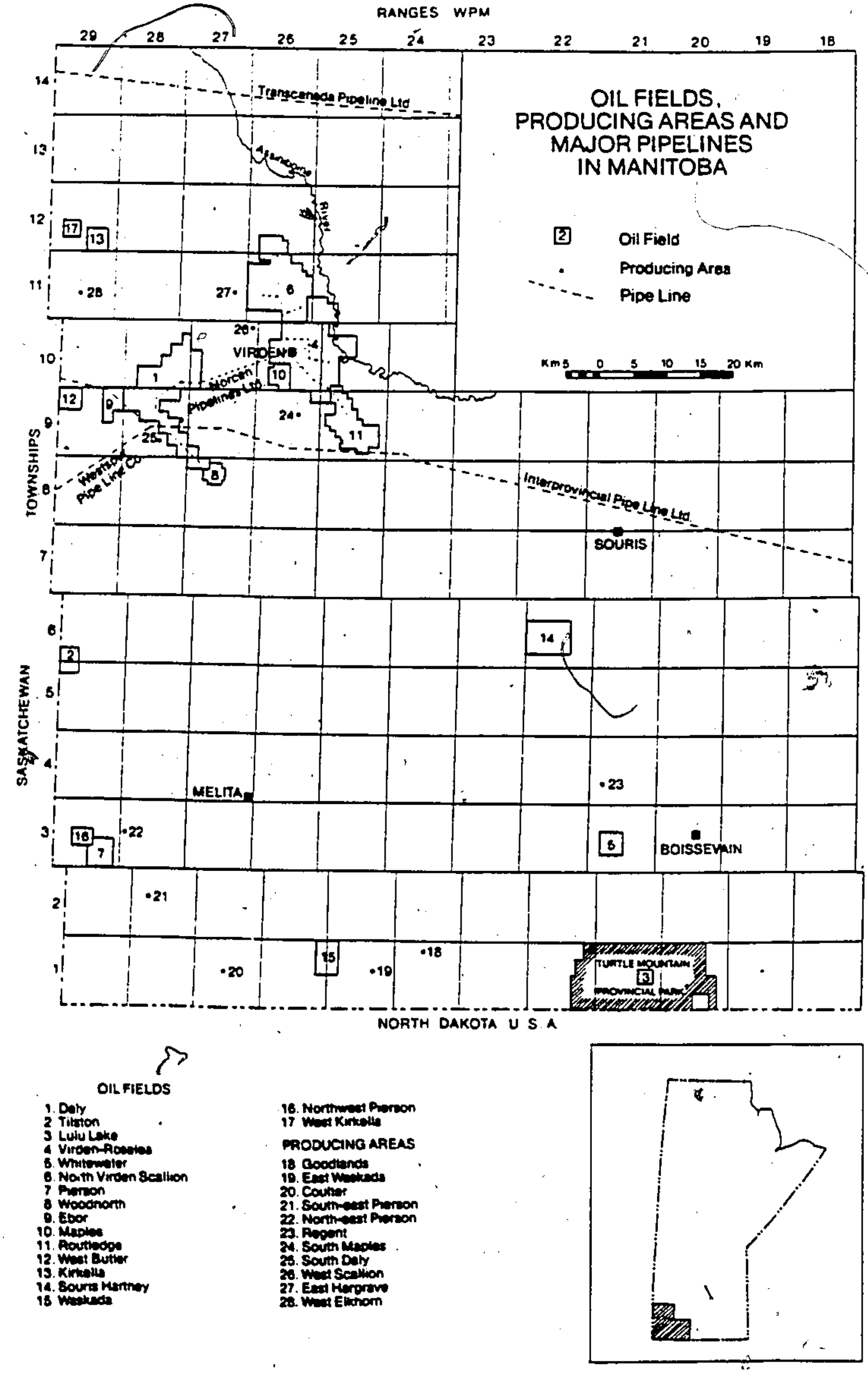

Fig. 9. Oil fields and producing areas in southwestern Manitoba (after Zahalon, 1980).

The stratigraphic control is the critical one, and is associated with the existence of the Lower Jurassic Amaranth Formation which overlaps the pre-Mesozoic unconformity. However, despite the fact that most of the hydrocarbon accumulations are close to their subcrop edge where they are truncated at the unconformity, the critical trapping agent in many cases is neither the red beds of the Lower Amaranth nor the Amaranth Evaporite, but a dolomite-anhydrite-impregnated zone within the upper part of the carbonates. It represents a secondary zone formed within the carbonates during Amaranth deposition, when saline or hypersaline conditions prevailed. Its thickness varies from place to place depending mainly on the presence of the Lower Amaranth red beds. Generally, the dolomite-anhydrite alteration zone is thin or even absent in those instances where the Paleozoic carbonates are overlain by red beds.

In contrast, an excessive thickness of this zone may be observed where the Amaranth Evaporite is laid directly over the carbonates (McCabe, 1959; Young and Greggs, 1975). The Daly and Virden oil fields are located close to the Daly-Madeline trend, where the red beds are absent and the unconformity is directly overlain by the Amaranth Evaporite. Thus, a thick secondary zone was developed there resulting, along with other stratigraphic factors, in excellent trapping conditions.

There is considerable evidence that in places where the pre-Mesozoic unconformity is overlapped directly by Lower

Amaranth red beds, the latter might not constitute an effective seal for hydrocarbon accumulations, especially when sandy units occur at their base. This is exemplified to a great extent by the oil discovery in the Jurassic rocks of the Waskada field during 1980 (Hay and Robertson, 1981), where oil from the hydrocarbon bearing Mission Canyon Formation appears to have leaked through the pre-Mesozoic unconformity into Lower Amaranth sand units (Galarnyk _et al_., 1984).

2.3.4.5 Significance of the sub-Mesozoic unconformity

The major significance of the sub-Mesozoic unconformity in controlling hydrocarbon accumulations was outlined above. Other features such as solution cavities, regional flexures and local paleotopographic highs, which may represent salt-solution structures, might introduce environmental hazards into waste disposal strategies, should their existence and exact location go unnoticed. The new Amaranth discovery presents additional potential for hazard, as far as environmental implications are concerned.

2.4 Physiography

The effect that geology exerts on topography is so highly marked, that major geologic boundaries coincide approximately with those of physiographic regions (Cole, 1938). The entire province consists of the following four main physiographic zones from north to the south (Simpson et al., 1986, Fig. 4):

1. the Hudson Bay Lowlands, consisting of Paleozoic carbonates;

2. the Precambrian Shield, comprising Precambrian rocks of the Superior and Churchill provinces;

3. the Manitoba Lowlands (First Prairie Level), underlain in most of its part by Paleozoic carbonates; and

4. the Southwestern Uplands (Second Prairie Level), characterized by the presence of Mesozoic clastic rocks.

A major part of southwestern Manitoba, especially that corresponding to the Uplands, is marked by the presence of glacial drift which obliterates the bedrock topography, represented in some instances by the presence of buried valleys beneath the glacial veneer (Klassen and Wyder, 1970). In southern Manitoba and within the study area, the most prominent physiographic feature is the eastward facing Manitoba Escarpment, which delimits the boundary between the Uplands and the Lowlands. The eastern limit of some topographically high areas to the west of this feature, such as the Riding and Duck Mountains, delineates this physiographic boundary (Klassen 1969, 1979). The Manitoba Escarpment marks approximately the eastern limit of the Cretaceous strata and it was formed mainly in response to the differential erosion between the hard Odanah Shales and the underlying soft shales of the Millwood Member of the Riding Formation (Davies et al., 1962).

The main river within the study area, the Assiniboine River, drains through Lake Winnipeg into Hudson Bay in the north.

2.5 Formation Fluids

The presence of highly elevated areas in the western part of the western Canada sedimentary basin, combined with the considerably lower elevations of the discharge areas, has permitted basinwide modeling of the fluid flow regime (Toth, 1962, 1963). A regional flow system exists, originating probably in the vicinity of the Cypress Hills in Alberta which represent the recharge areas, and discharging in the Manitoba Lowlands, thus resulting in a northeastward regional flow pattern (Hitchon, 1969a). With the exception of some anomalies related to high permeability contrasts, potential distribution within individual formations result almost in the same northeastward flow pattern, thus indicating a major dependence on topographic variations (Hitchon, 1969b).

In southwestern Manitoba an interregional flow system may originate in the Manitoba Escarpment, as a consequence of the considerable topographic relief between the Uplands and the Lowlands. It is likely that this can account for, at least in part, halite solution along the present salt limit in Manitoba (Van Everdingen, 1968). If the latter holds true, then the presence on the sub-Mesozoic unconformity of the Mississippian Escarpment, could have been of great importance in controlling salt solution during post-Mississippian to pre-Jurassic times. Five additional local flow systems existing in the Manitoba Lowlands, are indicated by Simpson et al. (1987, Fig. 8).

In an overall study of the Williston basin, Porter and Fuller (1959) indicated the salt-free areas as those with the correspondingly lower salinities. They noted also the coincidence of known oil accumulations with regions displaying high salinities. Hitchon (1964) considered the entire Phanerozoic section to indicate an increase in the concentration of the total dissolved solids with depth and age of the stratigraphic units. Chlorinity maps indicated also the hydraulic connection between the formation fluids across the sub-Devonian unconformity. Also noteworthy is that an area of relatively fresh water within the Elk Point Group was almost coincident with the area of salt solution.

Generally, all the Paleozoic formations in Manitoba exhibit a prominent decrease in salinity in the up-dip direction towards the outcrop belt. This might reflect in part dilution by meteoric water (Bannatyne, 1960). The latter is possible to represent the fresh water system induced by the topographic relief across the Manitoba Escarpment (Van Everdingen, 1968). Brine springs of high salinity emanate also from Winnipegosis reefs in the Devonian outcrop belt. These might represent the termination of the regional flow system which dissolved a part of the Prairie Evaporite salt, discharging eventually in the Manitoba Lowlands. The contribution of pre-Devonian brines to those discharged from the Winnipegosis reefs, is also obvious (Van Everdingen, 1971). Of major significance are the areas in the southwestern corner of Manitoba where most of the formations contain waters of relatively high salinity. This can be accounted for by isolation of these areas from the regional flow system (Simpson et al., 1987).

Another important aspect related to salinity variation, is the presence of abnormally high or low formation pressures as a result of osmotic phenomena (Van Everdingen, 1968; Bradley, 1975). Such a case was reported by Hitchon (1969b) for the Viking Formation of Alberta.

Generally, from the observation that salt-free areas have low salinities, it can probably be inferred that the latter constitute a part of a regional flow system, and the formation water which dissolves the salt is continuously renewed and is eventually discharged in the lowlands. In contrast, reservoir separation appears to be the case when high salinities prevail. The coincidence of oil accumulations with areas of relatively high salinity, is a point in case. Formation-water salinities are likely to be low in areas comprising parts of the regional flow system, so that oil may have migrated downflow to escape at the surface.

Regions characterized by relatively low salinities, should not be considered for waste disposal practices, since fluids injected in the subsurface might assume the vector properties of the regional flow system (Simpson <u>et al</u>., 1987) and reappear at the surface giving rise to irreversible, environmental hazards.

CHAPTER 3

BACKGROUND INFORMATION

Data on formation fluids within the study area were derived from drill stem tests. This approach permits determination of several reservoir properties. Brief consideration of the application of drill stem tests to hydrodynamics and problems inherent in its use constitutes to a great extent the theoretical background behind the rationale employed in the present account.

3.1 Drill Stem Tests

It is beyond the scope of the present study to attempt a detailed consideration of this well testing practice. However, a brief description and the importance of this technique in terms of its applications follows in the next paragraphs. The following information derive mainly from the comprehensive accounts by Maier and Ripley (1967) and Allen and Roberts (1978).

3.1.1 Brief description

In general terms, a drill stem test is a temporary completion of a well. An assembly containing pressure recorders is joined at the bottom of the drill string and is lowered to the desired depth. Packers are set to isolate the interval tested from the rest of the formation and the column of drilling fluid. At the onset of the test, a flow period with the valve inside the assembly open, depressurizes the formation from overpressures created by the invasion of drilling mud. It is followed by a shut-in period, during which the valve is closed and the pressure build-up generated by the formation fluids is recorded on a chart. Depending on the purpose of the test, the same procedure may be run twice.

3.1.2 Application to hydrodynamics

Formation pressure is the most important reservoir property to be obtained from the drill stem test chart with respect to hydrodynamics. Depending on the time allowed for the shut-in period, static conditions may be achieved in which case the static or shut-in reservoir pressure is read off directly from the chart. In any other occasion extrapolation to infinite time using the Horner plot is required (Allen and Roberts, 1978).

Generally, two methods can be employed to use the shut-in pressures for hydrodynamic implications (Prier, 1979). The first comprises the pressure/depth graph (fluid-pressure profile) which is useful for inferences related to the continuity or discontinuity of pressure systems in the subsurface, as well as for the detection of subnormal and abnormal fluid pressures. The former is based on the principle that pressure continuity is depicted by straight line relationship in the fluid-pressure profile. The later can be deduced on the basis of the position of the data points relative to the two extreme gradients, for fresh water (9.795 kPa/m) and for heavy oils (11.152 kPa/m).

The second method is the potentiometric surface from which fluid-flow directions and permeability differences, on the basis of variation in the contour spacing, can be inferred. It is based on the following equation (Prier, 1979):

E=(KB-D)+((1/G)*P), where

E=Elevation of the potentiometric surface from sea level.

KB=Kelly bushing elevation from sea level.

D=Depth from kelly bushing of the pressure recorder.

G=Water gradient, determined from its density.

P=Virgin formation pressure, obtained from the drill stem test chart.

3.2 Rationale of the Present Study

For the purpose of the present account, rationale can be defined as the procedure followed for the alleviation of the problems related to the application of drill stem tests to hydrodynamics.

3.2.1 Problems and remedial measures

The first, and probably the most critical, problem concerns the density of the formation fluids and is dictating the inescapable assumption that this property has a constant value. Generally, knowledge and subsequent use of the actual densities for individual sites might be useful for local scale aspects only, while for large areal extent considerations, as in the case of the study area, no serious mistake is introduced by assuming an overall constant density (Levorsen, 1967). For the purpose of the present study, fresh water density has been adopted which results in a water gradient (G) of 9.795 kPa/m.

The second problem has to do with the question of whether the shut-in pressure obtained from the chart reflects the virgin reservoir pressure or a lower fluid pressure. This holds true especially for the Mississippian formations within the study area where production-induced pressure drawdown in the vicinity of the oil fields appears to be a very common case. In some instances the opposite phenomenon, reflecting probably brine-disposal practices or water-injection wells for secondary recovery operations, is also encountered. Special attention has been paid to overcome the above problems mentioned that constitute a major source of possible error, as far as the hydrogeologic environment is concerned. The procedure followed for the Mississippian System is considered in the next chapter.

The depth of the pressure recorder poses another problem since no information exist regarding this aspect. So in all the cases the depth of the bottom of the interval tested was used for the calculation of the potentiometric surface. However, the exact position of the pressure recorder does not appear to be of significant importance since the drill stem test is representative of a certain interval and not of a specific depth.

In many instances, some drill stem tests might incorporate two formations. In these cases their nature was an important factor in the effort to assign the shut-in pressures to either of the formations. The author suggests that tests displaying relatively high static pressures, which are terminated in shaly units behaving as aquitards and are overlain by aquifers (e.g. carbonates) that are partially included in the interval tested, might be considered to be representative and therefore be assigned to the upper formation. Where two different formations of the same nature (aquifers or aquitards) are tested, their relative partitioning has been taken into account along with pressure values existing in the adjacent area for tests involving either of the two units.

In very few cases during particular tests, initial and final shut-in pressures resulting from two shut-in periods, are the same. Predominantly, the final shut-in pressure is the lower one since temporary reservoir depletion subsequent to the first flowing and shut-in period might have occurred. In cases where a higher final shut-in pressure is encountered, an insufficient initial shut-in period pressure build-up is probably the case. For the reasons mentioned above, the highest pressure value was employed for all the calculations. A more difficult problem to cope with is represented by the cases where, individual wells testing subsequent sections of the same formation exhibit considerable pressure differences which can be accounted for by vertical permeability variations. For reasons of consistency and for the purpose of the present study, the highest value was used, since solution-generated collapse structures, unless sealed, will probably be associated with high pressures.

The absolute error resulting from the pressure gauge, is approximately in the range of -6.90 to +6.90 kPa. Thus it becomes apparent that the relative error of the shut-in pressure (absolute error in percentage) is very small, by taking into account the high fluid pressures associated with the deep formations that are considered in the present study. The effect of the latter in turn on the potentiometric surface values is obviously insignificant.

3.2.2 Potentiometric surface maps - Fluid-pressure profiles

In the present study, the computer program Golden Graphics System was used for the processing (gridding) and initial contouring of the data points. The distribution of the contours, as depicted by the potentiometric surface maps, is a function of the smoothing factor that was used. A high smoothing factor (0.95) is useful for inferences related to both regional trend and presence of potentiometric anomalies. In contrast, a low smoothing factor (<0.80) yields only the regional trend and the most prominent anomalies. In the present study a smoothing factor of 0.95 was employed in all the cases, unless otherwise specified. Corrections and adjustments of the system derived contours were applied when this was judged to be necessary. The same software system was also employed for the construction of surface maps representing the three-dimensional distribution of potentiometric surfaces.

The Harvard Graphics System was employed to generate fluid-pressure profiles. In the latter, two reference lines were drawn in all the cases, corresponding to the extreme gradients for formation fluids; one for fresh water (normal hydrostatic gradient=9.795 kPa/m) and the other for very heavy oils (11.152 kPa/m). In this way, abnormal or subnormal pressures and vertical continuity or discontinuity of pressure systems, can be inferred.

CHAPTER 4

HYDROGEOLOGIC ENVIRONMENT

4.1 General Remarks

The major lithological variations within the entire Phanerozoic sedimentary sequence in southwestern Manitoba have given rise to three main lithostratigraphic divisions; the basal clastic, the middle carbonate-evaporite and the upper clastic divisions. The contrasting lithologic associations render the same classification convenient for considerations of formation fluids, so that the prevailing hydrogeologic conditions can be treated separately for the particular divisions. For hydrogeologic purposes each division can be best described as an interbedding of sandstone or carbonate aquifers and shale or evaporite aquitards.

In many instances, especially in the case of the carbonate-evaporite sequence, absence of laterally extensive impermeable intervals establishes at least a vertical lithological continuity between separate formations and indicates also the likelihood of hydraulic continuity. However, shut-in pressures exist for distinct formations, thus allowing for reconstruction of the hydrogeologic environment for particular units. Inferences related to the hydraulic continuity or discontinuity can be drawn on the basis of the degree of similarity of the individual fluid-flow patterns, as well as the position of the formations on the pressure/depth graphs. The former case conforms to the existence of hydrostratigraphic units as defined by Maxey (1964).

It is also noteworthy that hydrostratigraphic units can be roughly defined, even in cases where there is interference of persistent impermeable intervals within aquifers. Fracture systems associated with the aquitards probably account for this condition. The hydraulic connection across the sub-Devonian unconformity established through formation fluids salinity data is a case in point, if one considers the presence of the red beds of the Ashern Formation at the top of the erosional surface. The same phenomenon can be expected to occur more intensely in post-Prairie units, promoted by salt-solution-induced fractures.

All the above mentioned contentions are exhibited through an understanding of the hydrogeologic environment, which is attempted in the following sections through a detailed description of potentiometric-surface maps and selected fluid-pressure profiles.

4.2 Basal Siliciclastic Division

The lower sedimentary division within the study area is mainly represented by the Winnipeg Formation and is characterized by major heterogeneities, since it coincides approximately with the transitional zone between the predominant sand and shale facies to the north and south respectively (Vigrass, 1971). The latter holds true especially for the lower unit of the Winnipeg Formation. These heterogeneities can to some extent be expected to affect the fluid flow pattern of this formation. However, the extremely sparse drill stem test control allows only for a general estimation of the distribution of fluid potential. Also noteworthy is the fact that data from tests incorporating Precambrian rocks have been included in the Winnipeg Formation, since the Precambrian basement has been considered as the impermeable boundary at the base of the Phanerozoic sequence.

The potentiometric surface map of the basal clastic unit (Fig. 10a) reveals a northeastward-dipping potentiometric surface with an average gradient of 12.5 m/km, disrupted by anomalously low values at the central-eastern part of the area. This most probably reflects reservoir heterogeneities and gives the appearance of a hydraulic trough. This is manifested in the test performed in the Arco Shilo 10-24-9-16 well (LSD 10-24-09-16WPM) which was run in a zone of high shale content (McCabe, 1978, Appendix I) and resulted in a potentiometric surface of 424 m below sea level. In contrast, the Arco Shilo 10-2-9-16 well (LSD 10-02-09-16WPM) tested a zone that appears to be located close to the transition into a porous and uncemented sand (McCabe, 1978,

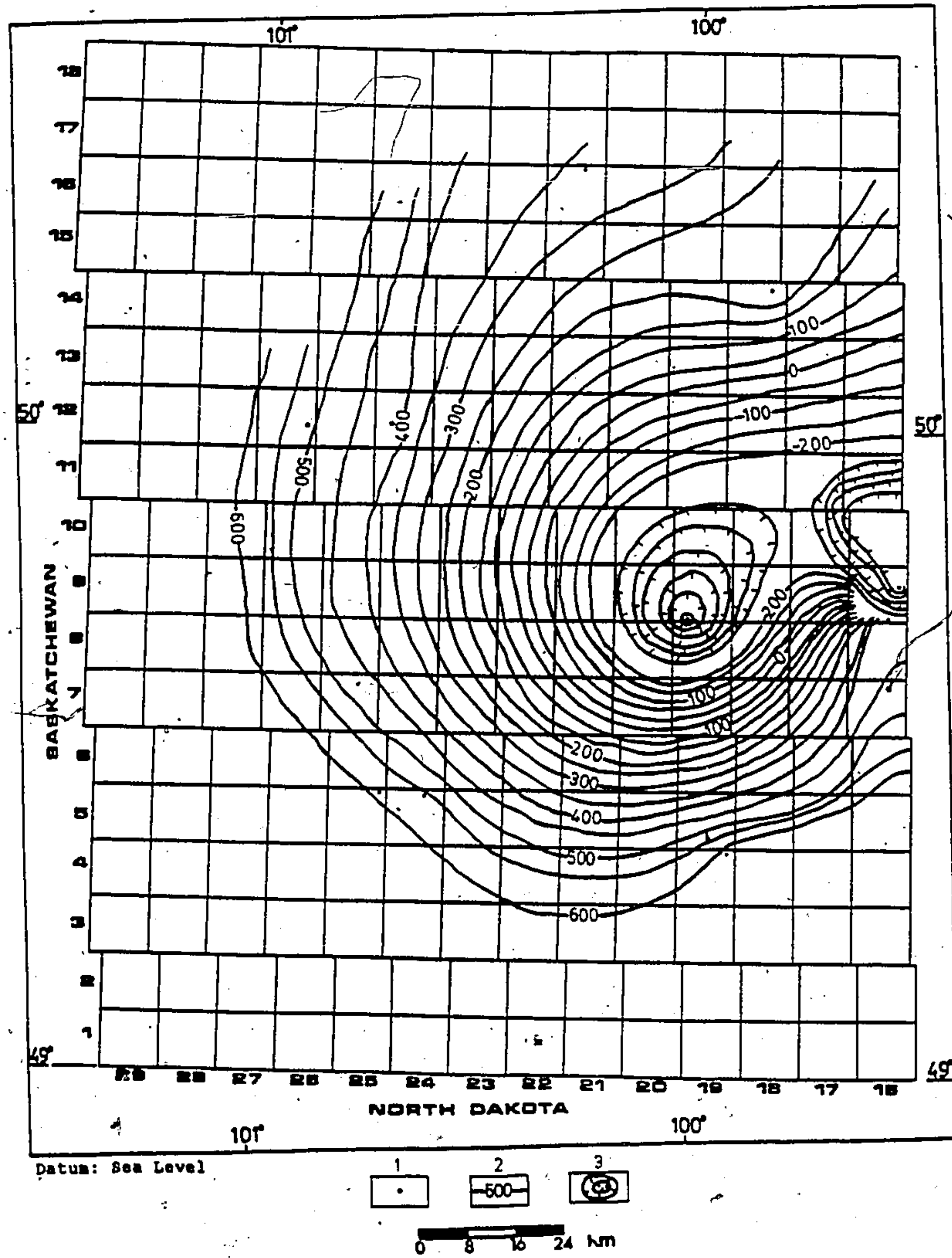

Fig. 10a. Potentiometric surface for basal clastic unit (including subnormal pressure values). 1) location of wells; 2) equipotential lines (contour interval= 50 m); 3) potentiometric low.

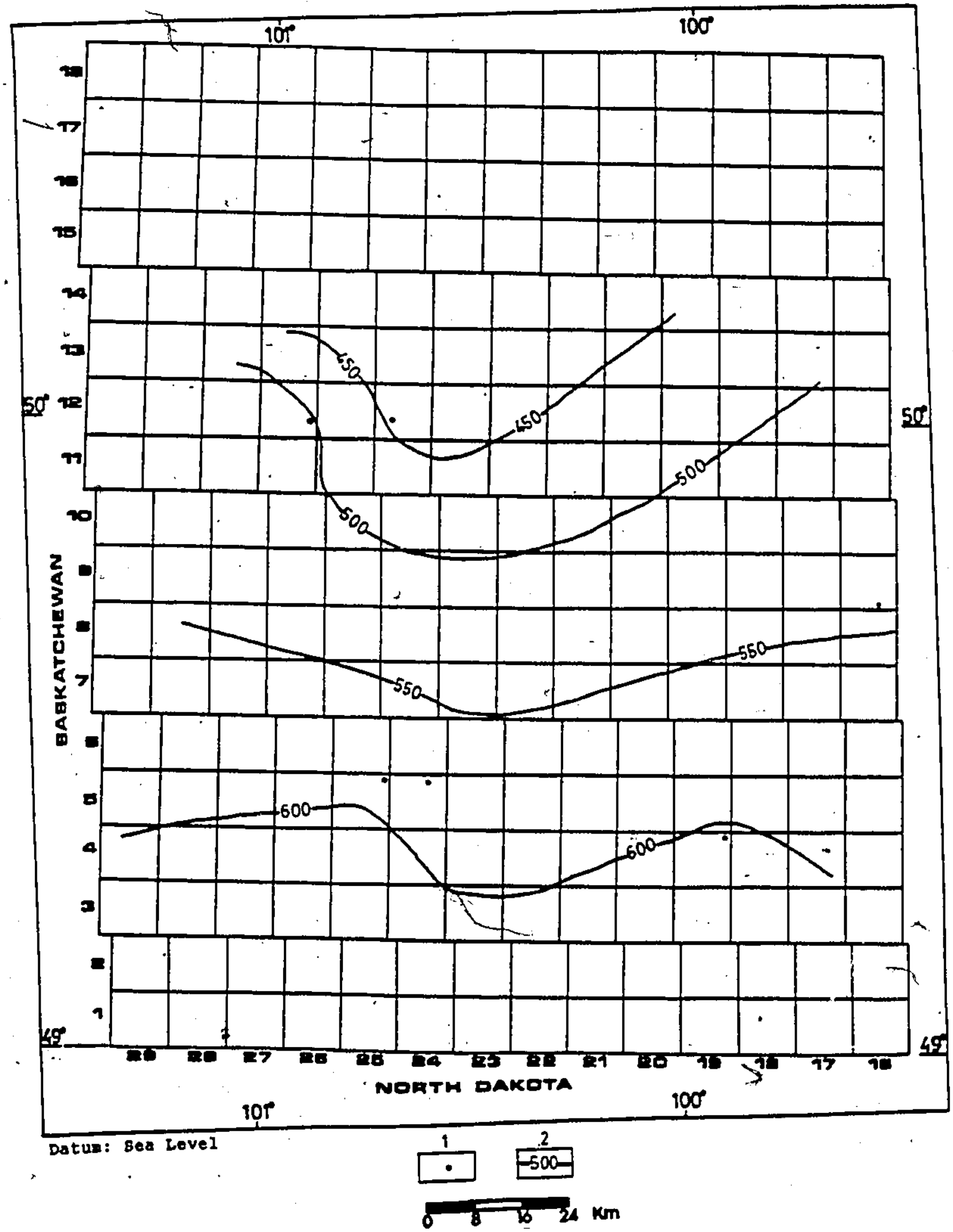

Fig. 10b. Potentiometric surface for basal clastic unit (excluding subnormal pressure values). 1) location of wells; 2) equipotential lines (contour interval= 50 m).

Appendix I) and the corresponding potentiometric surface is 544 m above sea level.

The effect of heterogeneities also becomes evident in Figure 11 where the location of the Winnipeg Formation relative to the fresh water gradient (9.795 kPa/m) denotes the presence of excessively low pressures. It is also important to note, that the two potentiometric lows in the eastern part of the area, correspond spatially to the region of the highest shale content (Andrichuk, 1959, Fig. 10). Thus the depicted flow pattern is not likely to reflect the actual hydrogeologic environment, since intercalations of impermeable intervals from which the subnormal pressures most probably result, are not representative of the fluid potential pattern.

In an effort to eliminate the effect of heterogeneities on the fluid flow pattern, a potentiometric surface map of the basal clastic unit has been produced excluding subnormal pressure values from the data set. In this way a flow system with a northward gradient of approximately 2 m/km becomes apparent (Fig. 10b). The smooth flow pattern exhibited in this way is probably indicative at the same time of the directional permeability within the basal clastic unit in an area, where the interference of sand and shale intercalations is established.

A slight decrease in spacing of the contours in the vicinity of Townships 12 and 13, Ranges 24 and 25WPM, accompanied by an eastward swing of the gradient, is

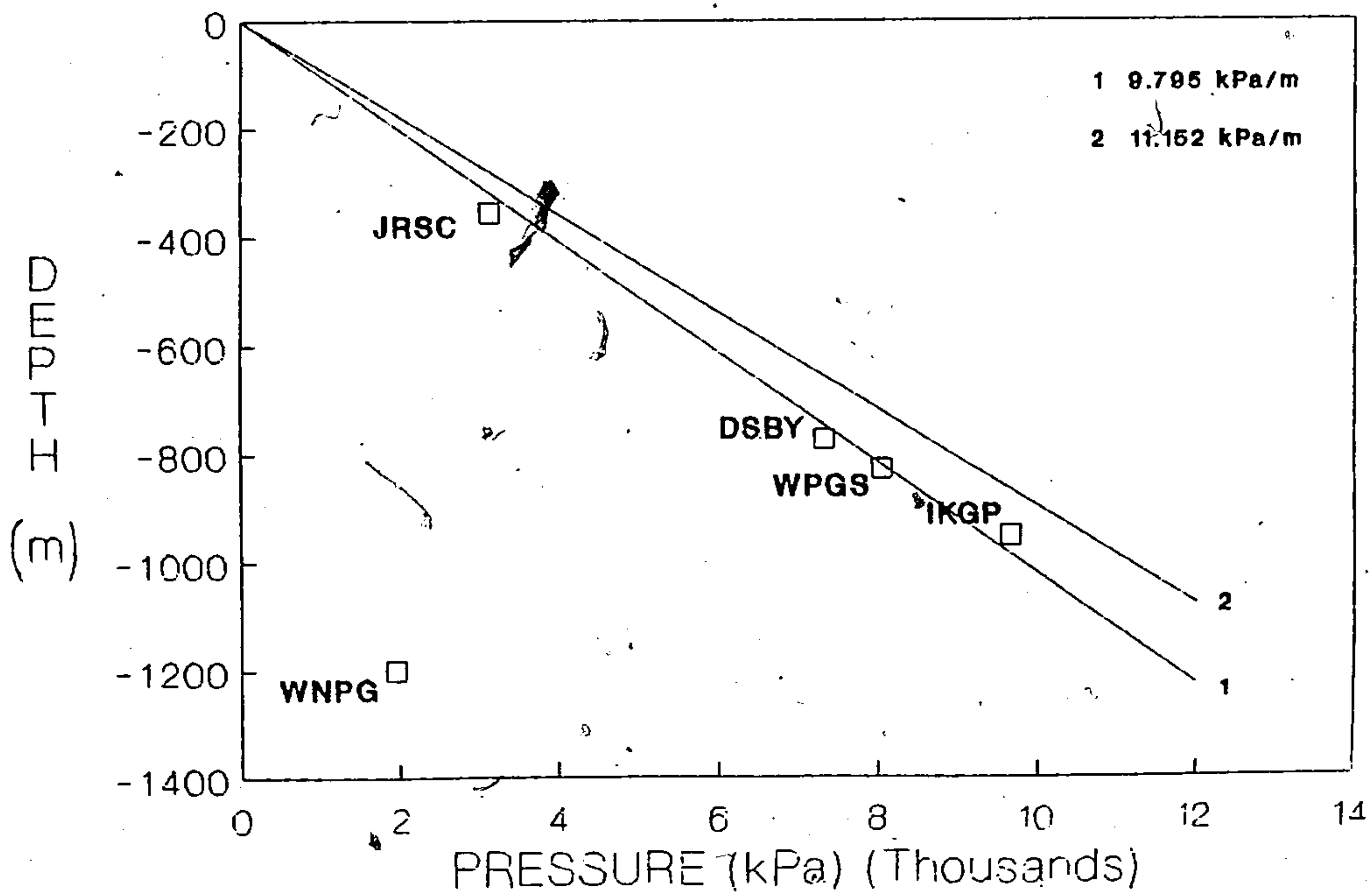

Fig. 11. Fluid-pressure profile for Dome Brandon 3 5 9 19 well (LSD 03-05-09-19WPM).
WNPG: Winnipeg Formation; IKGP: Interlake Group; WPGS: Winnipegosis Formation; DSBY: Dawson Bay Formation; JRSC: Jurassic formations.

approximately coincident with a trend of minor magnetic anomalies on the Precambrian basement, and is located near the Birdtail-Waskada axis. The flow system represented is more or less compatible with the established northeastward regional flow pattern. The deviation from the eastward direction can probably account for the lack of brine springs in the outcrop belt of Lake Winnipeg.

It is also noteworthy that potentiometric surfaces above ground level in the western part of the area in the vicinity of Townships 5 and 12, Ranges 25 and 26WPM respectively, appear to be located approximately along the trend of the Birdtail-Waskada axis. It is possible that basement linear features through recurrent activation pressurize the formation fluids of the overlying basal clastic unit, thus giving rise to flowing artesian conditions.

4.3 Carbonate-Evaporite Division

The middle sedimentary division is a nearly continuous carbonate sequence, interrupted by widespread aquitards. The most hydrogeologically significant impermeable interval is the Middle Devonian Prairie Evaporite. Solution of this evaporite unit has disrupted to a major extent a great portion of the overlying strata and has given rise to modifications of the original hydrogeologic environment.

4.3.1 Pre-Prairie units

Pre-Prairie Evaporite formations are mainly composed of dolomitic limestones and dolostones. The only persistent major aquitard is represented by the Red Beds of the Ashern Formation. Other subordinate impermeable intervals are the evaporites of the Red River Formation, of the dolomitic Gunton Member of the Stony Mountain Formation and of the Stonewall Formation, as well as the shaly Gunn and Penitentiary Members of the Stony Mountain Formation. However, except for the Red River as a whole, complete lack of data precludes the assessment of the hydrogeologic environment for the rest of the units which incorporate aquitards.

4.3.1.1 Red River Formation

The smooth flow pattern depicted by the potentiometric surface map of the Red River Formation (Fig. 12), reflects the sparse well control and the lithologic homogeneity of this unit. Shut-in pressures from the Yeoman Member, which is most commonly encountered in southern Saskatchewan, have been also included in the data set. The map reveals a prevailing northward direction of fluid flow, with an average gradient ranging from approximately 3 m/km to 5.5 m/km.

The steepening of the gradient in the north is probably due to the presence of evaporites (Andrichuk, 1959, Fig. 15).

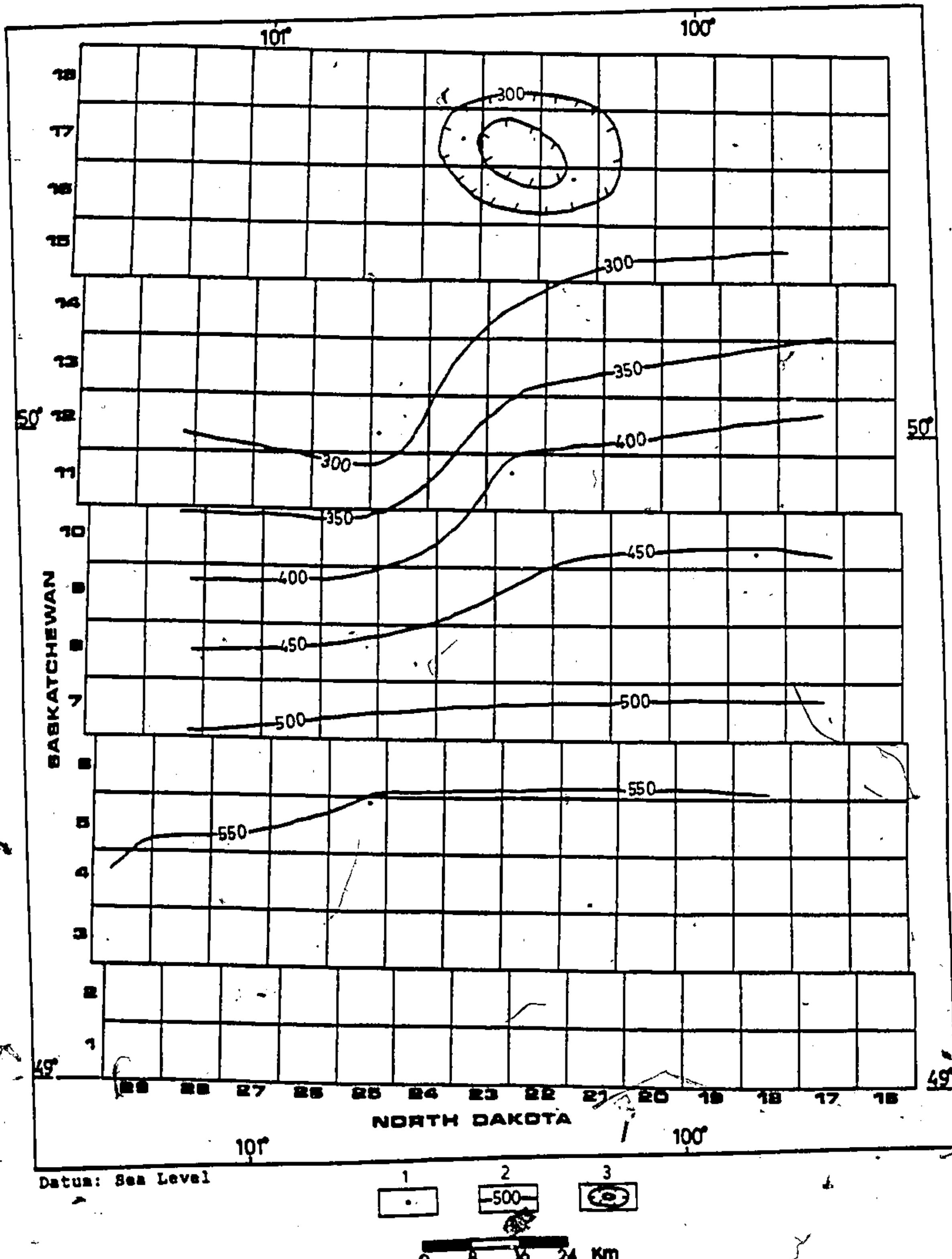

Fig. 12. Potentiometric surface for Red River Formation. 1) location of wells; 2) equipotential lines (contour interval= 50 m); 3) potentiometric low.

within the dolomitic limestones of the upper part of the Red River Formation, where most of the tests were performed. The same feature also appears to be located adjacent to the same trend of minor basement magnetic anomalies as in the case of the Winnipeg Formation. Presence of evaporites can also account for the apparent potentiometric low in the central-northern part of the area. An alternative explanation for the latter is probably the existence of osmotic phenomena, which produce downward movement of fresh water thus creating low pressures, since the underlying Winnipeg Formation is characterized by the existence of higher salinity fluids and contains in addition shale intercalations that might act as semi-permeable membranes. Cursory examination of the fluid flow pattern reveals a general similarity with that of the basal division and indicates the likelihood of a hydraulic connection between those strata. This is especially promoted by the artesian flowing conditions encountered by the Amerada Lauder Prov M F 9 35 5 25 well (LSD 09-35-05-25WPM), which is located on the Birdtail-Waskada axis. The same well also encountered similar conditions on the underlying Winnipeg Formation and the corresponding potentiometric surface values are almost the same.

4.3.1.2 Interlake Group

A slight change in the fluid potential pattern appears to occur in dolostones of the Interlake Group (Fig. 13). The

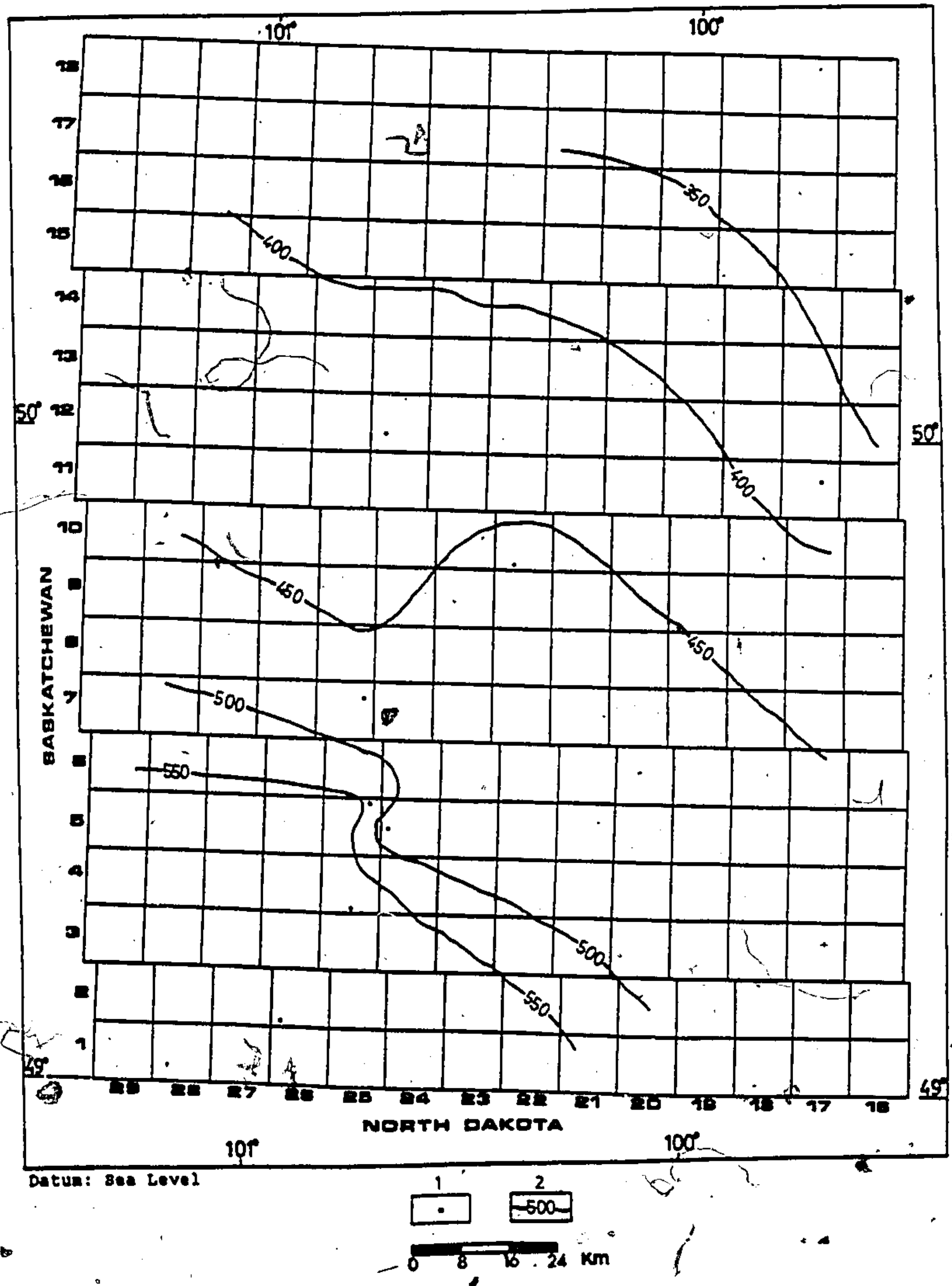

Fig. 13. Potentiometric surface for Interlake Group. 1) location of wells; 2) equipotential lines (contour interval= 50 m).

gradient turns mainly to a northeastward direction with a steep slope of approximately 6.5 m/km in the southwestern part of the area, grading northeastward to 2 m/km. The smooth flow pattern in the latter is probably representative of the homogeneous dolomitic nature of the Interlake Group, and it appears that reservoir separation cannot be invoked to account for the tightening in spacing of the contours in the former case. This is likely to be related to an area characterized probably by the dominance of limestone. In fact, the latter is reported in the California Standard-Hartney 16-33 well (LSD 16-33-05-24WPM), whereas other wells very sparsely distributed within the rest of the study area where gentle gradients are encountered, reveal mainly the presence of dolostones (Baillie, 1953, Appendix II).

An alternative hypothesis is that the region characterized by the steep gradient is located in the vicinity of Township 5, Ranges 24 and 25WPM on the trend of the Birtdail-Waskada axis, as well as within the area affected by the Hartney structure. It is likely that basement-related tectonics have contributed to the formation of this feature and have facilitated, to a major extent, cross-formational flow through the enhanced vertical permeability, thus giving rise to steep gradients and potentiometric high values. The boundary zone appears once more to constitute a locale of flowing artesian conditions.

The Amerada Lauder Prov M F 9 35 5 25 well

(LSD 09-35-05-25WPM) registers again a potentiometric surface close to that corresponding for the Winnipeg and Red River Formations, if the corrections for the formation fluids salinity are taken into account. A possible relationship between Interlake reef occurrence and steep gradients should be also considered. Such a case has been cited by Hitchon (1969b) for the Swan Hills reef complex in Alberta. It is noteworthy that a southeastwards broadening, as defined by the 450 and 500 m contours, is delimited by the trend of basement magnetic anomalies present to the east of the Birdtail-Waskada axis.

The fluid flow pattern of the Interlake Group can be expected in some instances to be affected by brecciation associated probably with the pre-Devonian erosional interval. The latter might be the cause for the high potentiometric surface values in the southwestern part of the study area. Breccias are reported in the Souris Valley-Robert Moore No.1 Well (LSD 05-20-01-27WPM) (Baillie, 1953, Appendix II).

The overall northeastward fluid flow direction, conforms to the established regional flow pattern. No brine springs are reported in the outcrop belt of the Interlake Group. However, the contribution of formation fluids to the brines discharging from Devonian formations will be further discussed.

4.3.1.3 Ashern Red Beds

The Interlake Group is separated from the last pre-Prairie carbonate unit by the Ashern Red Beds. No comments on its actual hydrogeologic nature are possible, since no information on formation pressures exists. The only drill stem test, performed in the Cal Stan Findlay 9 26 7 25 well (LSD 09-26-07-25WPM), yielded a potentiometric surface of 368 m above sea level, corresponding to the excessively high for an aquitard pressure head of 1126 m. The latter probably is not very reliable, since a significant portion of the overlying Winnipegosis Formation was also incorporated in the test. For the same well (Fig. 14) the location of the Interlake Group and the Souris River Formation relative to the normal hydrostatic gradient, coupled with the position of the Ashern Red Beds, probably indicate the ineffectiveness of the latter in imparting pressure discontinuities. The same comment applies also to all the other aquitards, namely the Second and First Red Beds, that are present between the Winnipegosis and the Souris River Formations.

The opposite appears to be the case for the Dome Brandon 3 5 9 19 well (LSD 03-05-09-19WPM) (Fig. 11), where the presence of the Ashern Formation appears to impart a certain degree of vertical reservoir separation. Descriptions also of drilling cuttings from this unit (Baillie, 1953, Appendix II) reveal the presence of dolomitic material which can probably account for, at least

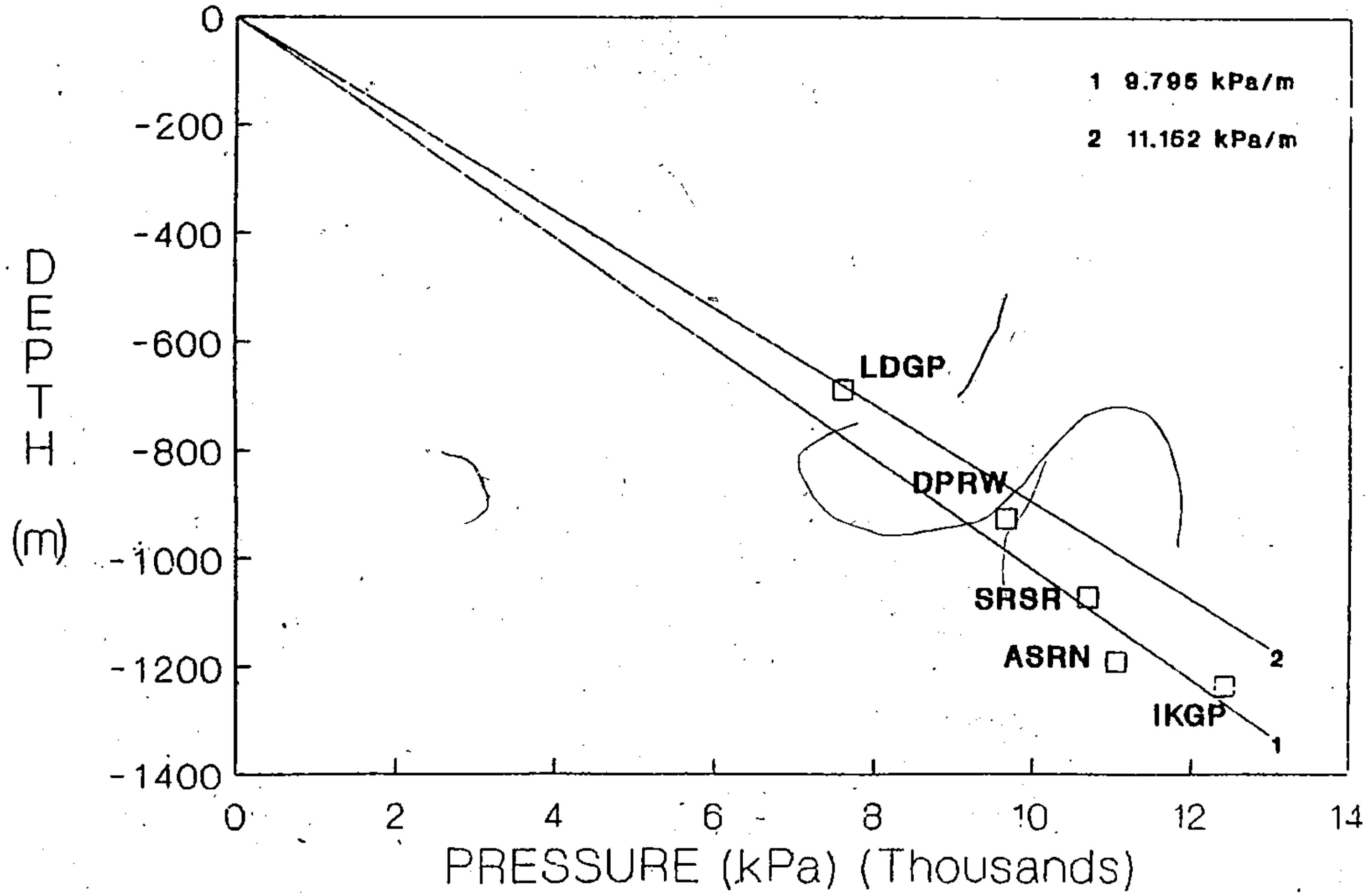

Fig. 14. Fluid-pressure profile for Cal Stan Findlay 9 26 7 25 well (LSD 09-26-07-25WPM).
IKGP: Interlake Group; ASRN: Ashern Formation;
SRSR: Souris River Formation; DPRW: Duperow Formation;
LDGP: Lodgepole Formation.

in part, a degree of permeability. It appears therefore that the above results, combined with considerations of salinity data, call to question the nature of the Ashern Formation as an aquitard.

4.3.1.4 Winnipegosis Formation

The potentiometric surface of the Winnipegosis Formation (Fig. 15a), exhibits north-northeastward flow with an average gradient of 2.5 m/km. The most prominent feature of the map is a northward-trending hydraulic ridge, adjacent and parallel to the Birdtail-Waskada axis, which becomes more evident in the three-dimensional potentiometric surface map in Figure 15b. The same feature is also located close to the trend of the Winnipegosis fringing reef and somewhat coincides with the solution edge of the Prairie salt. The scenario most likely to account for this is reactivation of the boundary zone pressurizing the formation fluids of the fringing reef which are deflected upwards, thus dissolving a part of the overlying salt section. The latter is likely to constitute the mechanism of salt solution during present times. The approximate coincidence also of the hydraulic ridge with the salt limit lends credence to the view that at present in southwestern Manitoba salt removal is probably taking place along its edge.

The existence of flowing artesian conditions in the wells located along the boundary zone and a similar potentiometric surface value for the Amerada Lauder Prov M F

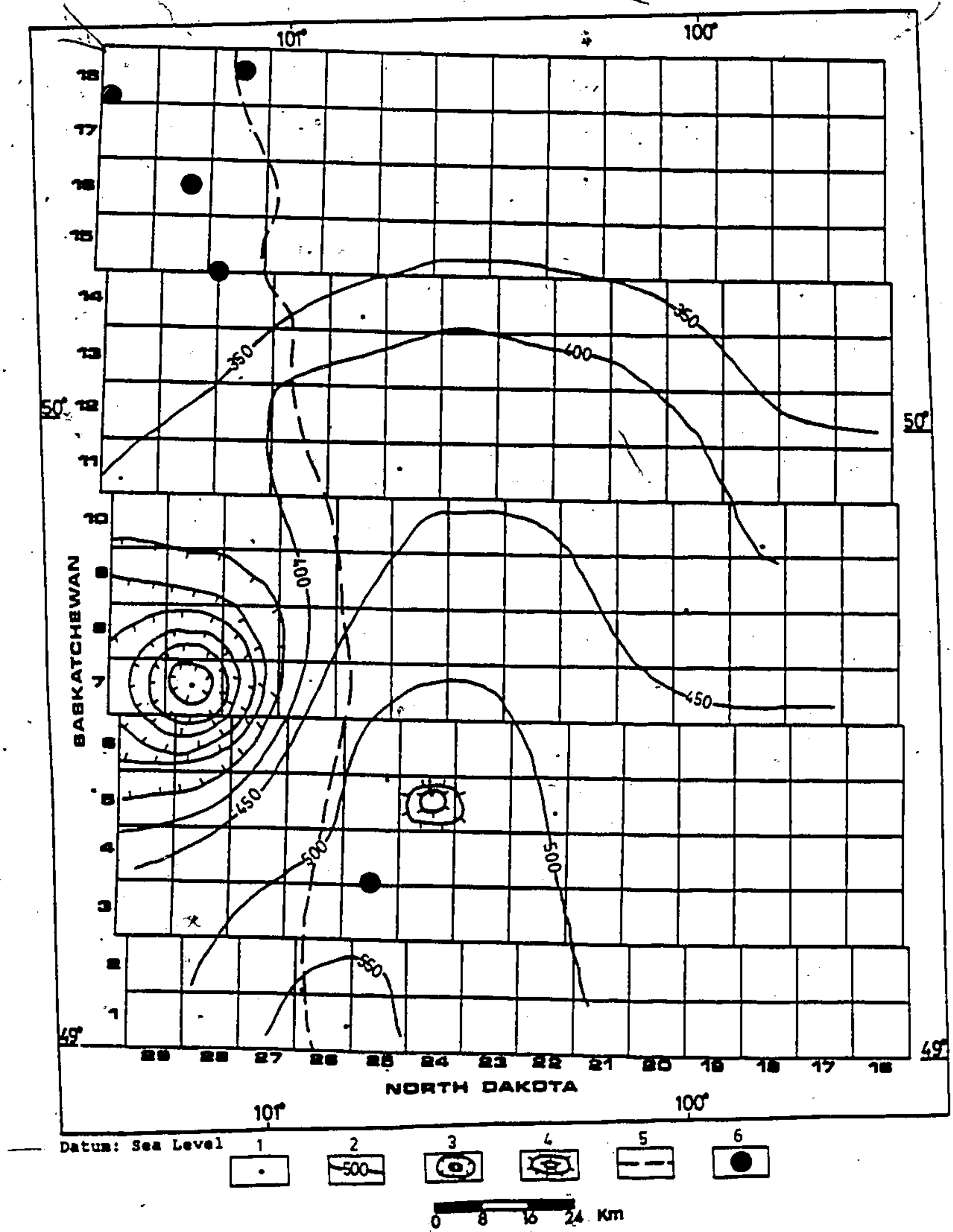

Fig. 15a. Potentiometric surface for Winnipegosis Formation. 1) location of wells; 2) equipotential lines; 3) potentiometric low; 4) potentiometric high; 5) limit of Prairie Evaporite salt beds (solution edge); 6) location of Winnipegosis reefs.
Credits: Simpson, 1983.
Simpson *et al.*, 1987.

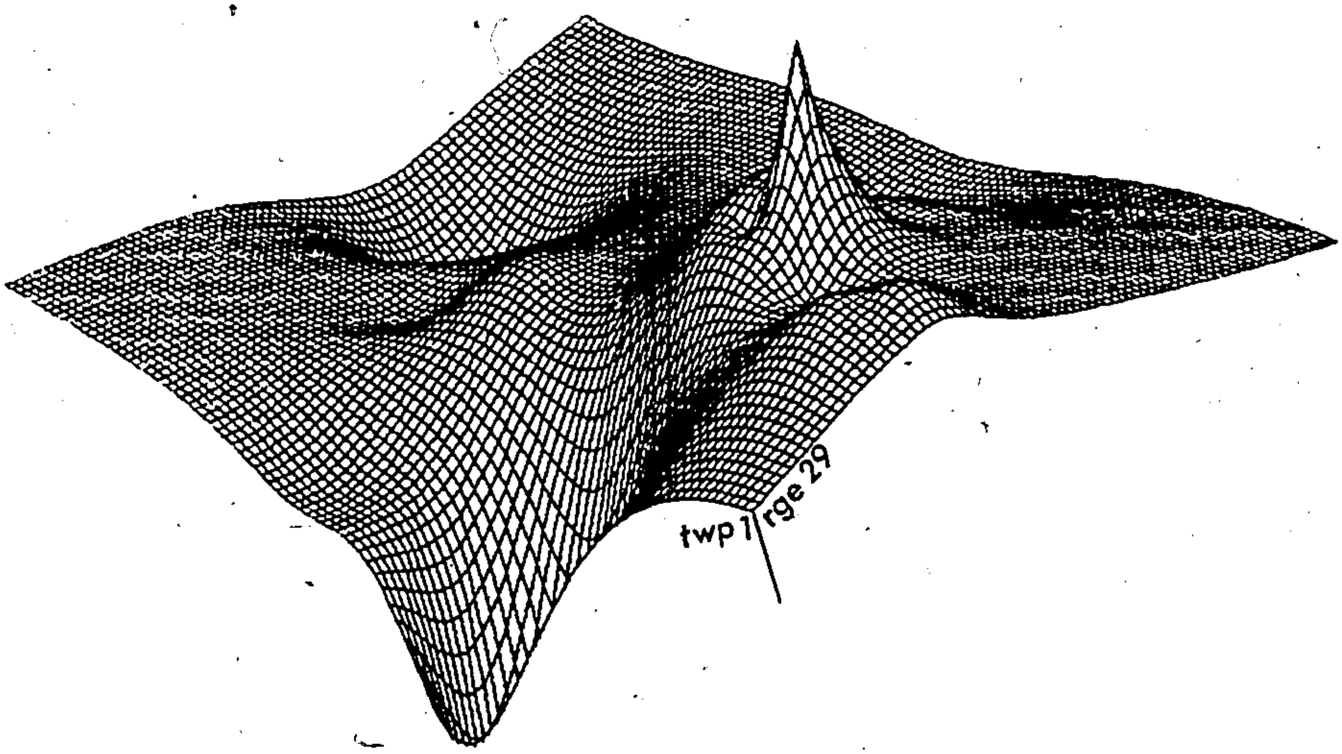

Fig. 15b. Three-dimensional plot of potentiometric surface for Winnipegosis Formation.

9 35 5 25 well (LSD 09-35-05-25WPM), as in the case of the formations already considered, is also noteworthy. The potentiometric high in the vicinity of Township 5, Range 24WPM coincides with the Hartney structure. The fault and fracture systems associated with this feature probably affect the entire Paleozoic section and are likely to represent preferential flow paths in the vicinity of the structure, thus giving rise to high fluid pressures.

The abnormally high pressures that can be expected to occur in the Winnipegosis Formation in the Hartney area are also reflected in the pressure-depth profile in Figure 16, where the location of the Winnipegosis relative to the highest possible gradient is observed. In the same well the position of the Souris River Formation exhibits a pressure close to normal hydrostatic conditions for fresh water, thus precluding any vertical hydraulic connection between these two formations along the lithologic sequence in this particular well. The possible structural disturbance associated with the Winnipegosis in the same area, which most probably accounts for the excessive pressures, is manifested in the fragmental nature of the dolostones as evidenced by the core and drilling cutting descriptions in the California Standard-Hartney 16-33 well (LSD 16-33-05-24WPM) (Baillie, 1953, Appendix II).

An anomalous potentiometric low in the western part of the area is probably not indicative of the actual flow pattern, but of minor heterogeneities. A core recovered by

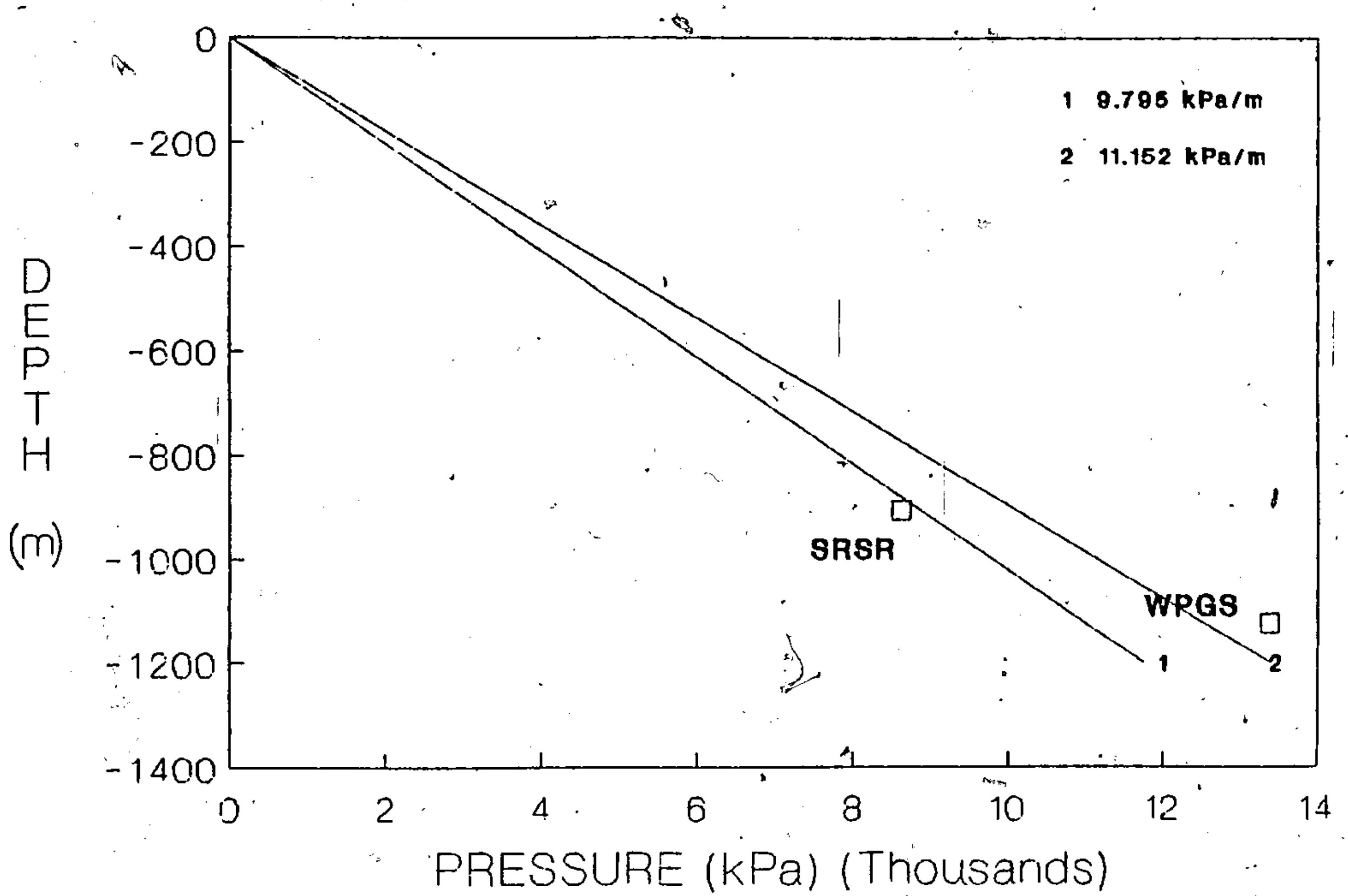

Fig. 16. Fluid-pressure profile for Royalite Triad et al East Hartney 1 well (LSD 07-27-05-24WPM).
WPGS: Winnipegosis Formation; SRSR: Souris River Formation.

the California Standard-Linklater 2 21 7 28 well (LSD 02-21-07-28WPM) that included a portion of the interval tested, revealed the presence of limestone (Baillie, 1953, Appendix II) probably indicative of Elm Point facies. The latter, since it is undolomitized, will be characterized by lower permeability and hence a correspondingly low elevation of the potentiometric surface. This becomes more evident from the position of the Winnipegosis Formation in the fluid-pressure profile of this particular well (Fig. 17). The rest of the wells within the study area reveal only the presence of dolostones.

On a regional scale it appears that the northeastward flow pattern depicted by the potentiometric surface map, results in the discharge of brine springs from Winnipegosis reefs in the Devonian outcrop belt of Lake Winnipegosis.

4.3.1.5 Discussion

The sparse well control is the major drawback in the effort to attempt a more accurate assessment of the prevailing hydrogeologic conditions for the pre-Prairie Lower Paleozoic formations. The most important observation concerns the general north-northeastward direction of fluid flow, as well as the more-or-less uniform gradients, with the exception of cases, probably associated with minor reservoir heterogeneities or even basement features. Continuity of pressure systems indicative in turn of hydraulic connection and cross-formational flow can be

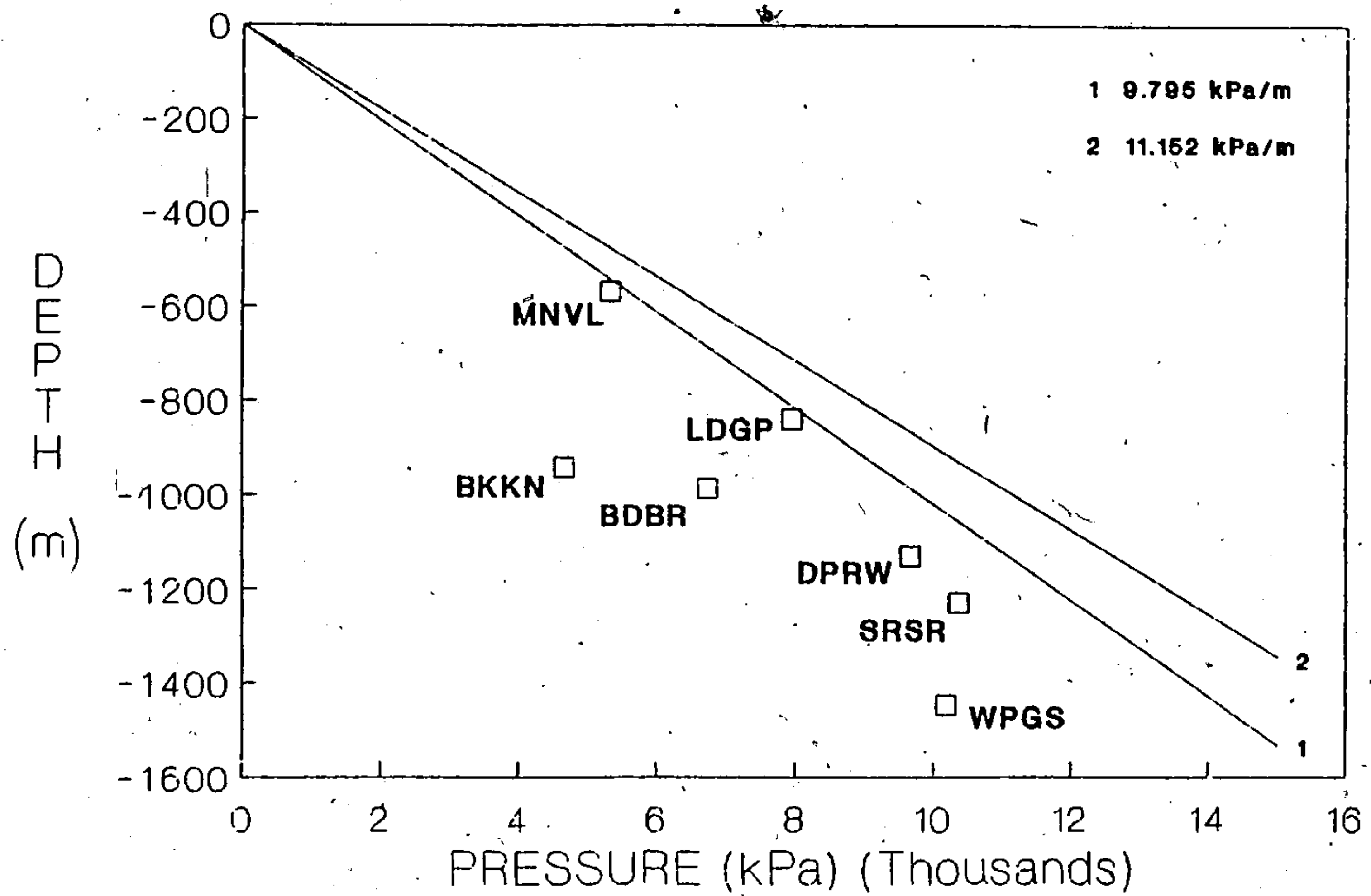

Fig. 17. Fluid-pressure profile for Cal Stan Linklater 2 21 7 28 well (LSD 02-21-07-28WPM). WPGS: Winnipegosis Formation; SRSR: Souris River Formation; DPRW: Duperow Formation; BDBR: Birdbear Formation; BKKN: Bakken Formation; LDGP: Lodgepole Formation; MNVL: Mannville Group.

convincingly displayed for at least one case in the vicinity of Township 5, Range 25WPM.

It is likely that the low-permeability intervals within the Lower Paleozoic formations are not very effective in isolating distinct hydrogeologic units. In some instances, however, a certain degree of vertical reservoir separation imparted by the presence of aquitards, can be deduced. Note, for example, in the fluid pressure profile in Figure 18 the position of the Red River Formation and the younger formations relative to the Winnipegosis Formation, which is in turn indicative of distinct pressure systems. It is possible that the separation at least between the Winnipeg and Red River Formations can be accounted for by the presence of the Red River evaporites that appear to develop in this area (Andrichuk, 1959, Fig. 15)

The salinity of brine springs issuing from Winnipegosis reefs in the Manitoba outcrop belt, which is incompatible with salinity data from the Winnipegosis Formation, provides additional evidence of hydraulic continuity. It is ascribed to cross-formational flow through fracture systems affecting the aquitards from underlying formations characterized by higher salinity. The latter can be also invoked to explain the absence of brine springs in the outcrop belts of the pre-Winnipegosis units.

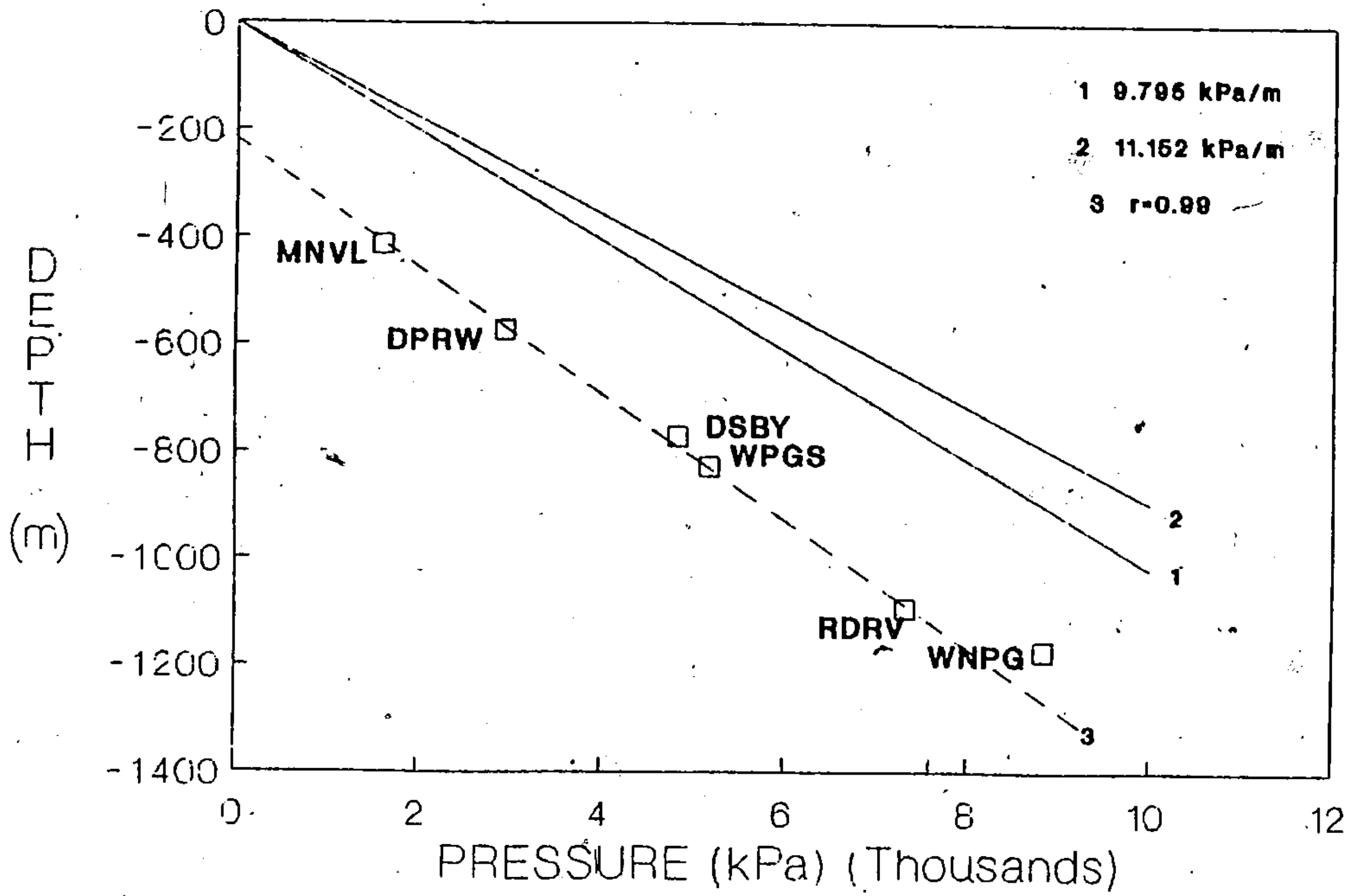

Fig. 18. Fluid-pressure profile for Dome Strathclair 8 34 16 21 well (LSD 08-34-16-21WPM).
WNPG: Winnipeg Formation; RDRV: Red River Formation; WPGS: Winnipegosis Formation; DSBY: Dawson Bay Formation; DPRW: Duperow Formation; MNVL: Mannville Group.

4.3.2 Prairie Evaporite

It is evident that within the study area and the entire Williston basin generally, salt removal from the Prairie Evaporite comprises probably the most important clue in the endeavour to unravel the structural integrity of the Phanerozoic sedimentary sequence. Salt solution and collapse of the overlying strata are also the responsible components for several commercial hydrocarbon accumulations. The latter is probably indicative of alterations in the subsurface hydrodynamic conditions coinciding with the onset of salt retreat. Salt-related tectonics exemplify the hydrodynamic conditions prevalent in the Williston basin. Should static conditions prevail, thus the formation fluids be immobile, only minor salt leaching can occur, since the solvent will become saturated. With continuous flow however, recurrent salt solution may take place. This conforms to the principle of the relationship between hydrochemistry and hydrodynamics, as succinctly stated by Hitchon (1980). It is manifested to a great extent by the relatively high salinity values of the Winnipegosis formation fluids in the area beneath and west of the present salt edge, and their gradual decrease northeastwards towards the outcrop belt.

It is a major drawback, especially in view of the scope of the present study, that no data exist on formation fluids of the Prairie Evaporite. The only test performed in the

Chevron W. Oak Lake 1-18-8-25 well (LSD 01-18-08-25WPM), provides an excellent opportunity to gain insight into the excessively high pressures that can be expected to occur. A shut-in pressure corresponding to 507 m of potentiometric surface above sea level and 1232 m of pressure head, was encountered. It becomes apparent that no such conditions can be easily envisaged for an evaporitic section, at least under natural circumstances. The above can be accounted for by incipient fracture systems, probably precursors of complete salt removal around this site. Also noteworthy, is the location of this site relative to the Winnipegosis fringing reef and the Birdtail-Waskada axis that evidence their role in initiating salt solution in depth.

4.3.3 Post-Prairie units

All of the aquifers discussed above, from the Middle Cambrian Winnipeg Formation up to and including the Middle Devonian Winnipegosis Formation have two common denominators. Firstly, they are all exposed at the surface in the outcrop belts near Lakes Winnipeg, Winnipegosis and Manitoba and are characterized by a uniform flow pattern that appears to lead toward their outcrops. Secondly, as pre-Prairie units they are not disrupted by salt solution-induced structures, as opposed to post-Prairie formations of Paleozoic age. The former however, holds true for the first two post-Prairie carbonates, at least as far as surface exposure is concerned (unconfined aquifers). The rest of the Paleozoic aquifers are isolated from the surface (confined aquifers), since they are truncated at the sub-Mesozoic unconformity. For hydrogeologic purposes the distinction between unconfined and confined aquifers will comprise the basis for the division of the post-Prairie Paleozoic carbonates

4.3.3.1 Unconfined aquifers

The vertical continuity of the exposed aquifers is interrupted by the presence of the First Red Beds at the base of the Souris River Formation. The entire sequence is separated from the underlying Prairie Evaporite and the Winnipegosis Formation by the Second Red Beds of the Dawson Bay Formation.

4.3.3.1a Dawson Bay Formation

It is questionable whether isopach anomalies present in the Dawson Bay Formation, especially along Townships 1-5, Ranges 25 and 26WPM in the southern part of the area along the Birdtail-Waskada axis, as well as eastward from the boundary zone, are related to salt solution affecting the Prairie Evaporite, differential subsidence of the basement or removal by solution of the Hubbard Evaporite (McCabe, 1971). It appears therefore that the degree of structural disturbance cannot be easily assessed. It can be assumed, however, that salt removal following Dawson Bay sedimentation will have affected the structural integrity of this formation. In addition to that, the nature of this unit as a shale-carbonate sequence probably imparts major heterogeneities, as might be the case for the apparent potentiometric low in the vicinity of Township 12, Range 24WPM (Fig. 19). The same conditions are especially manifested by the excessively low pressure registered by the Pr Potash et al McAuley Prov 13 2 well (LSD 13-02-16-29WPM) that was excluded from the data set. The test yielded a shut-in pressure corresponding to a potentiometric surface of 240 m below sea level. The latter is incongruous with the results obtained from other tests and can be best ascribed to reservoir heterogeneities. Another possible explanation is offered by the fact that salt solution has occurred adjacent to this area, specifically in Township 29, Ranges 17 and 19WPM (Norris _et al_., 1982).

Probably the same phenomenon may extend further southward and the low pressure might reflect sealing of the fractures attendant upon solution and collapse. The potentiometric surface map of the Dawson Bay Formation (Fig. 19) depicts northeastward flow with an average gradient of 2.5 m/km in the southern part, steepening in the central-northern part to 10 m/km.

An important feature to observe is that the flow direction towards the outcrop belt is in accordance with the regional flow pattern. Absence of springs in the outcrop belt is probably due to interception of the flow system by

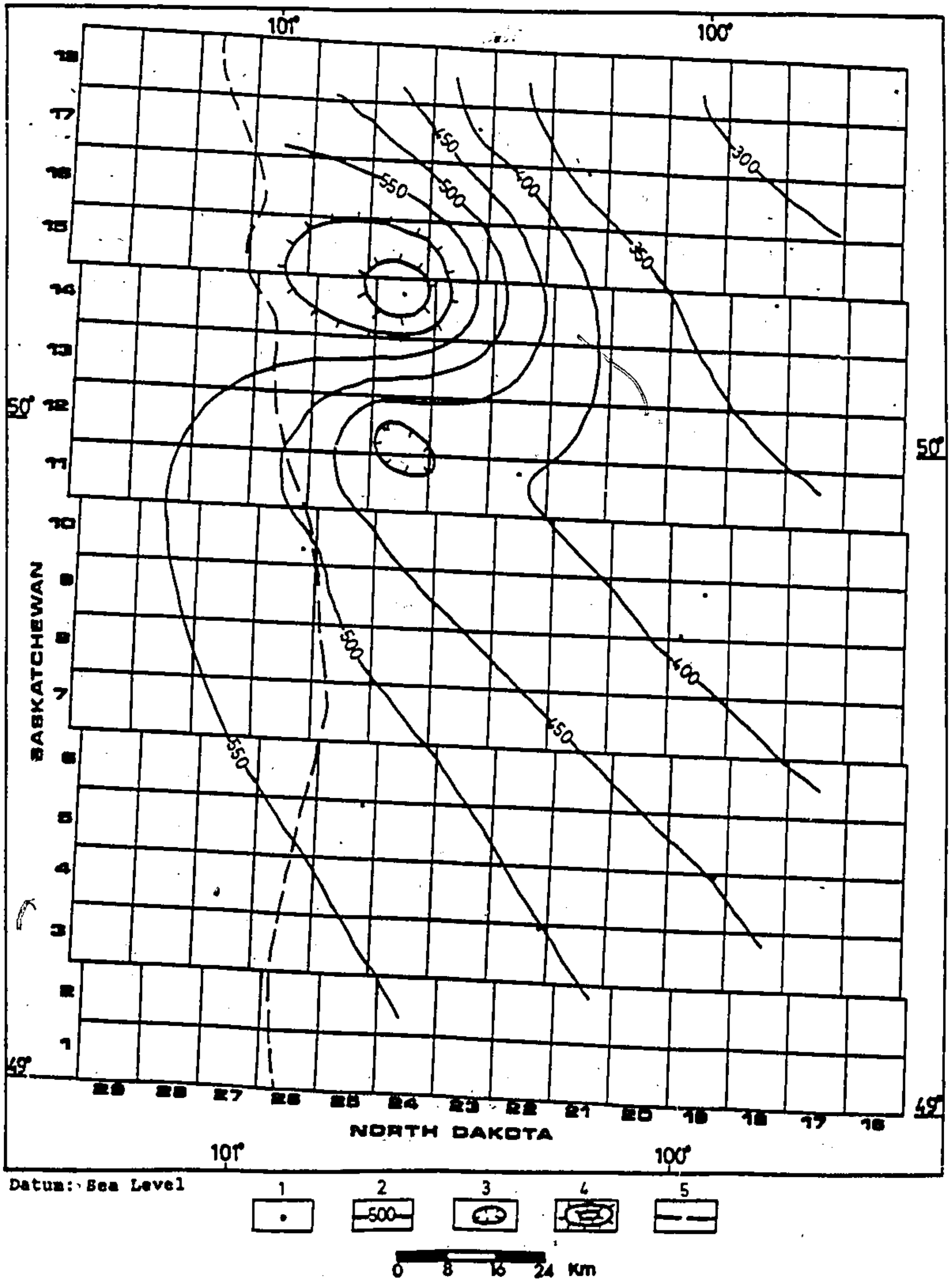

Fig. 19. Potentiometric surface for Dawson Bay Formation. 1) location of wells; 2) equipotential lines (contour interval= 50 m); 3) potentiometric high; 5) limit of Prairie Evaporite salt beds (solution edge).

Credit: Simpson, 1983.

salt-solution-induced fractures and subsequent cross-formational flow towards the overlying formations. Such a case might be represented by the potentiometric high in the vicinity of Township 14, Range 24WPM, as will be further discussed, and by the steep hydraulic ridge further eastward. The latter might be of considerable significance when its approximate coincidence with the same trend of minor magnetic anomalies on the Precambrian basement, as in the case of the Winnipeg and Red River Formations, is taken into account. It is therefore possible that this particular zone of the basement transmits high pressures on the above mentioned formations through recurrent activation, thus facilitating cross-formational flow. It can probably be argued that the flow pattern depicted is quite similar to that displayed for the Pre-Prairie formations and is thus indicative of a possible hydraulic connection.

Undoubtedly, the impermeable nature of the Second Red Beds is questioned at least in one case. The Amerada Lauder Prov M F 9 35 5 25 well (LSD 09-35-05-25WPM) yielded a hydraulic head indicative of a hydraulic connection with the entire underlying Paleozoic section. The latter is especially exemplified by the fluid pressure profile of this particular well (Fig. 20), where the vertical hydraulic continuity from the basal clastic unit through the Dawson Bay Formation becomes evident.

The slight contrast also in the potentiometric surfaces, appears to lead in an upward gradient, that

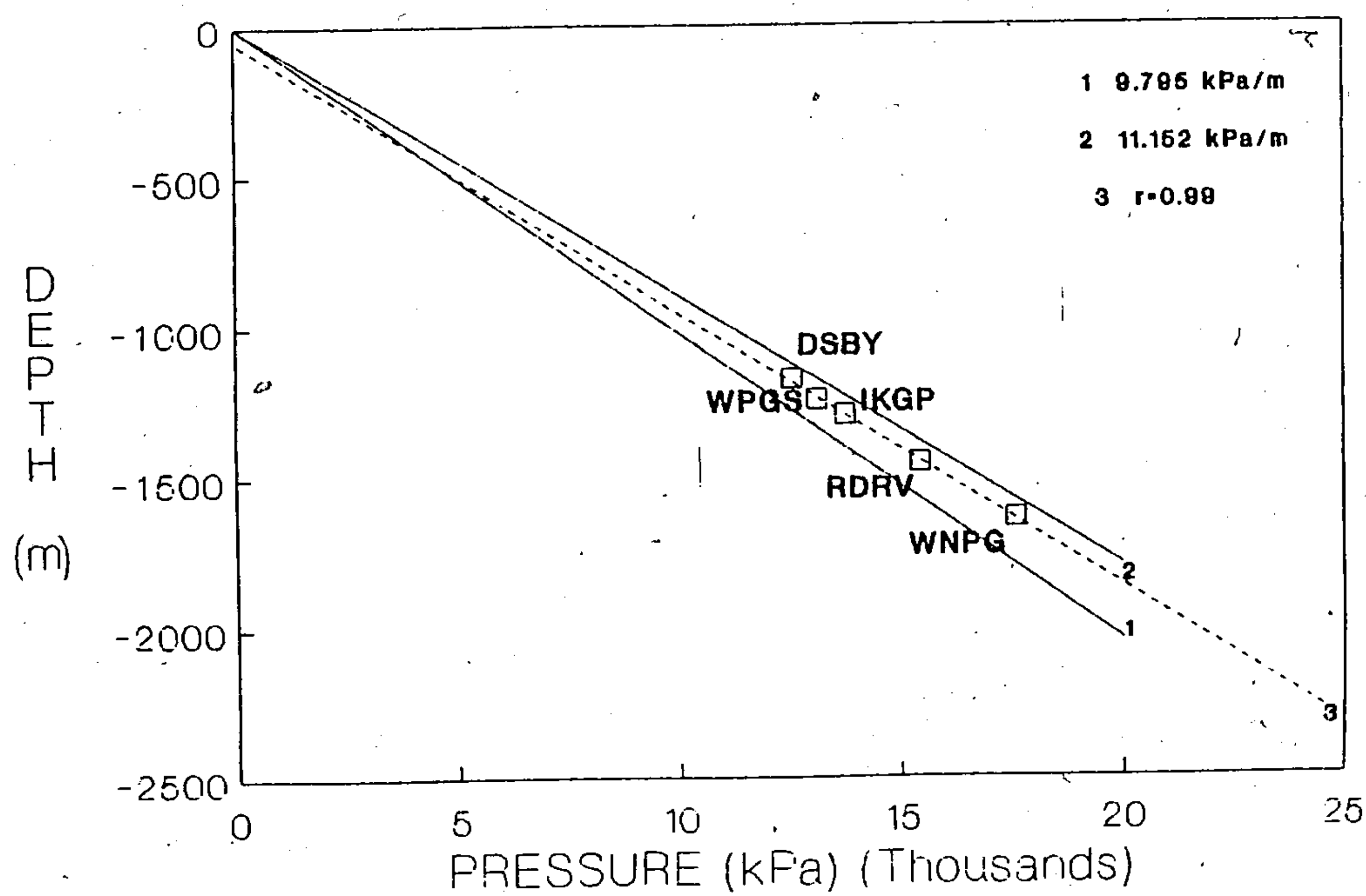

Fig. 20. Fluid-pressure profile for Amerada Lauder Prov M F 9 35 5 25 well (LSD 09-35-05-25WPM).
WNPG: Winnipeg Formation; RDRV: Red River Formation; IKGP: Interlake Group; WPGS: Winnipegosis Formation; DSBY: Dawson Bay Formation.

indicates potential upward cross-formational flow. The Dawson Bay also is characterized in the vicinity of Township 5, Range 25WPM by a slight synclinal flexure and in addition the overlying Souris River Formation exhibits, in the same area, an anomalous increase in thickness, probably indicative of salt-related tectonics (McCabe, 1967). Thus the approximate coincidence of a site, characterized by vertical continuity of the pressure system and cross-formational flow, with an area where salt solution has occurred, comprises the hitherto best evidence of the effect of salt removal and ensuing collapse of the overlying strata on the hydrogeologic environment.

Hydraulic connection of the Dawson Bay Formation with the underlying carbonates, can be expected to be a common case in most of the study area where the Prairie Evaporite salt is missing. The graph of pressure against depth for the Dome Strathclair 8 34 16 21 well (LSD 08-34-16-21WPM) (Fig. 18) is a case in point. The potentiometric surface values also, except for the Winnipeg Formation that appears to comprise a separate pressure system, are indicative of downward cross-formational flow. It is therefore likely that this site might comprise a locale where undefined solution-generated collapse structures occur.

It can be assumed, since no data exist, that pressure discontinuities might be present between the Dawson Bay Formation and the underlying carbonates in the area underlain by the salt of the Prairie Evaporite. The hydraulic connection in the areas of the missing salt casts doubt also, in some instances, on the nature of the Second Red Beds as an aquitard.

4.3.3.1b Souris River Formation

The potentiometric map of the Souris River Formation (Fig. 21) reveals a dramatical change in the fluid potential pattern. The effect of salt solution appears to be exemplified by the presence of major anomalies especially along the Birdtail-Waskada axis where, as already disclosed, salt removal along the present salt edge has taken place. The lows in the northern and southern parts of the boundary zone are likely to reflect reservoir heterogeneities, since the Souris River Formation is a cyclical limestone-shale sequence. However, the latter area is located in the vicinity of the Waskada region where salt solution is known to have taken place.

The anomaly might be indicative of the incipient stages of salt removal, before more intense solution gave rise to the Waskada dome. By the time the dome was formed, the initial fracture systems had been probably sealed, thus giving rise to low permeability and hence potentiometric surface. A potentiometric high east of the Birdtail-Waskada axis in the vicinity of Township 5, Range 24WPM is located in an area where structural disturbance and anomalous thickening of the Souris River Formation occur (McCabe, 1967, Fig. 16).

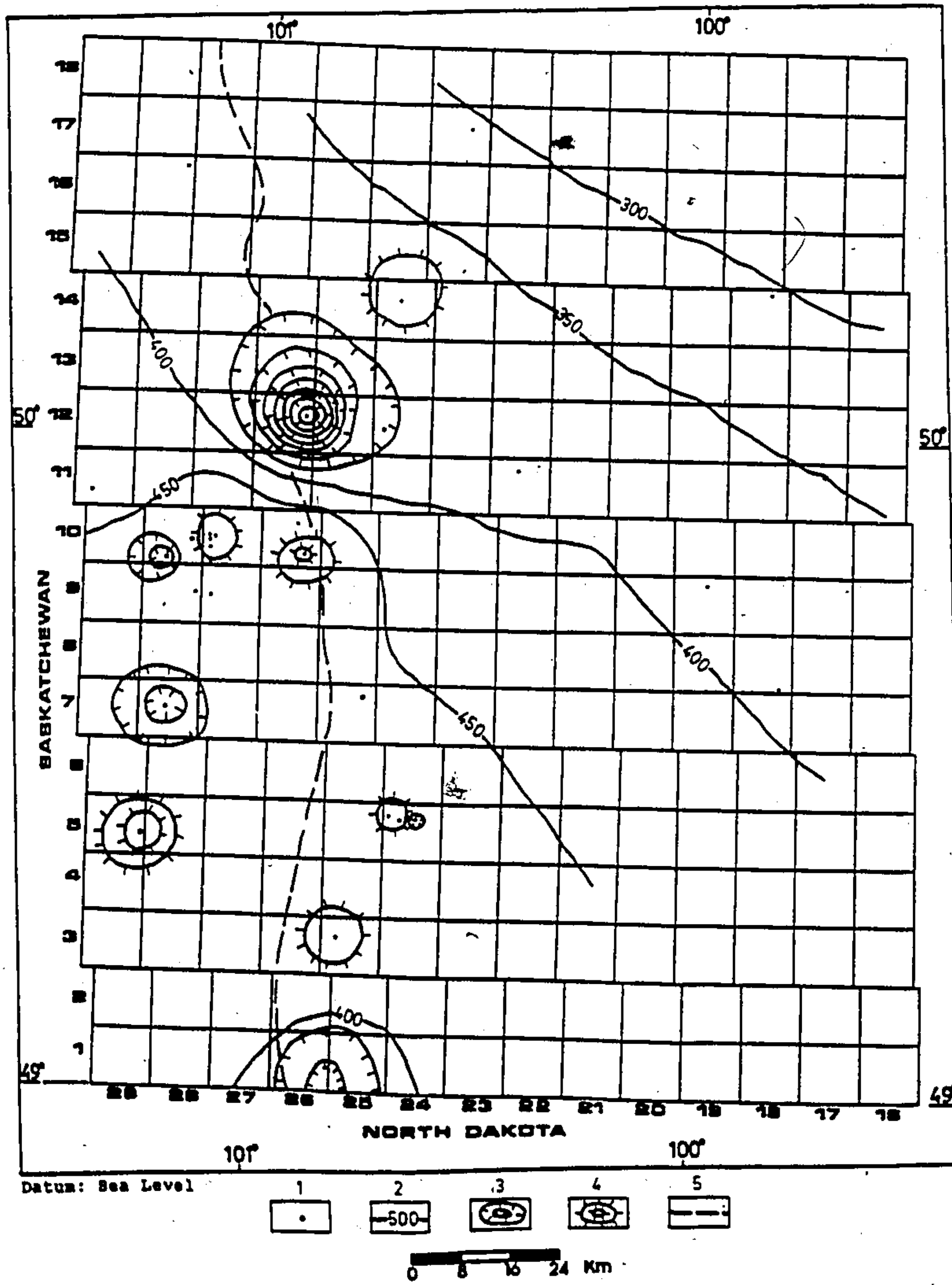

Fig. 21 Potentiometric surface for Souris River Formation. 1) location of wells; 2) equipotential lines (contour interval= 50 m); 3) potentiometric low; 4) potentiometric high; 5) limit of Prairie Evaporite salt beds (solution edge).

Credit: Simpson, 1983.

This coincidence comprises the best evidence on the relationship between areas of "known" salt solution, as inferred from structural and isopach anomalies, and formation fluids pressures. In this case the fractures remained open after formation, thus providing potential conduits for a relatively unrestricted flow that resulted in high fluid pressures. The same locale also of structural and isopach anomalies is almost coincident with the Hartney structure. This indicates probably genetic relationships between the structural disturbance associated with the Hartney structure, salt-related tectonics and high fluid pressures. Within the region affected by the Hartney structure, partial infilling of fracture systems with impermeable material, has resulted in the formation of separate vertical pressure systems, as appears to be the case for the Royalite Triad et al East Hartney 1 well (LSD 07-27-05-24WPM) (Fig. 16).

The effect of vertical salinity variation within the stratigraphic column is probably depicted by the anomalously high head located in Township 10, Range 26WPM. In this particular locale, the underlying Dawson Bay Formation is characterized by salinities in the order of 120,000 mg/l in contrast to 260,000 mg/l approximately for the Souris River Formation (Manitoba Department of Mines, 1971). Thus the salinity contrast noted above can create, through osmotic phenomena, abnormally high pressures in the overlying formation (Fig. 22). The First Red Beds at the base of the

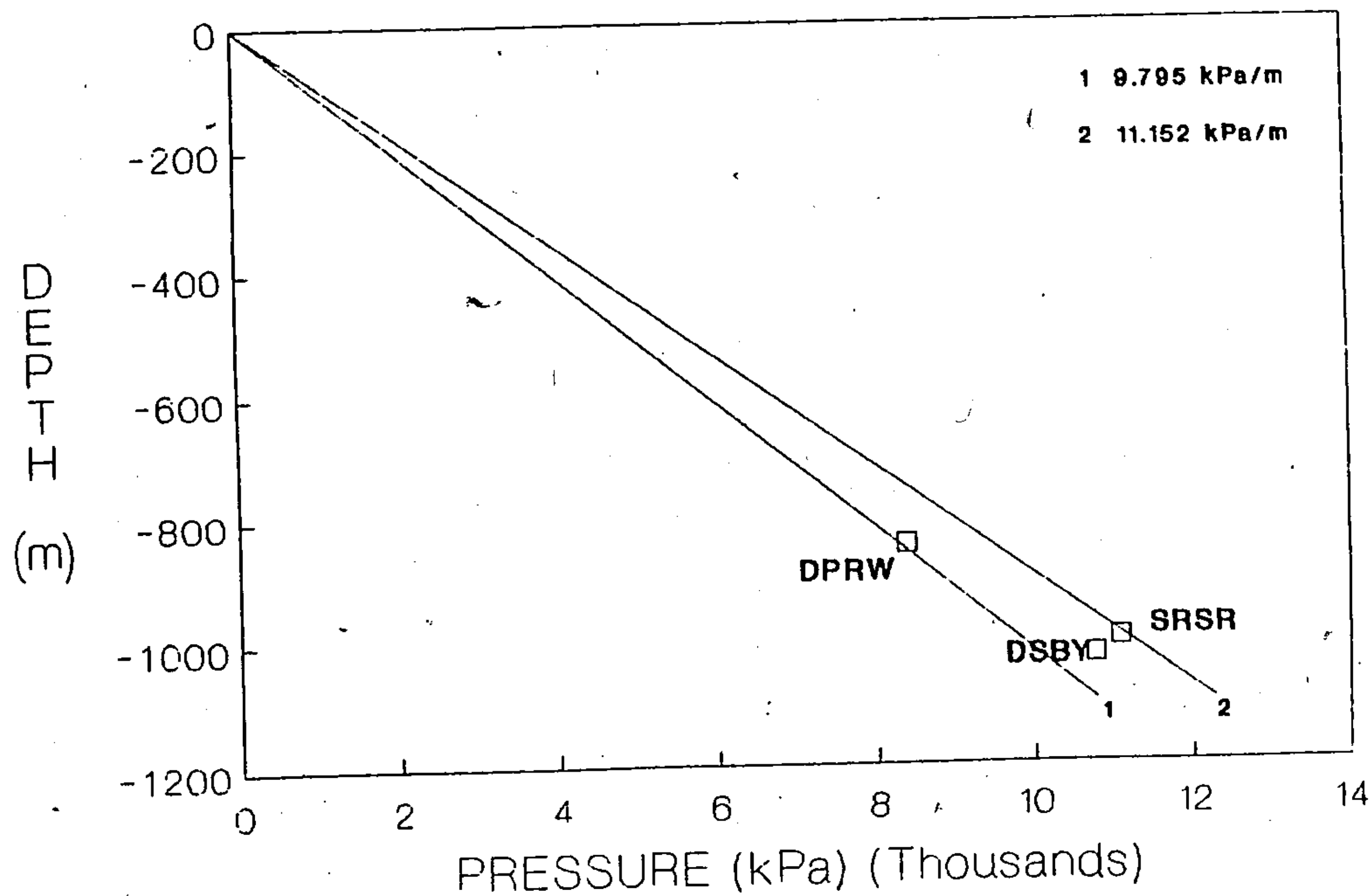

Fig. 22. Fluid-pressure profile for Calstan South Virden Prov. SWD 3-11 well (LSD 03-11-10-26WPM). DSBY: Dawson Bay Formation; SRSR: Souris River Formation; DPRW: Duperow Formation.

Souris River Formation have probably acted in this particular case as semi-permeable membranes.

The potentiometric high in the vicinity of Township 14, Range 24WPM constitutes an outstanding example of cross-formational flow. The underlying Dawson Bay Formation is also characterized by a high in the same area, and both tests were performed by the Apache et al Chumah 2-28-14-24 well (LSD 02-28-14-24WPM). The contrast in the potentiometric surface has led to an upward vertical gradient. The coincidence of the highs, on the other hand, probably indicates that the potential conduits for cross-formational flow exist, most likely through fracture systems of the First Red Beds. The isolated potentiometric anomalies in the western part of the area within the present salt limit do not appear to coincide with any area of known salt collapse. However, it should be noted that the relatively sparse well control in the Devonian formations does not permit exact demarcation of solution-generated collapse structures.

In these instances, a knowledge of subsurface hydrodynamic conditions has potential to provide an invaluable tool for their detection. Hydrogeologic conditions resume a smooth pattern in the northwestern part of the area, with a northwestward-trending gradient toward the outcrop belt. The high magnitude anomalies, however, in the rest of the area that might reflect active cross-formational flow, can be invoked in this case to account for the absence of brine springs in the outcrop belt.

It appears also that in some instances the presence of the shaly First Red Beds is effective in isolating hydraulically the Souris River Formation from the underlying Dawson Bay Formation. This is manifested in the fluid-pressure profile of the Strath 6 23 17 23 well (LSD 06-23-17-23WPM) (Fig. 23). The location of the Souris River and Duperow Formations relative to the Dawson Bay Formation can be best explained with reference to the presence of the First Red Beds, which interrupt the vertical hydraulic continuity. It is also noteworthy that there is no impermeable interval between the first two formations. Two tests in the First Red Beds which included a portion of the overlying Souris River Formation, revealed relatively high potentiometric surfaces. The Cdn Sup Daly Swd No.1 well (LSD 12-04-10-28WPM) yielded drill stem tests, in which one incorporated the First Red Beds and Souris River Formation and the other included the Souris River only, and exhibits a high contrast in the potentiometric surface indicative of high vertical upward gradient.

The same area exhibits an anomalous potentiometric low for the Souris River Formation, probably indicating an additional case of cross-formational flow. The high pressure that derives from the lower interval might be deflected in the vicinity of the potentiometric low to more permeable conduits. Thus, in some instances, it might be

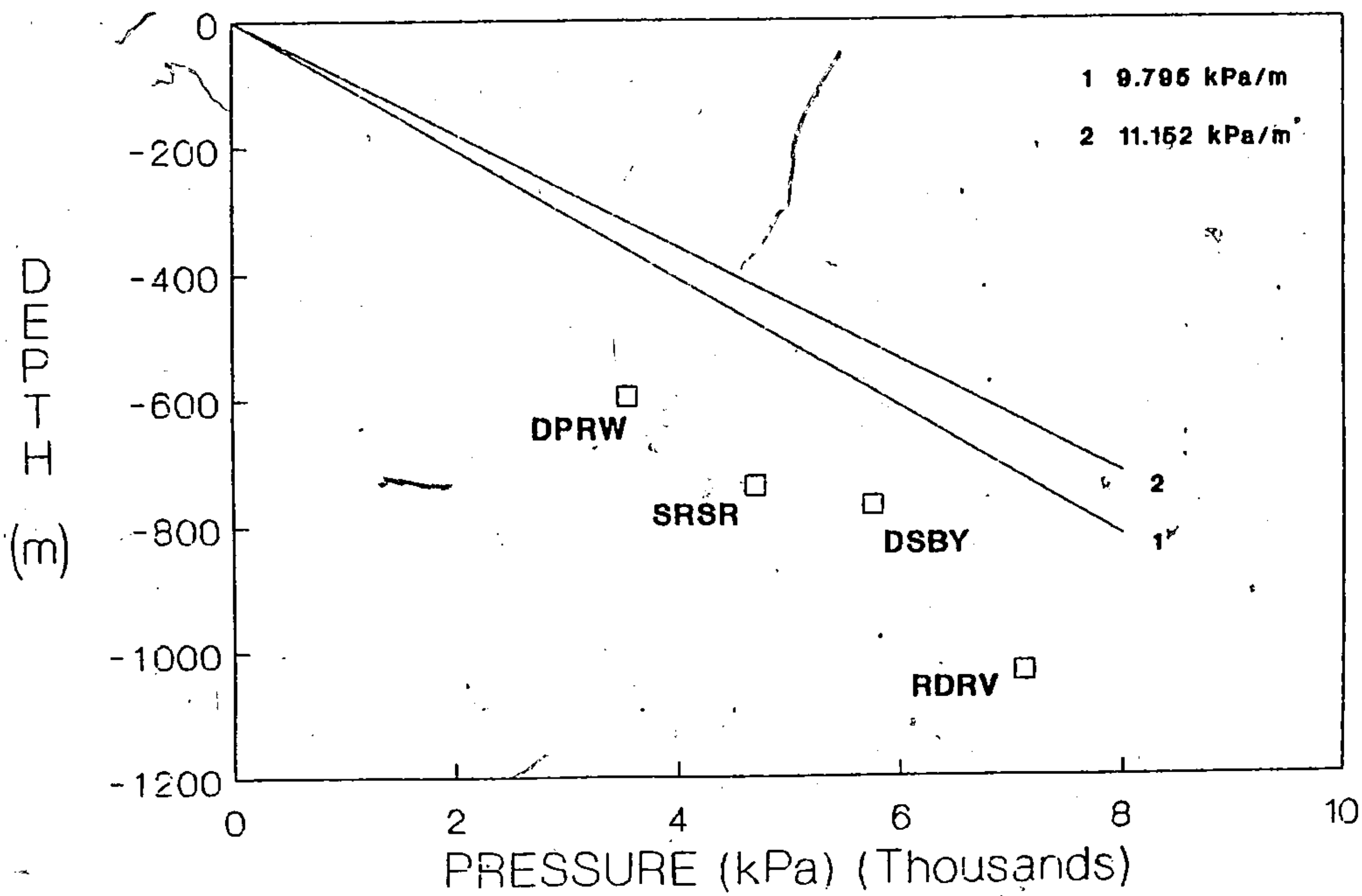

Fig. 23. Fluid-pressure profile for Strath 6 23 17 23 well (LSD 06-23-17-23WPM).
RDRV: Red River Formation; DSBY: Dawson Bay Formation; SRSR: Souris River Formation; DPRW: Duperow Formation.

questionable whether any unconfined post-Prairie aquifer can be treated as a distinct hydrostratigraphic unit.

4.3.3.2 Confined aquifers

The second category of the post-Prairie carbonates is one of the most important. It includes oil-producing strata, as well as units which are targets for subsurface waste disposal. Its significance is related to its unconformable truncation below the Amaranth Formation (Jurassic) at the sub-Mesozoic unconformity. The latter is the component that determines oil entrapment and containment of fluid wastes.

4.3.3.2a Duperow Formation

The fluid potential pattern of the Duperow Formation (Fig. 24) appears to comprise a continuation of the pattern present in the Souris River Formation. Numerous anomalies are present again along the Birdtail-Waskada axis and some of them will be considered in detail. Solution-generated collapse structures are known to occur in the Duperow Formation in the vicinity of Townships 3-6, Range 25WPM where structural and isopach anomalies are encountered (McCabe, 1971). The potentiometric cells along the same trend most probably depict the hydrodynamic response of these structures.

The potentiometric high in Township 4, Range 25WPM especially, is located in the area where a sombrero

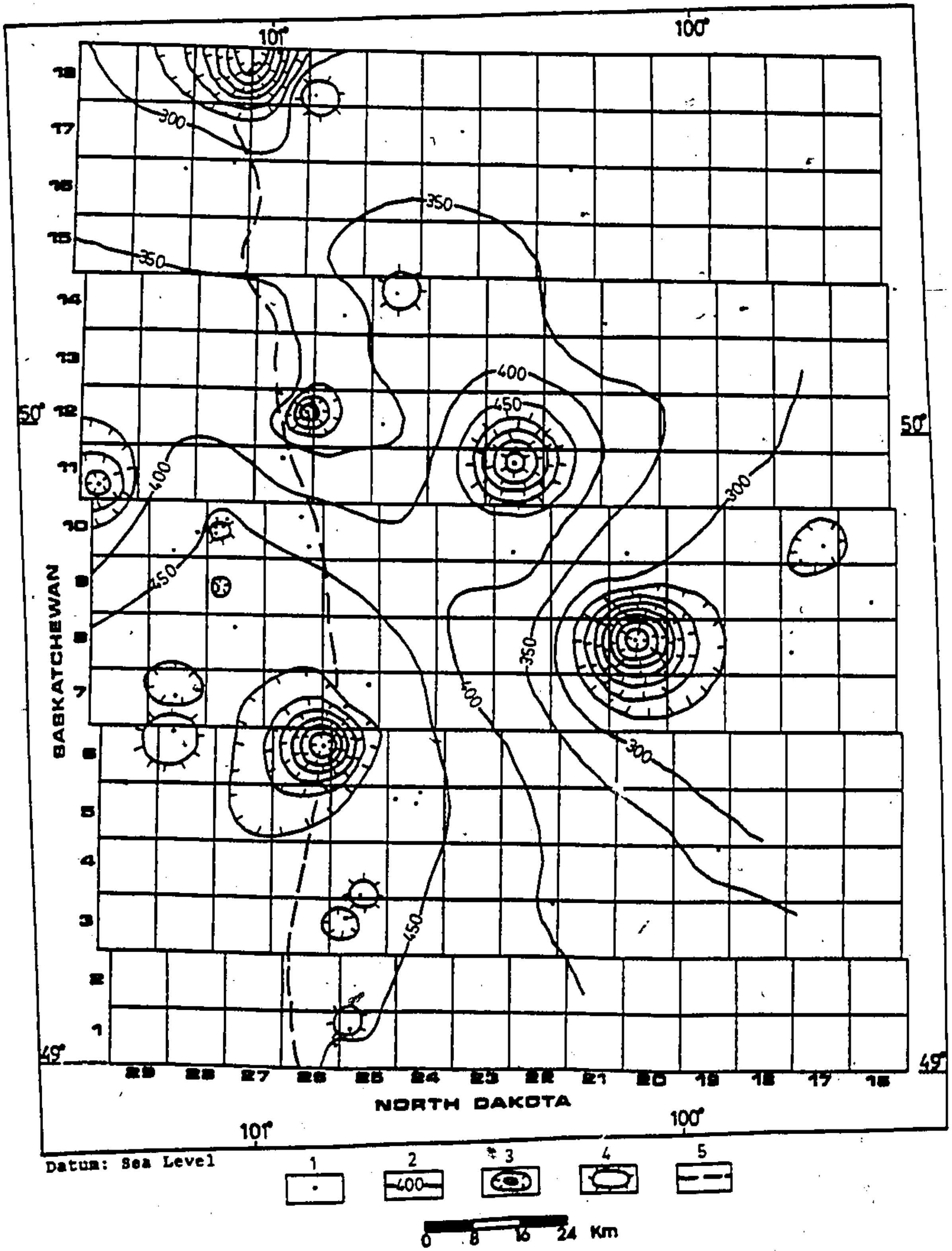

Fig. 24. Potentiometric surface for Duperow Formation. 1) location of wells; 2) equipotential lines (contour interval= 50 m); 3) potentiometric low; 4) potentiometric high; 5) limit of Prairie Evaporite salt beds (solution edge).
Credit: Simpson, 1983.

structure, specifically the window of the Lodgepole Formation, occurs. This feature thus might be representative of the incipient development stages of the sombrero anticline during Duperow times. It is also important to note the anomaly in the Waskada area in the southern part of the boundary zone which, in this case, in contrast to the previous one for the underlying formation, comprises a potentiometric high probably indicative of unsealed fractures.

The most prominent high on the potentiometric map is located in the vicinity of Township 11, Range 22WPM and the same well registered much lower potentiometric values for the underlying Souris River, Dawson Bay and Red River Formations. The three formations appear more or less to be hydraulically connected, while an abnormally high pressure is apparent for the Duperow Formation (Fig. 25). It becomes evident that in this particular site the Duperow is not pressurized by any of the underlying units. Also noteworthy is the fact that the same unit in this area is not overlain by Mississippian carbonates, but by the Red Beds of the Lower Amaranth Formation that also exhibit an anomalous increase in thickness (McCabe, 1959, Fig. 20), attributed to salt-related tectonics.

No data are available for any of the overlying formations in the adjacent region, but it is possible that the upper clastic unit in this site is responsible for imparting abnormally high pressures in the Duperow Formation

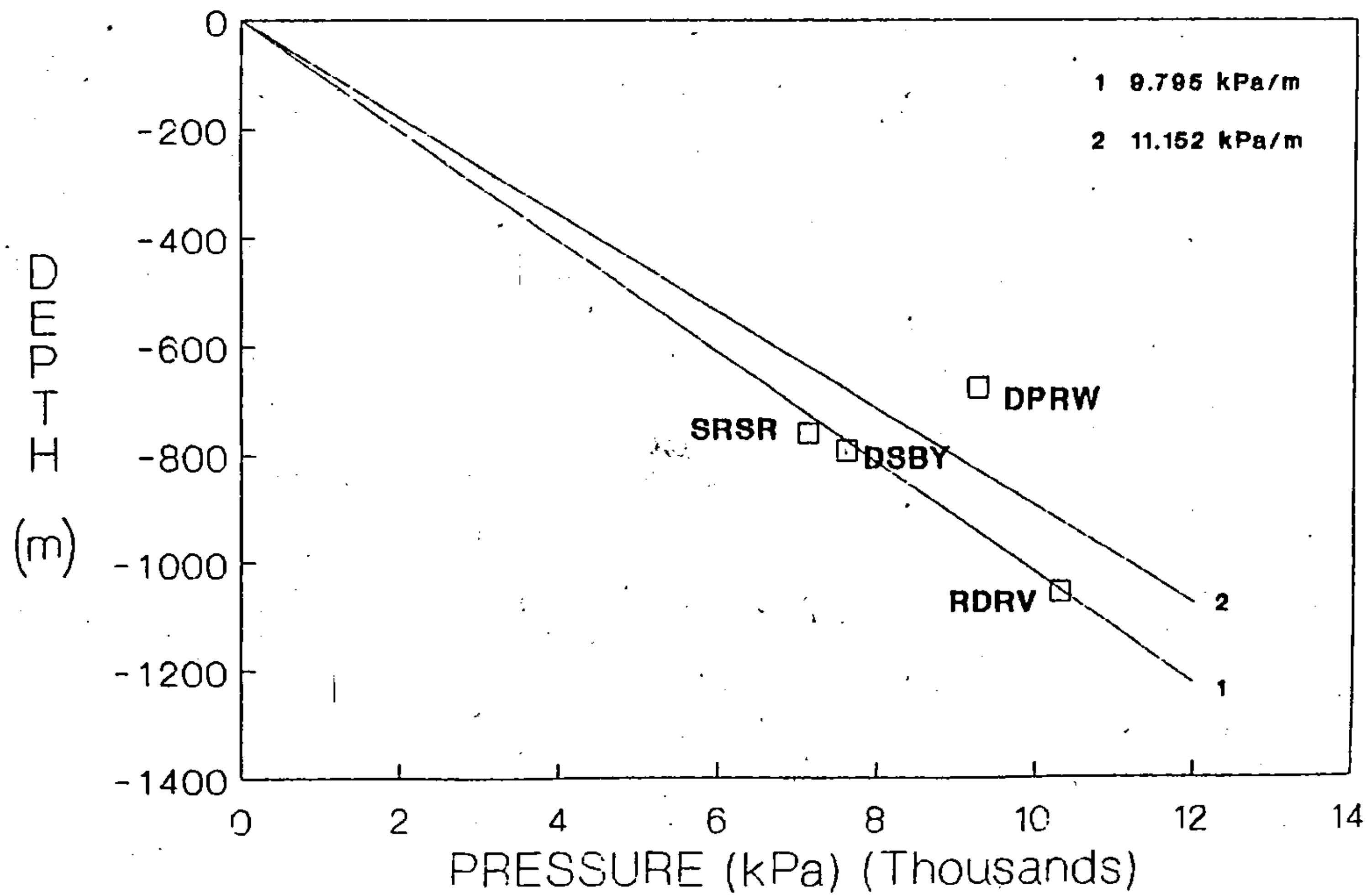

Fig. 25. Fluid-pressure profile for Dome Harding 4 27 11 22 well (LSD 04-27-11-22WPM).
RDRV: Red River Formation; DSBY: Dawson Bay Formation; SRSR: Souris River Formation; DPRW: Duperow Formation.

through downward cross-formational flow. Other important features are the potentiometric lows located of Townships 7 and 12, Ranges 28 and 26WPM respectively, which coincide with other lows on the Souris River Formation. It is suggested that in the case of exact coincidence of lows, which might reflect fracture infilling by impermeable material, although gradients might exist, no vertical flow can occur and cross-formational flow is relatively restricted. However, one of these anomalies could represent the effect of heterogeneities, as might be the case for the Cal Stan Linklater 2 21 7 28 well (LSD 02-21-07-28WPM) (Fig. 17) that revealed the presence of argillaceous and anhydritic material near the interval tested (Baillie, 1953, Appendix II). The other potentiometric low is located in an area where all the units from the Souris River through the Nisku Formation exhibit structural anomalies and the overlying Bakken-Lyleton interval an anomalous increase in thickness (McCabe, 1967, Figs. 16-19). Thus a salt-solution origin is proposed.

A similar origin can be assigned to the low in the vicinity of Township 8, Range 20WPM, as discussed below. The other prominent anomalies are located approximately along the Birdtail-Waskada axis and are a consequence of salt-related tectonics. On a regional scale, the potential drops off in a northeastward direction, which leads to a flow system moving up-dip, most probably towards the subcrop belt where it encounters the impermeable boundary.

4.3.3.2b Birdbear Formation

A somewhat different pattern is present in the Birdbear Formation. The most striking feature of the potentiometric map (Fig. 26), is the moderately uniform flow pattern that can be best explained with reference to the homogeneous nature of this formation. It has been pointed out by Prier (1979) that reservoir homogeneities are depicted in the fluid potential pattern by relatively uniform gradients, as appears to be the case for the Birdbear Formation. However, anomalies are again present and attention is drawn to the southern part of the Birdtail-Waskada axis, where highs are encountered in the area of the sombrero anticlines in Townships 1 and 4, Range 25WPM. Thus for these two locales, the coincidence of the potentiometric highs for the Duperow and Birdbear Formations implies the existence of high vertical pressure gradients across these units, reflecting a certain degree of hydraulic connection. This is also manifested in the fluid pressure profile of the Calstan South Napinka 5 3 4 25 well (LSD 05-03-04-25WPM) (Fig. 27), where again there exists spatial coincidence between a distinct pressure system and solution-generated collapse.

The potentiometric high in the vicinity of Townships 8, 9, and 10, Ranges 27, 28 and 29WPM is located in part close to the Daly oil field, where salt solution is known to have taken place. In the same area, structural disturbance and an anomalous increase in thickness of the Birdbear Formation are also observed (McCabe, 1967, Fig. 18). A similar case

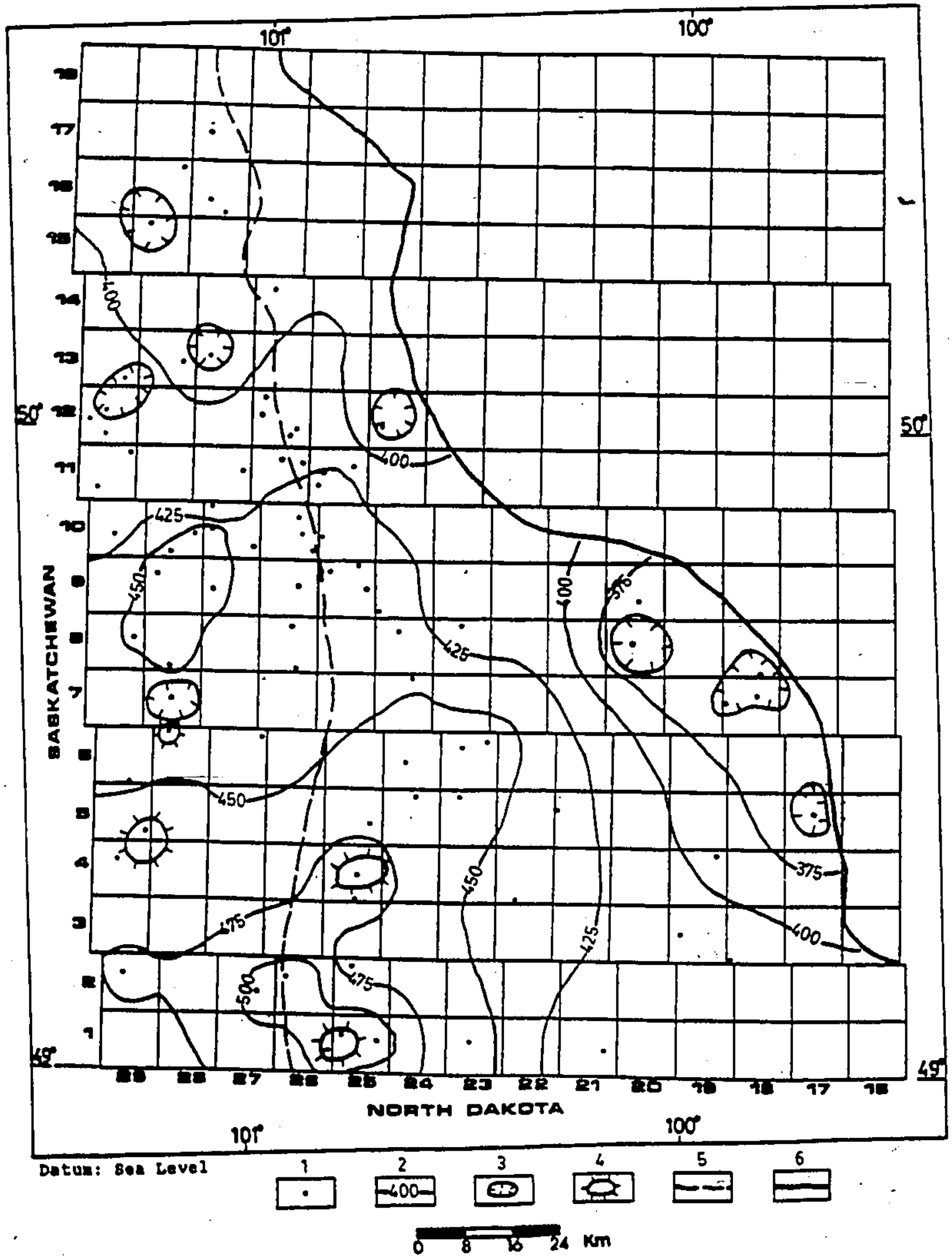

Fig. 26. Potentiometric surface for Birdbear (Nisku) Formation. 1) location of wells; 2) equipotential lines (contour interval= 25 m); 3) potentiometric low; 4) potentiometric high; 5) limit of Prairie Evaporite salt beds (solution edge).

Credits: McCabe, 1971.
Simpson, 1983.

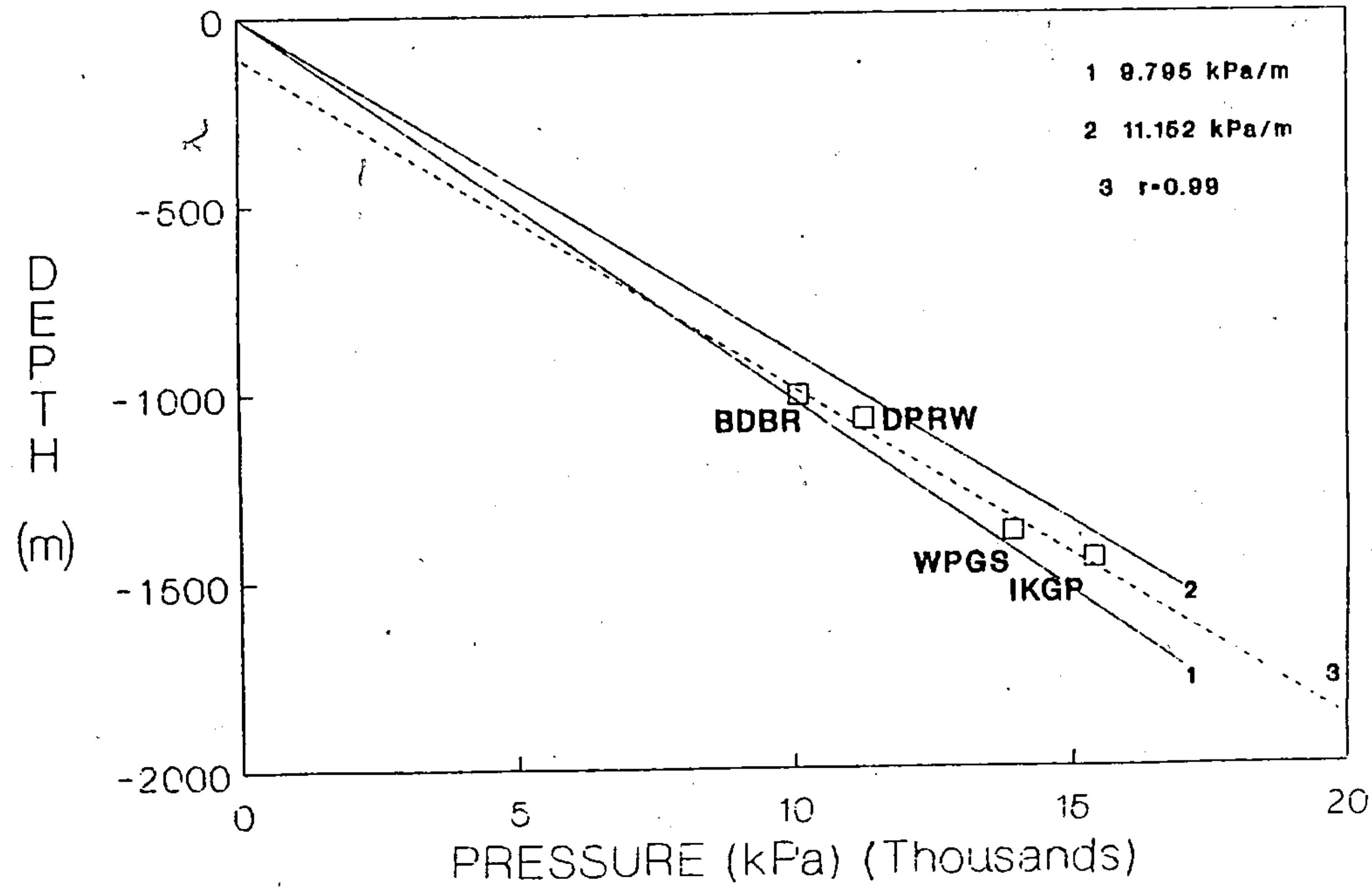

Fig. 27. Fluid-pressure profile for Calstan South Napinka 5 3 4 25 well (LSD 05-03-04-25WPM).
IKGP: Interlake Group; WPGS: Winnipegosis Formation; DPRW: Duperow Formation; BDBR: Birdbear Formation.

also is represented by the anomaly located in Townships 12 and 13, Range 29WPM. An anomalous potentiometric low in Township 8, Range 20WPM is coincident with a similar feature for the Duperow Formation. Since major heterogeneities are probably not present, at least in the Birdbear Formation because of its pure dolomitic nature (McCabe, 1971), a salt-solution origin is possible.

Comparison of the potentiometric maps for the Souris River through the Birdbear Formations reveals a linear trend of anomalies extending northwards from Township 5, Ranges 28 and 29WPM. This might be indicative of a trend along which salt solution structures exist, since it is almost coincident with an area of structural anomalies on the Duperow and Birdbear Formations (McCabe, 1967, Figs. 17, 18). Isolated potentiometric lows in the northern part of the area, are located within a region where the Nisku is characterized by structural disturbance (McCabe, 1967, Fig. 18). Once more, a north-northeastward large-scale flow pattern appears to occur which most probably terminates at the subcrop belt.

4.3.3.2c Lyleton-Bakken shale interval

The Lyleton (Torquay)-Bakken shale interval represents the most important aquitard within the post-Prairie carbonates. Its properties are significant in determining the likelihood of hydraulic connection and cross-formational flow from the underlying Devonian to the overlying Mississippian formations and vice versa.

Numerous data exist on static pressures for this aquitard. However, since potentiometric surface maps for impermeable intervals might be inconclusive, another procedure was followed. More specifically, the potentiometric values were used for the calculation of pressure heads which in turn were employed for the approximate demarcation of relatively dry and wet zones (Fig. 28). The limit between dry and wet zones was based on the observation that clusters of data points fall within a certain range of values. Generally, wet areas within an aquitard should be most likely related to open fracture systems.

The wet zone along the Saskatchewan-Manitoba border from Townships 2-6, Range 29WPM is located in a trend along which the Lyleton-Baken interval is characterized by structural disturbances (McCabe, 1967, Fig. 19). However, no isopach anomalies are observed in the same region, indicative probably of post-Bakken times salt solution. Not surprisingly, the same appears to be the case for the other prominent wet area where structural disturbance is again evident. Salt removal in the latter is manifested by the presence of an isopach anomaly in the vicinity of Township 12, Range 26WPM (McCabe, 1971).

Also noteworthy is the fact that within this zone an oil discovery in the Bakken Formation was reported in 1985 in the Kola area north of the Daly field (Manitoba Department of Energy and Mines, Annual Report 1985-1986).

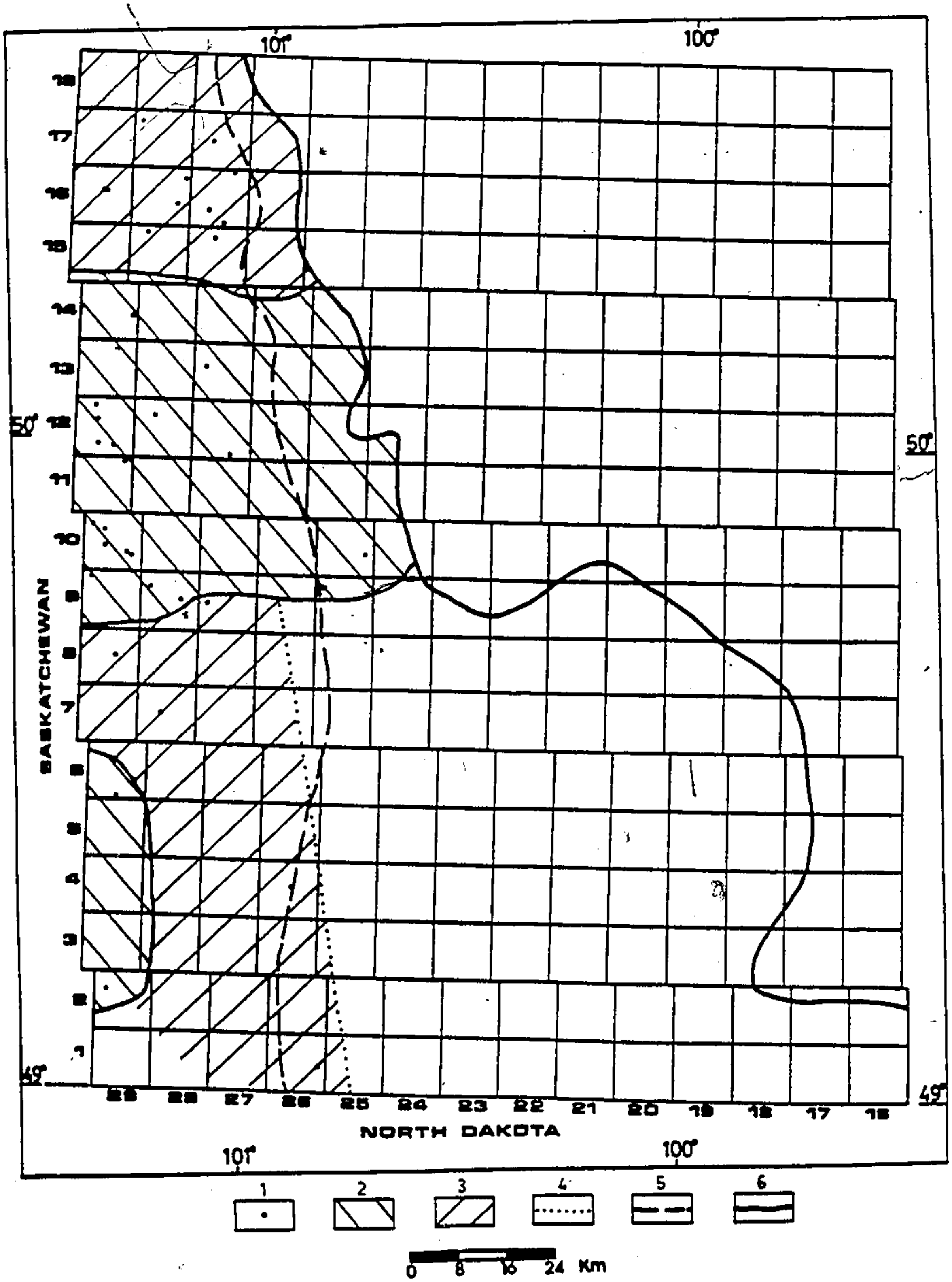

Fig. 28. Delineation of wet and dry zones for Lyleton Torquay)-Bakken shale interval.
1) location of wells; 2) wet zone (pressure head more than 500 m); 3) dry zone (pressure head less than 500 m); 4) inferred limit of dry zone of unknown extent; 5) limit of Prairie Evaporite salt beds (solution edge); 6) subcrop erosional edge.

Credits: McCabe, 1971.
Simpson, 1983.

Thus it appears that the wet regions represent areas that have been affected by salt tectonics structures and include paths for hydraulic connection between Devonian and Mississippian strata. For example, there is hydraulic continuity between the Birdbear Formation and the Alida Beds as evidenced by the fluid-pressure profile in Figure 29 at a site located in the southwestern wet area. It is also apparent that the contrast in the potentiometric surfaces is leading to upward cross-formational flow. The opposite appears to be the case for the Calstan Woodnorth Prov. 5 18 9 27 well (LSD 05-18-09-27WPM) (Fig. 30) which is located close to the Bakken-Lyleton dry zone.

While a nearly continuous pressure system is present within the Devonian units, the occurrence of the shaly interval yields abnormally low pressure in the Lodgepole Formation. Thus it becomes apparent that the hydrogeologic properties of the Lyleton-Bakken shale interval are significant in imparting continuity or discontinuity of pressure systems across the Devonian and Mississippian strata.

4.3.3.2d Lodgepole Formation

Coping with aspects of formation fluids in the Mississippian formations of southwestern Manitoba is no easy task. Prolific oil production, waterflooding for secondary recovery operations and brine injection might have altered completely in some instances the actual hydrogeologic

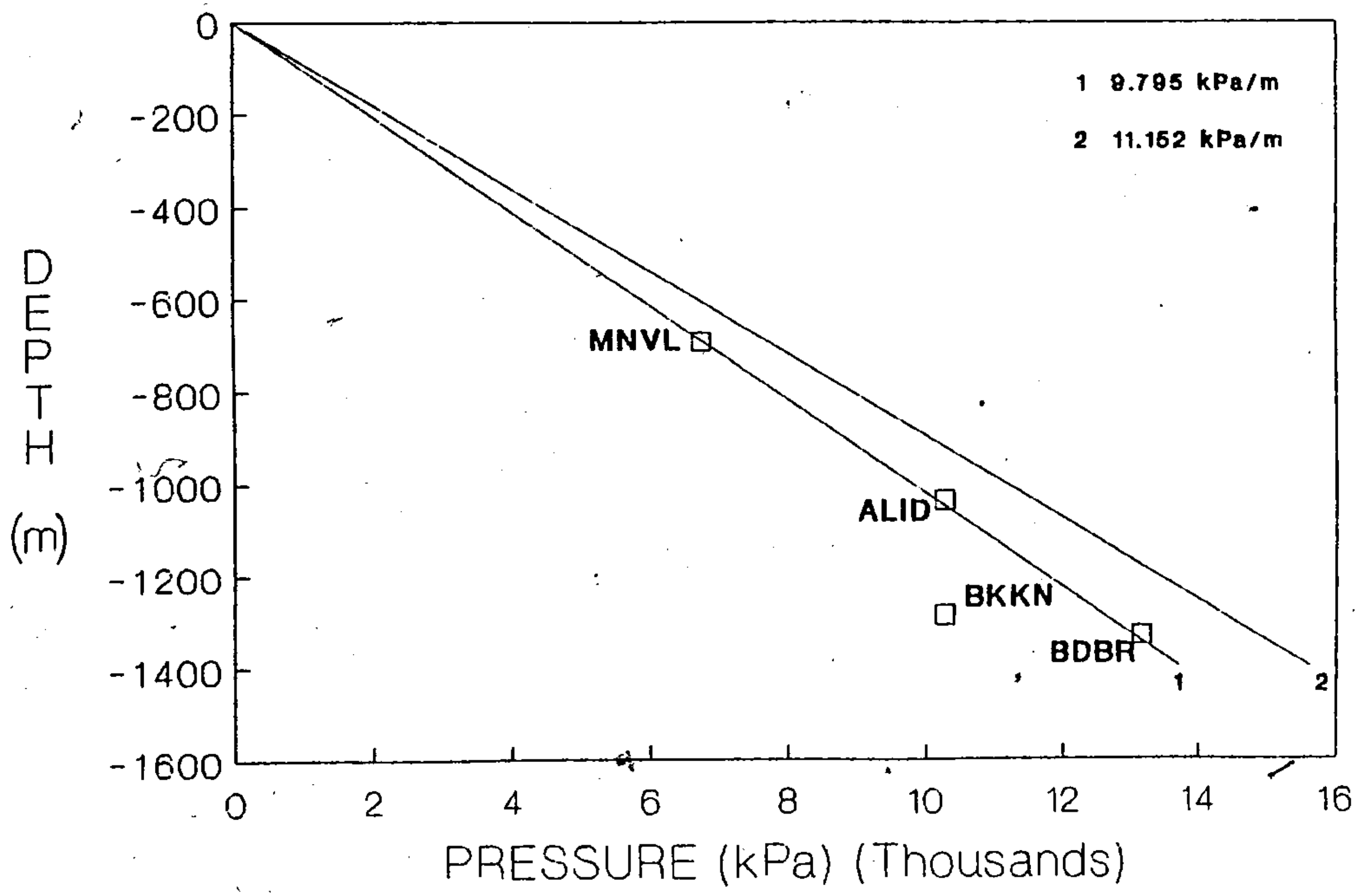

Fig. 29. Fluid-pressure profile for Calstan Pierson Prov 2 29 2 29 well (LSD 02-29-02-29WPM).
BDBR: Birdbear Formation; BKKN: Bakken Formation; ALID: Alida Beds; MNVL: Mannville Group.

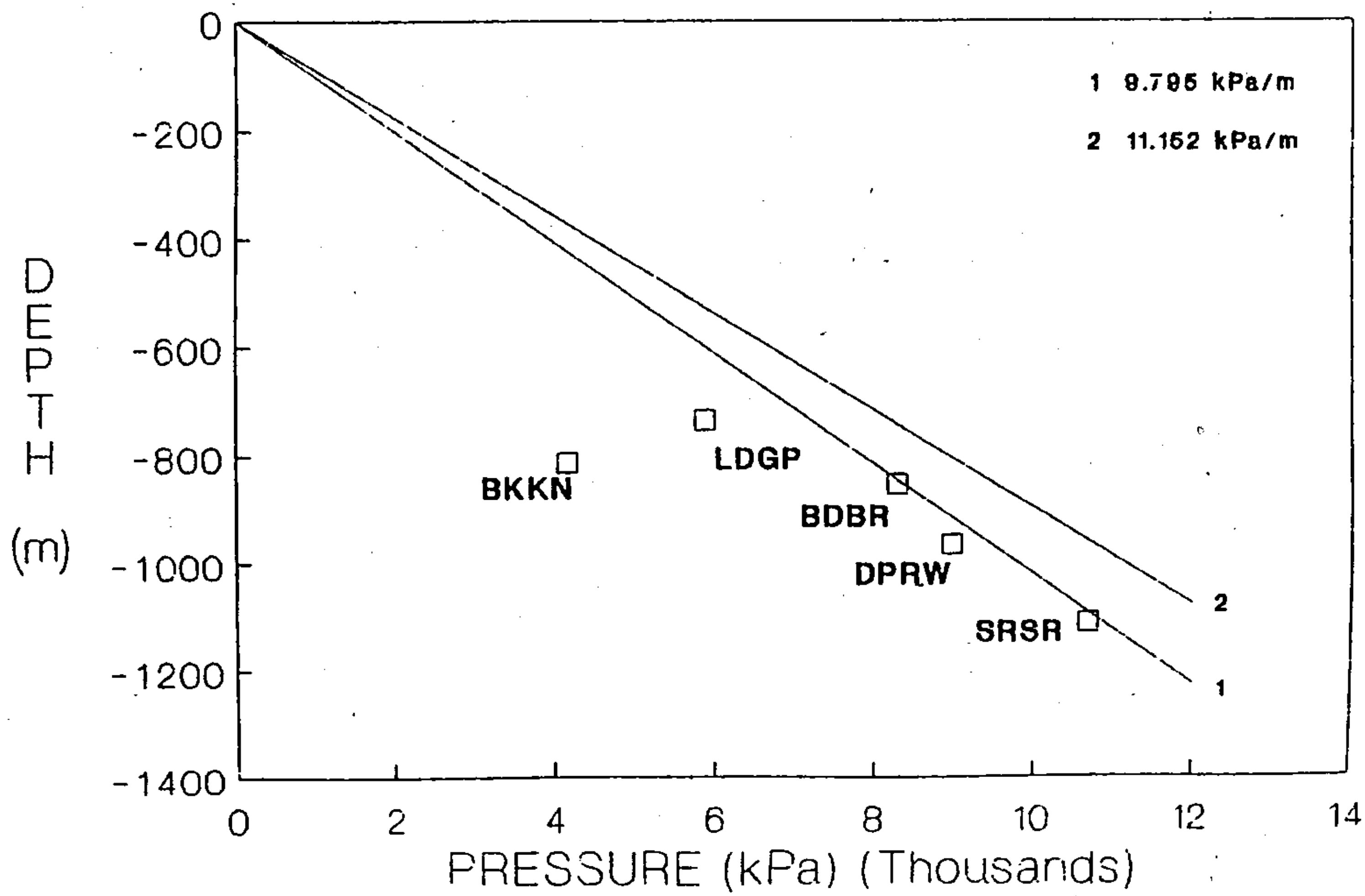

Fig. 30. Fluid-pressure profile for Calstan Woodnorth Prov. 5 18 9 27 well (LSD 05-18-09-27WPM). SRSR: Souris River Formation; DPRW: Duperow Formation; BDBR: Birdbear Formation; BKKN: Bakken Formation; LDGP: Lodgepole Formation.

environment. This applies only to areas adjacent to oil fields where large numbers of wells exist.

In order to overcome the problems mentioned above, a special procedure was employed. A large amount of information derives from wells, drilled during the initial development stage of particular oil fields. Formation pressures from these wells are likely to be reliable and are included in the data set. It is also evident that different areas within individual oil-producing regions were developed during a particular time span, so that the earliest and hence most representative tests were readily defined and subsequently used. On the other hand, the extremely dense well control in some parts of the area dictated data reduction, which was accomplished by using one well per section.

The highest potentiometric value within a section was employed in all cases, regardless of the location of the well, within an oil field or otherwise. In some instances, on the basis of the spatial relationship between individual wells and production-injection operations, data were judged to reflect not actual conditions, but probably the effect of production or injection. This was the case for several wells from the post-middle 60's, especially for the Lodgepole Formation, and were automatically excluded from the data set. Thus it is not surprising that in some cases no data were used for particular sections.

Two regional potentiometric maps were produced for the Lodgepole Formation, one showing the regional trend (Fig. 31a) and the other showing the effect of anomalies on the regional flow pattern (Fig. 31d). The reason for the former is to isolate and assess the effect of the most pronounced features on the flow pattern. The map (Fig. 31a) reveals a north-northeastward gradient. It is likely that the flow system appearing on the map originates further south in North Dakota where,as mentioned above, the basinal limestones may constitute the potential source rock for hydrocarbon generation. Thus, entrained oil globules within the water might have migrated along strike towards the differentially emergent northern subcrop belt, where local stratigraphic and structural factors governed the prolific hydrocarbon accumulations.

The local entrapment control is best displayed through detailed maps for the Virden and Daly area. The Virden field is located along the Birdtail-Waskada axis, in part within and in part beyond the salt limit, and age differences along flexures evidence a major role of salt-related tectonics in imparting structural anomalies and subsequently a portion of the entrapment control (McCabe, 1963). The potentiometric map of the Lodgepole Formation for the Virden area (Fig. 31b) exhibits, along with the regional flow pattern, several anomalies and especially a transition from potentiometric highs in the south to lows in the north.

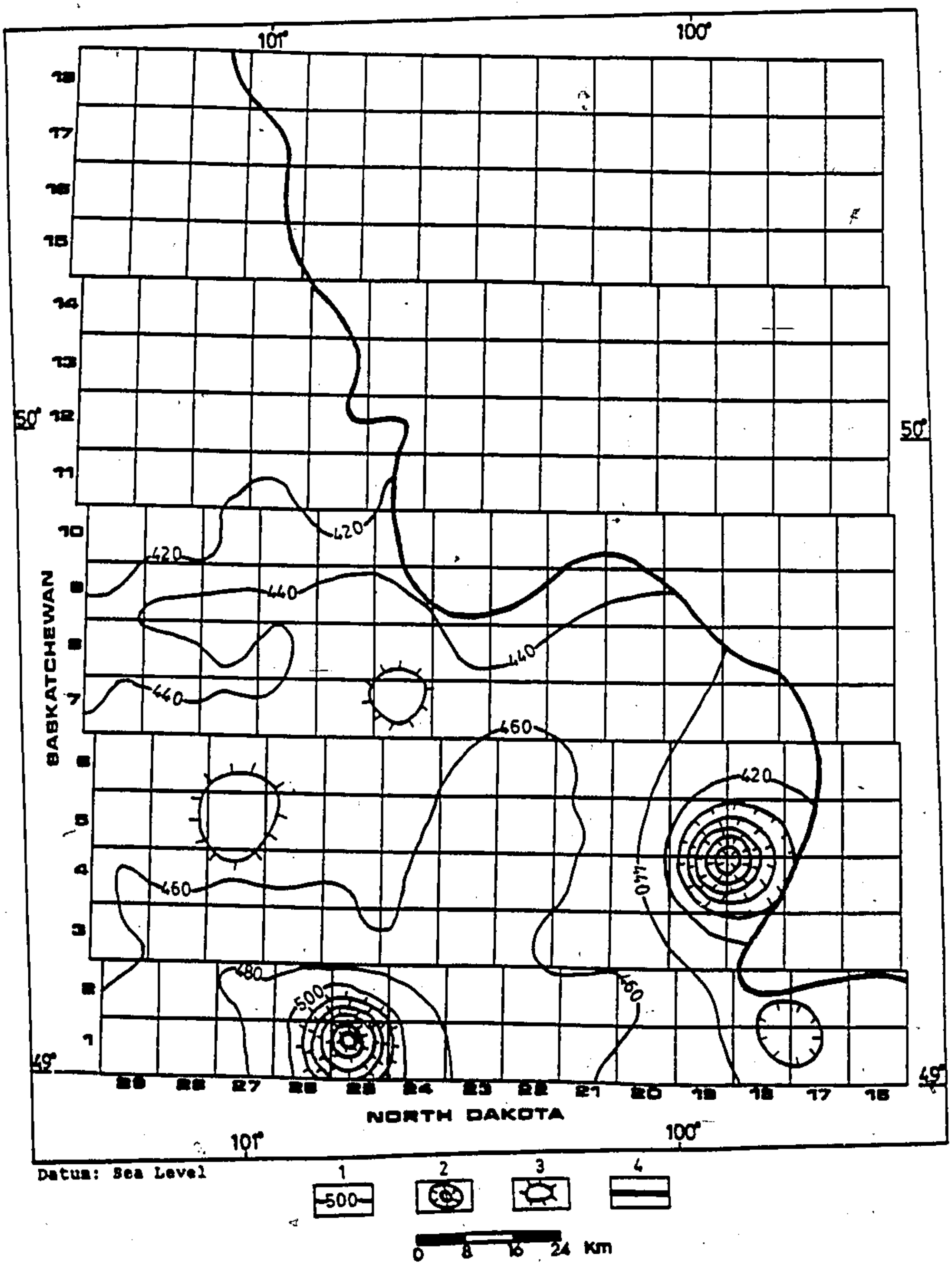

Fig. 31a. Potentiometric surface for Lodgepole Formation showing the regional trend. 1) equipotential lines (contour interval= 20 m); 2) potentiometric low; 3) potentiometric high; 4) subcrop erosional edge.

Credit: Manitoba Mineral Resources Division, 1976.

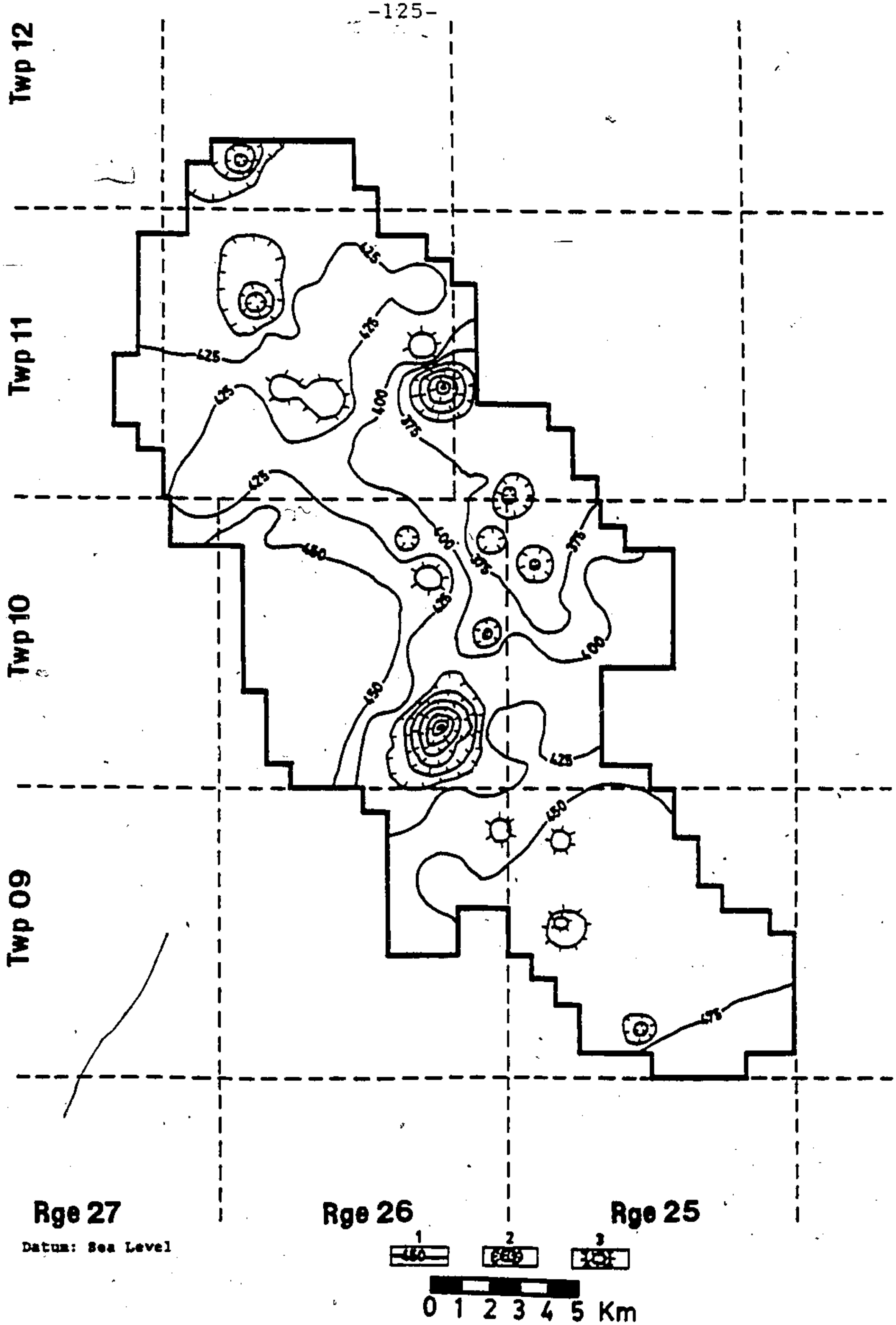

Fig. 31b. Potentiometric surface for Lodgepole Formation in the Virden oil field district. 1) equipotential lines (contour interval= 25 m); 2) potentiometric low; 3) potentiometric high.

This transition can be ascribed to two attributes of different origin, albeit of the same significance in localizing hydrocarbon accumulations. Firstly, it might represent the established (McCabe, 1971) intrinsic north-northwestward decrease in porosity and hence permeability of the reservoir units, which probably resulted in the restriction to further migration. Secondly, it might reflect sealing of true or salt tectonics fracture systems with impermeable material which might have exerted significant control in entrapment.

Not surprisingly, somewhat the same appears to be the case also for the Daly field (Fig. 31c) where, although the general configuration is that of a structural nose, stratigraphic control in terms of permeability pinch-outs is of major importance in localizing hydrocarbon accumulation (McCabe, 1963). A prominent high is observed in the southwestern part of the field, with the lows becoming more common north-northwestward. Thus, at least for the case of the two major oil fields in southwestern Manitoba, their connection with anomalies in the fluid-potential distribution is obvious.

The other prominent feature in the map of Figure 31a is the potentiometric high in the vicinity of the Waskada area, where the Mississippian Mission Canyon Formation comprises a sombrero anticline. In the same area the MC1 Member (Tilston Beds) is oil producing and it appears that cross-formational flow from the underlying Lodgepole

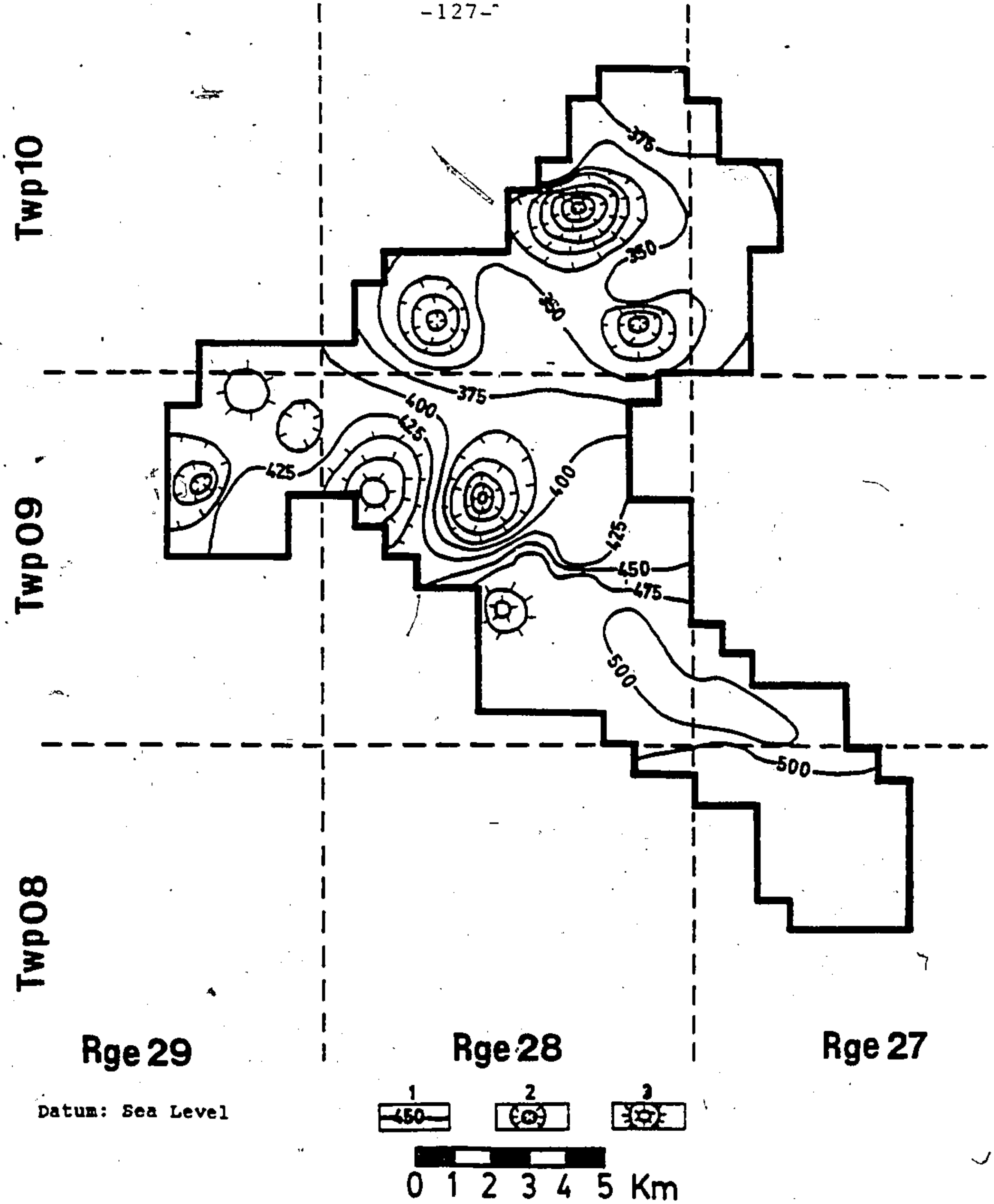

Fig. 31c. Potentiometric surface for Lodgepole Formation in the Daly oil field district. 1) equipotential lines (contour interval= 25 m); 2) potentiometric low; 3) potentiometric high.

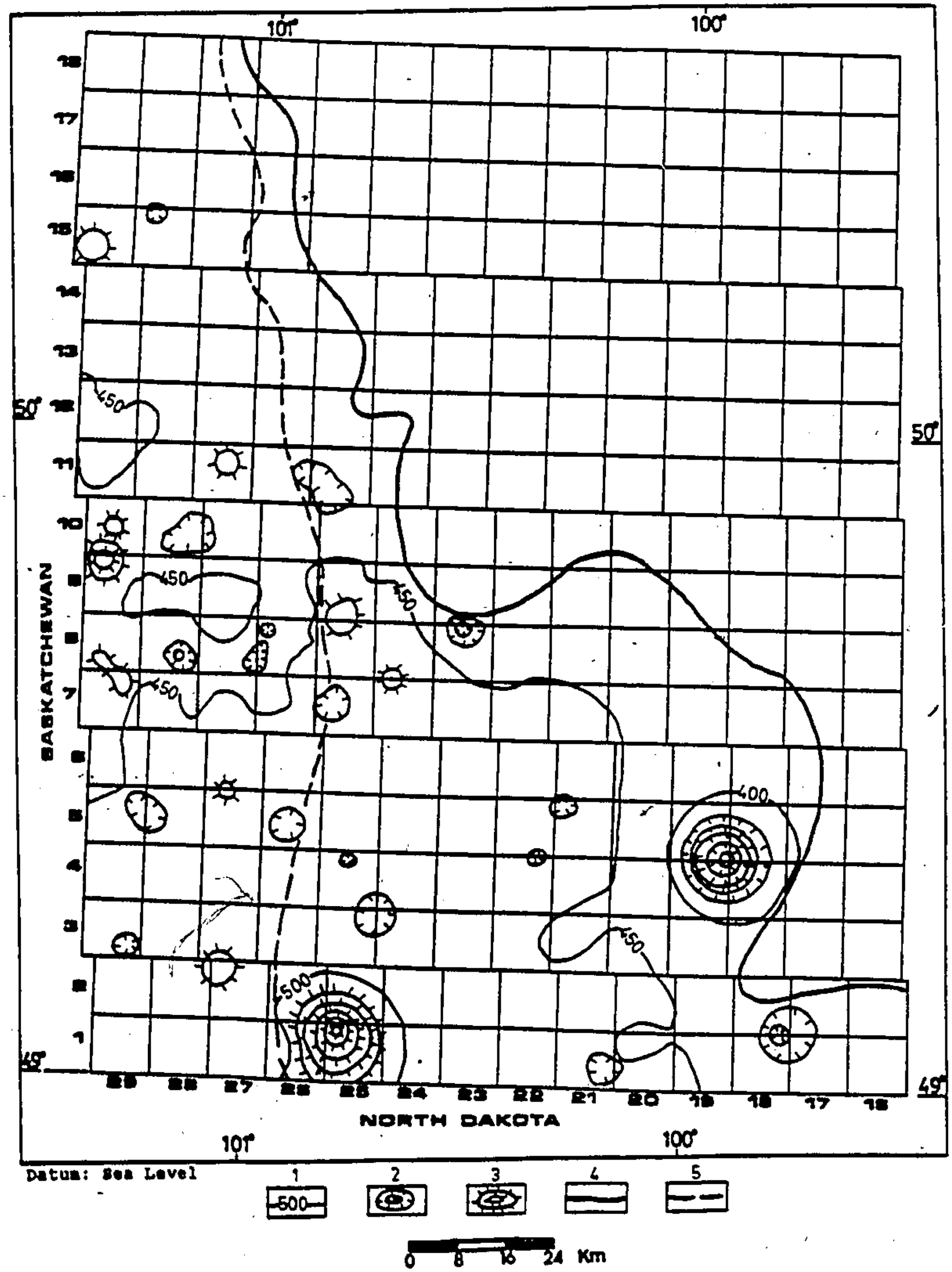

Fig. 31d. Potentiometric surface for Lodgepole Formation showing the effect of anomalies on the regional trend. 1) equipotential lines (contour interval= 50 m); 2) potentiometric low; 3) potentiometric high; 4) subcrop erosional edge; 5) limit of Prairie Evaporite salt beds (solution edge).
Credits: Manitoba Mineral Resources Division, 1976. Simpson, 1983.

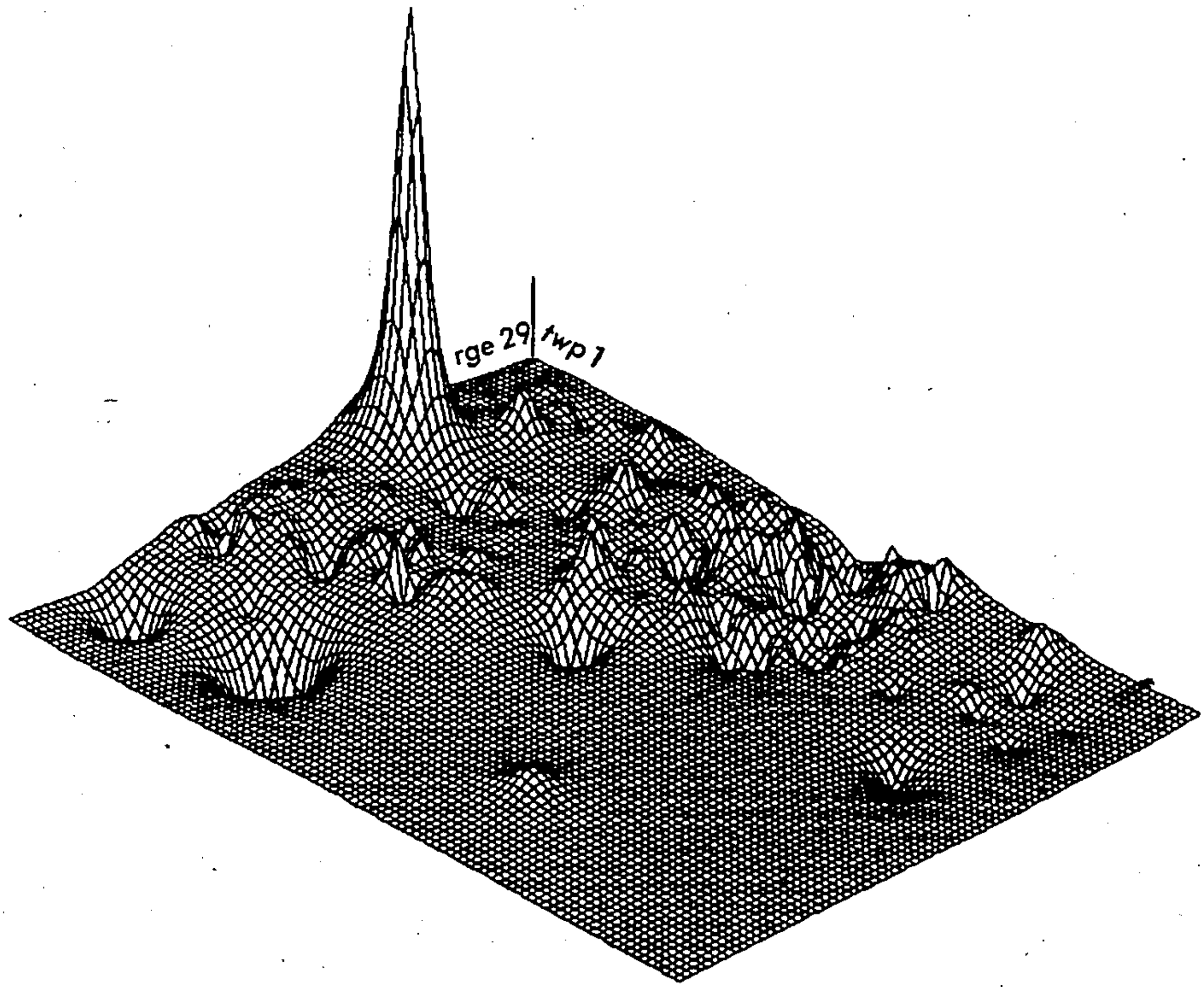

Fig. 31e. Three-dimensional plot of potentiometric surface for Lodgepole Formation.

Formation was an active process in assisting hydrocarbon accumulation, as discussed below. An additional outstanding example of cross-formational flow is shown in the fluid pressure profile of the Francana et al Hartney 6-34-5-24 well (LSD 06-34-05-24WPM) (Fig. 32). The hydraulic connection along this particular site is apparent and also noteworthy, in that the contrast in the potentiometric surfaces gives an upward cross-formational flow.

Worthy of special mention also, is the area around Township 16, Range 28WPM, which is not coincident with any locale of documented salt solution. It can be argued, however, that the latter might be the case, firstly on the basis of the apparent hydraulic connection as evidenced by the pressure against depth graph in Figure 33, and secondly because of the presence of a Winnipegosis reef in the same area (Fig. 15a). For the same site also the potentiometric surface distribution indicates downward cross-formational flow.

Two anomalous lows in the southeastern part of the area can be related to the presence of the Routledge shale within the Lower Lodgepole (McCabe, 1959, Fig. 9). The potentiometric high in Townships 7 and 8, Range 24WPM is located in an area where the structure of the Lodgepole Formation exhibits an anticlinal flexure that might reflect a hitherto undocumented sombrero anticline. It occurs on a southeastern extension of the Virden field. The orientation of the flexure, however, relative to the regional flow

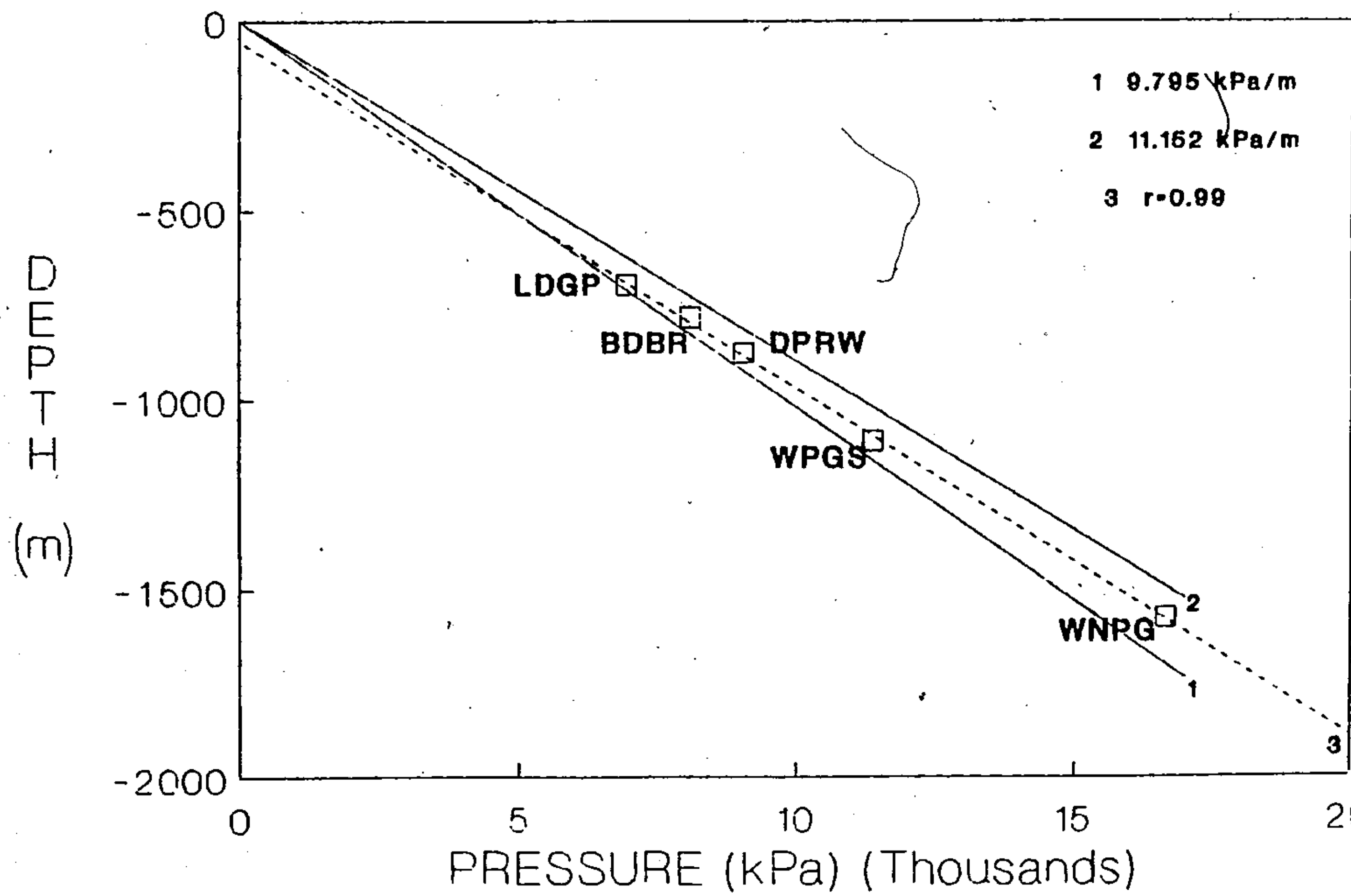

Fig. 32. Fluid-pressure profile for Francana et al Hartney 6-34-5-24 well (LSD 06-34-05-24WPM). WNPG: Winnipeg Formation; WPGS: Winnipegosis Formation; DPRW: Duperow Formation; BDBR: Birdbear Formation; LDGP: Lodgepole Formation.

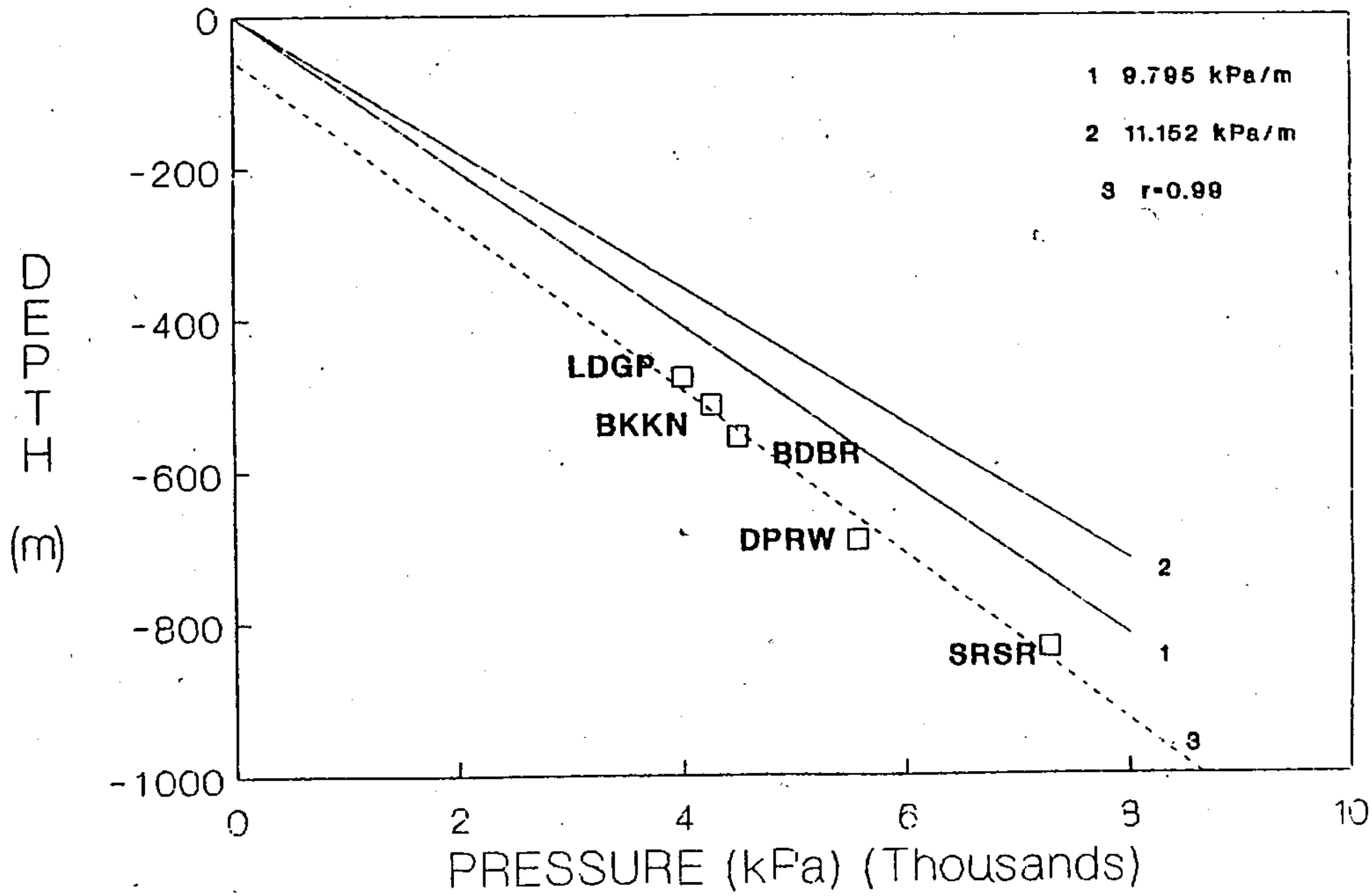

Fig. 33. Fluid-pressure profile for Dypont 14 25 16 28 well (LSD 14-25-16-28WPM).
SRSR: Souris River Formation; DPRW: Duperow Formation; BDBR: Birdbear Formation; BKKN: Bakken Formation; LDGP: Lodgepole Formation.

system, is such that hydrocarbon accumulation was probably flushed out and migrated up-dip towards the Virden area.

The potentiometric anomalies are best disclosed in the potentiometric map in Figure 31d, that was generated by applying through the software package a high smoothing factor, as well as in the three-dimensional map in Figure 31e. The first important feature to observe in the former is the lack of major anomalies, except for those considered in the area of the Routledge shale, in the eastern part of the map characterized mainly by the presence of relatively clean limestones (McCabe, 1959, Fig.9). Thus, the narrow range of values can be ascribed to the homogeneity of the formation in this area.

Westward from the clean limestone facies, the effect of heterogeneities is probably exemplified by the presence of several potentiometric lows. Anomalies are also again defined along the trend of the Birdtail-Waskada axis. The axis is almost coincident with structural flexures on the sub-Mesozoic unconformity that might be indicative in part of salt solution or on the other hand of structural deformation (McCabe, 1971). The pre-defined wet zones of the Lyleton-Bakken shale interval coincide with areas of potentiometric anomalies on the Lodgepole Formation. Should the wet conditions of the underlying formation be representative of active flow paths within the impermeable interval, this coincidence might reflect some degree of hydraulic continuity through the aquitard between the Lodgepole Formation and the Devonian carbonates.

4.3.3.2e Tilston Beds

The overlying Tilston Beds are restricted to the southwestern corner of Manitoba and include the MC1 limestone and MC2 Evaporite of the Mission Canyon Formation. Thus, drill stem tests carried out south of the erosional limit of the MC2 Member might incorporate also a certain evaporitic section. The term " Tilston Beds" is used to denote the presence of either of the members or both of them. This is of significance, especially if the excessively low potentiometric values yielded by the tests performed in the Omega Waskada well (LSD 02-35-01-26WPM) and Omega Waskada 2 36 1 26 well (LSD 02-36-01-26WPM) are taken into account with the attendant anomalously lows on the potentiometric map of the Tilston Beds (Fig. 34). These conditions can be probably ascribed to the presence of evaporites.

The same area of potentiometric lows also, is located in the vicinity of Waskada, and these anomalies might be indicative of sealing with impermeable material of fracture systems accompanying the formation of the Waskada dome. This in turn might have assisted, to a major extent, the entrapment of hydrocarbons in the Tilston Beds. In the adjacent area the Omega Waskada Prov. 7-30-1-25 well (LSD 07-30-01-25WPM) registered for the underlying Lodgepole Formation a shut-in pressure of 15,327 kPa, equivalent to a potentiometric surface at 1105 m. The intense fracturing associated with the Waskada dome and the high contrast in

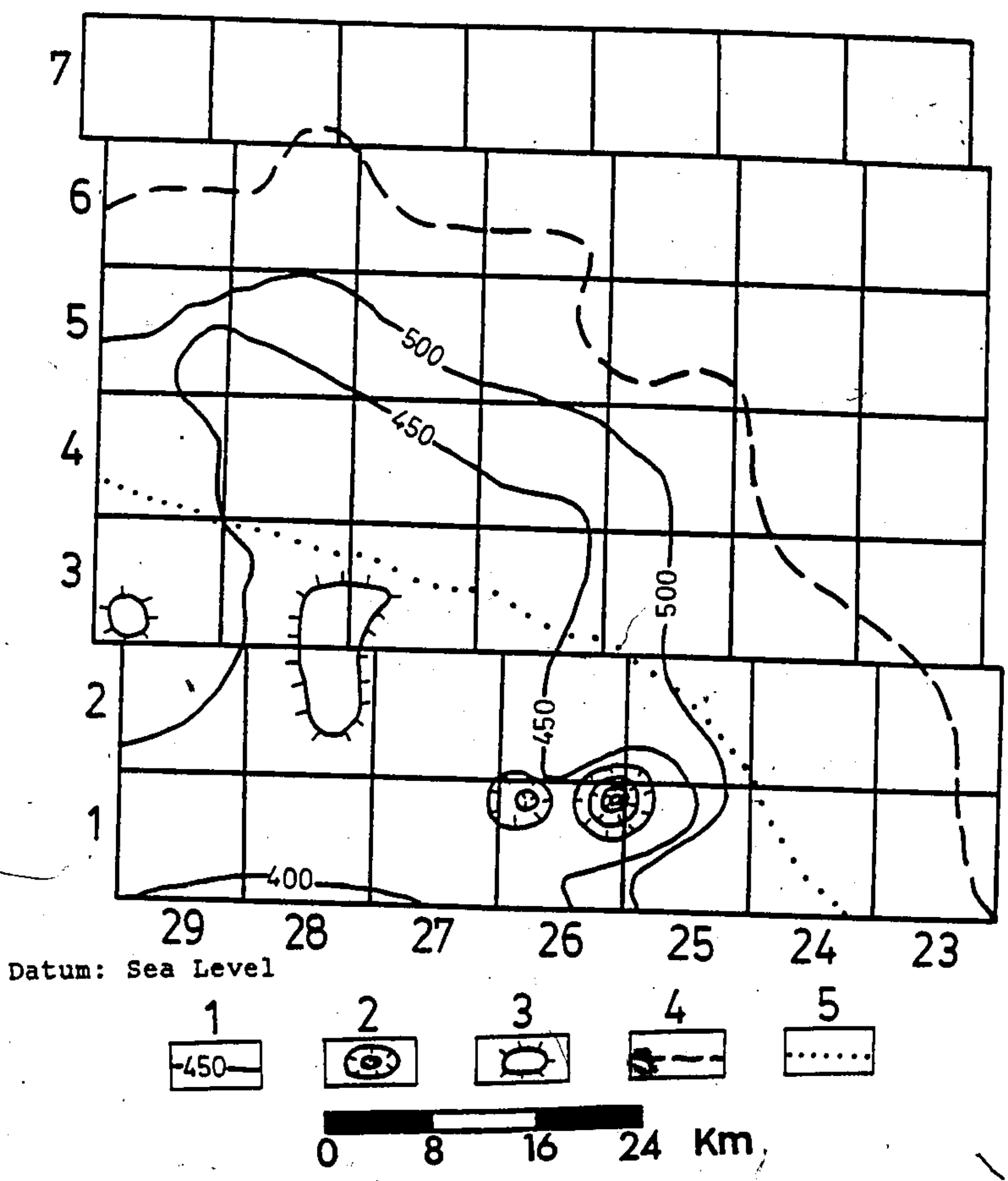

Fig. 34. Potentiometric surface for Tilston Beds.
1) equipotential lines (contour interval= 50 m);
2) potentiometric low; 3) potentiometric high;
4) subcrop erosional edge of MC1 limestone;
5) subcrop erosional edge of MC2 Evaporite.
Credit: Manitoba Mineral Resources Division, 1976.

the potentiometric surfaces lends credence to the view that upward cross-formational flow from the Lodgepole Formation toward the Tilston Beds was probably an effective process in facilitating vertical migration and accumulation of hydrocarbons.

Cross-formational flow in the same area is also depicted by the fluid-pressure profile in Figure 35, where the similarity of values of the potentiometric surface for the three formations along with their location along a straight line, provide evidence on the existence of only one pressure system. Another important feature is the potentiometric high in the vicinity of Townships 2 and 3, Ranges 27 and 28WPM, located in an area where the overlying MC3 Member is characterized by a slight structural disturbance (Manitoba Mineral Resources Division, 1976).

In the adjacent region the potentiometric surface values show a considerable decrease, and the feature is probably the response to local salt solution and collapse during MC3 times that affected also the underlying Tilston Beds. There is major change in the fluid-potential pattern which results in a mainly southward flow direction with an average gradient of 6.5 m/km. This could be related to a major recharge that took place in the north during the time span represented by the sub-Mesozoic unconformity. It has been argued by McCabe (1971) that lack of any major Mission Canyon oil accumulations is probably due to the structural rise of the outcrop belt to the southeast. The difference

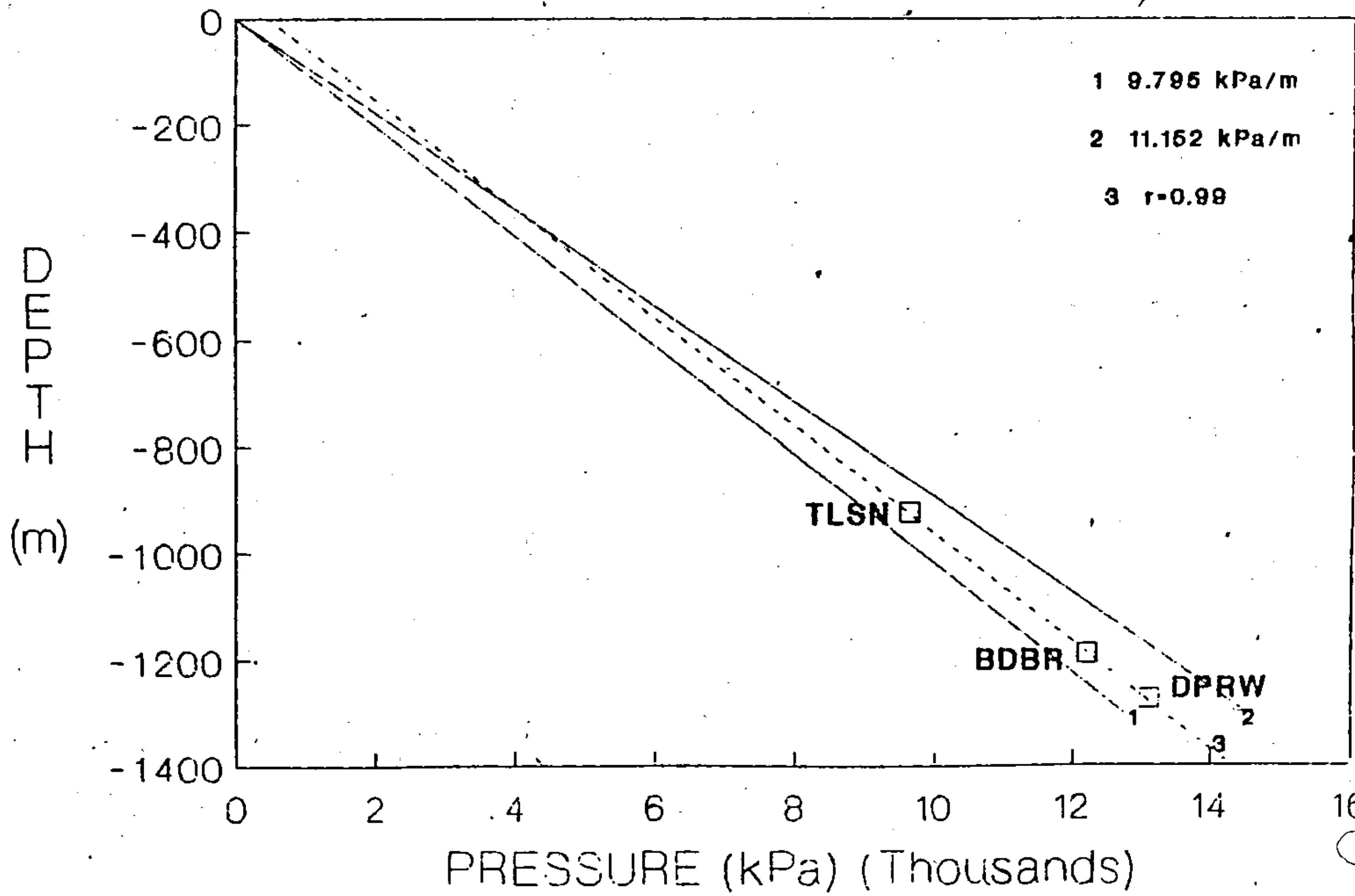

Fig. 35. Fluid-pressure profile for Imp Calstan Hernefield 1 30 well (LSD 01-30-01-25WPM).
DPRW: Duperow Formation; BDBR: Birdbear Formation; TLSN: Tilston Beds.

in gradient might have been an additional factor giving complete expulsion of oil from the Manitoba part of the Tilston Beds, with the only exception being that trapped in the anticlinal structure at the Tilston field. This appears plausible since the presumed trend of oil migration towards the southeast and the groundwater gradient appear to coincide.

4.3.3.2f Alida Beds

The same problem of the distinction between MC1 and MC2 Members is also the case for the Alida Beds, which are composed of the MC3 limestone of the Mission Canyon Formation and the Charles Evaporite. The latter is restricted in the extreme southwestern corner of the province. Thus the potentiometric low located in the vicinity of Township 1, Range 28WPM (Fig. 36) might be indicative of incorporation of evaporite in the test. An anomaly adjacent to the Pierson field (Township 3, Range 29WPM) that comprises an oil producer for the Alida Beds in Manitoba could reflect permeability pinch-outs controlling the stratigraphic entrapment. The potentiometric low north of the Pierson field is due to the incorporation of the overlying Spearfish Formation in the interval tested in the Texaco-McCall-Graham Creek A-24-29 well (LSD 04-29-03-28WPM). The opposite appears to occur in the case of the North American Arthur 2 20 1 26 well (LSD 02-20-01-26WPM) where incorporation of the same unit

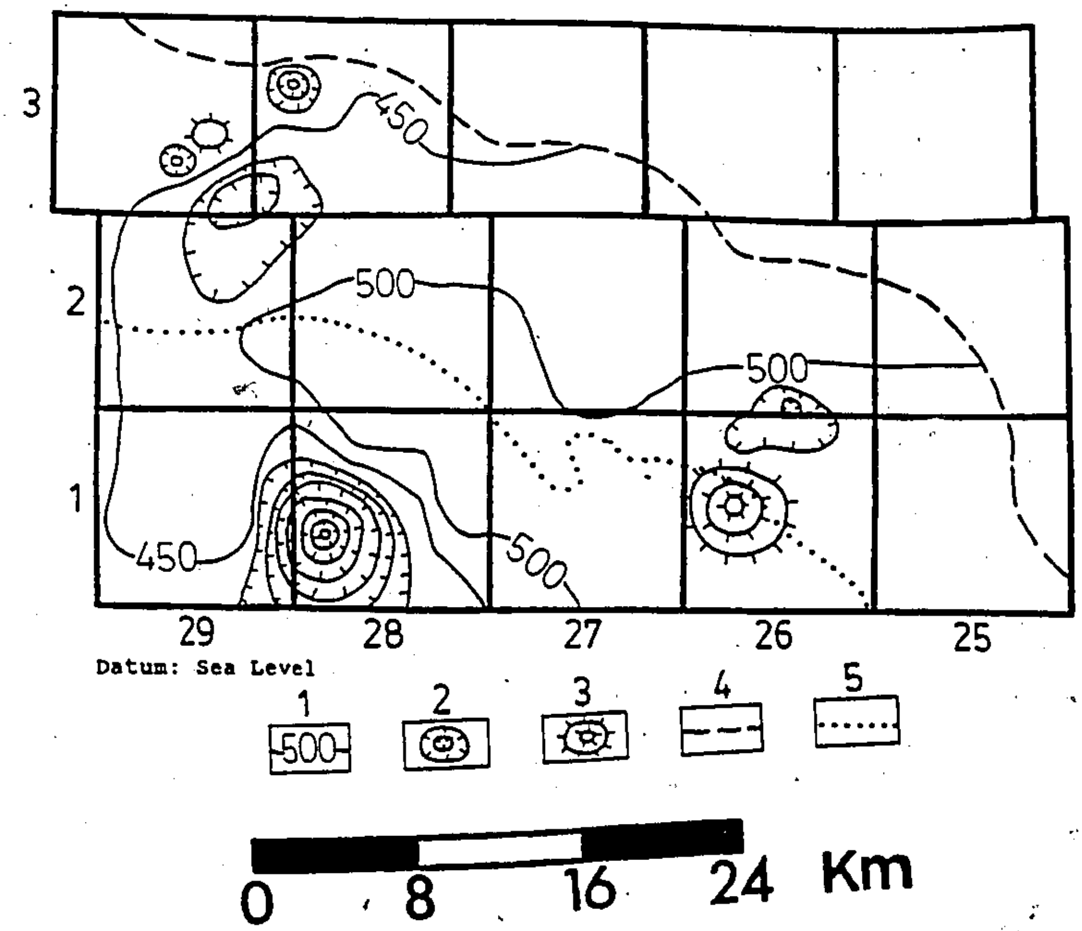

Fig. 36. Potentiometric surface for Alida Beds.
1) equipotential lines (contour interval= 50 m);
2) potentiometric low; 3) potentiometric high;
4) subcrop erosional edge of the MC3 limestone;
5) subcrop erosional edge of the Charles Evaporite.
Credit: Manitoba Mineral Resources Division, 1976.

accounts for the anomalous potentiometric high. In the latter area the Spearfish Formation is much more permeable than in the former, as discussed below. A change in the fluid-potential gradient of the Alida Beds occurs mainly in the west (Fig. 36).

Recharge during times of pre-Mesozoic erosion appears to be a much more valid hypothesis than in the case of the Tilston Beds, if the structural rise to the southeast, where the recharge areas would be most probably located, is related to the flow direction. This in turn would create a tendency for hydrocarbons to move toward the outcrop, so that the groundwater regime would restrict migration. The latter might imply that the hydrocarbon accumulation in the Pierson field could reflect hydrodynamic entrapment, at least in part. The hydrodynamic entrapment component in this oil field is also evidenced by the fluid pressure profile in Figure 37 from the location of the Alida Beds relative to the overlying Spearfish Beds on the one hand and the underlying Tilston Beds and Lodgepole Formation on the other hand. Thus oil accumulation in this particular case coincides spatially with an isolated pressure system.

4.3.3.3 Synthesis

The effect of reservoir heterogeneities, salt solution and structural disturbance on the hydrogeologic environment of the post-Prairie carbonates becomes evident. For pre-Prairie and post-Prairie units, cross-formational flow

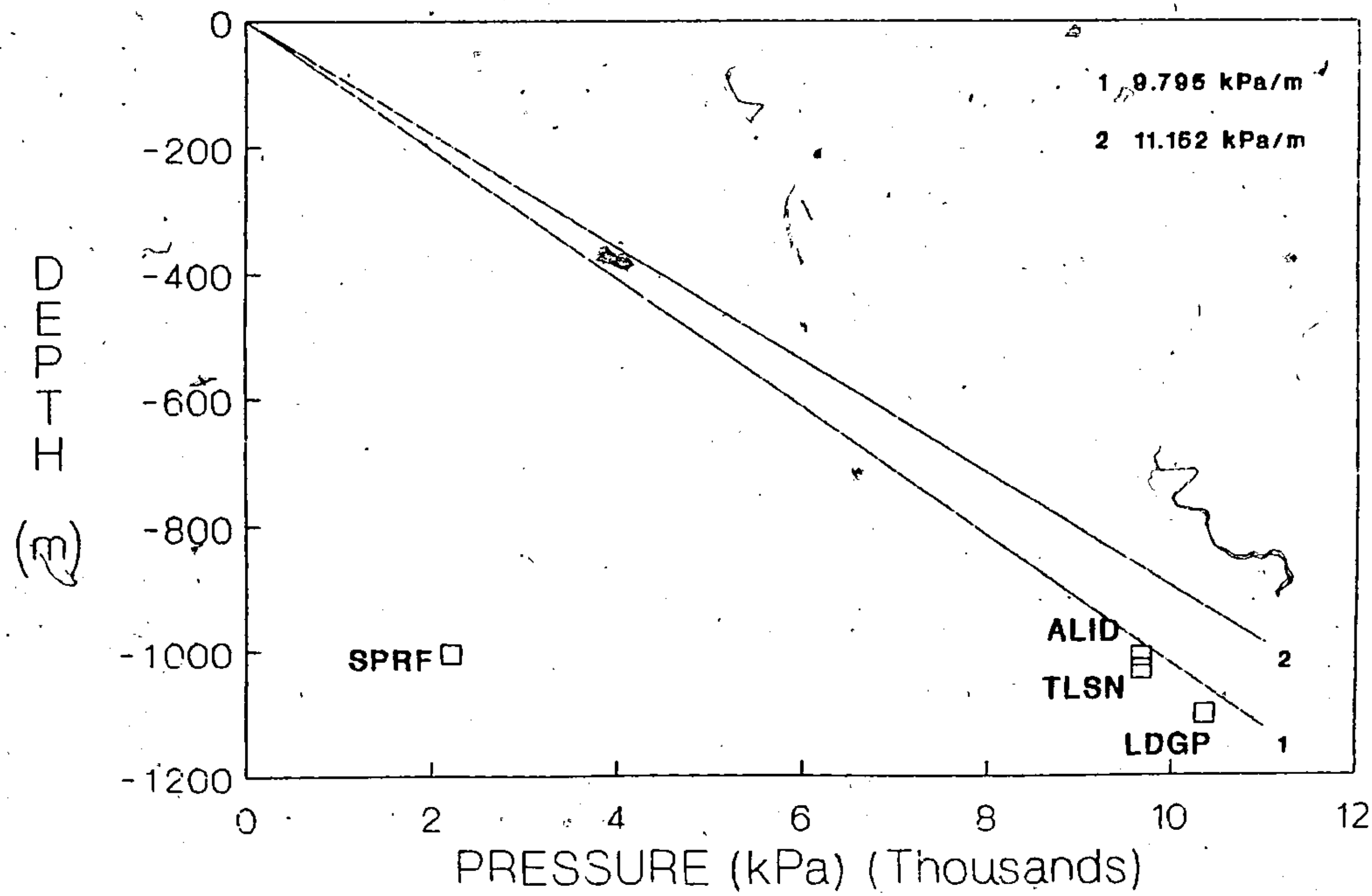

Fig. 37. Fluid-pressure profile for Imperial Pierson 13-2-3-29 well (LSD 13-02-03-29WPM). LDGP: Lodgepole Formation; TLSN: Tilston Beds; ALID: Alida Beds; SPRF: Spearfish Beds.

appears in several instances to constitute a major mechanism of movement for formation fluids. The difference, however, is that while in the former, which probably lack intense structural disturbance, cross-formational flow might be localized above weakness zones of the basement, in the latter the same phenomenon is promoted to a major extent by solution in depth of the salt beds of the Prairie Evaporite and is encountered in most of the area.

The fluid-potential pattern present in the upper Middle Devonian Dawson Bay Formation appears to be continuous through the rest of the Devonian units, where the Lyleton-Bakken impermeable interval, except probably in the case of the wet zones, seems to interrupt the vertical hydraulic continuity of the carbonate sequence. Significant changes occur in the fluid-potential pattern of the Mississippian formations comprising the Madison Group, the most important being the apparent reversal in the gradient observed in the Tilston beds of the Mission Canyon Formation. More surprisingly, a similar situation takes place in the transition from the Tilston to the Alida Beds. It is likely that the difference in the fluid potential pattern between the Tilston and the Alida Beds reflects in part their vertical hydraulic separation, imparted by the occurrence of the MC2 Evaporite.

4.4 Upper Siliciclastic Division

The upper clastic division can be best described hydrogeologically as a dominantly shale sequence interrupted in places by laterally discontinuous sandstone aquifers. Within the study area, basal Jurassic strata overlie unconformably Mississippian carbonates in the southwestern part and Devonian strata farther east.

4.4.1 Spearfish Beds

The Red Beds of the Lower Amaranth Formation (Spearfish Beds) form an aquitard at the base of the Mesozoic strata, and in many instances they have acted as the cap rock of hydrocarbon accumulations in southwestern Manitoba. The recent Lower Amaranth oil discovery in the Waskada area, calls to question its aquitard character, especially in areas where a sand unit develops in its lower part. Data from this aquitard have been employed in a similar way as those for the Lyleton-Bakken interval, in order to determine relatively wet and dry zones (Fig. 38).

On the basis of the range and spatial distribution of pressure head values, the limit between the wet and dry conditions was set to 700 m of pressure head. The most striking feature of the map (Fig. 38) is the prominent wet zone in the vicinity of Waskada where the Amaranth discovery took place. The high pressures associated with the

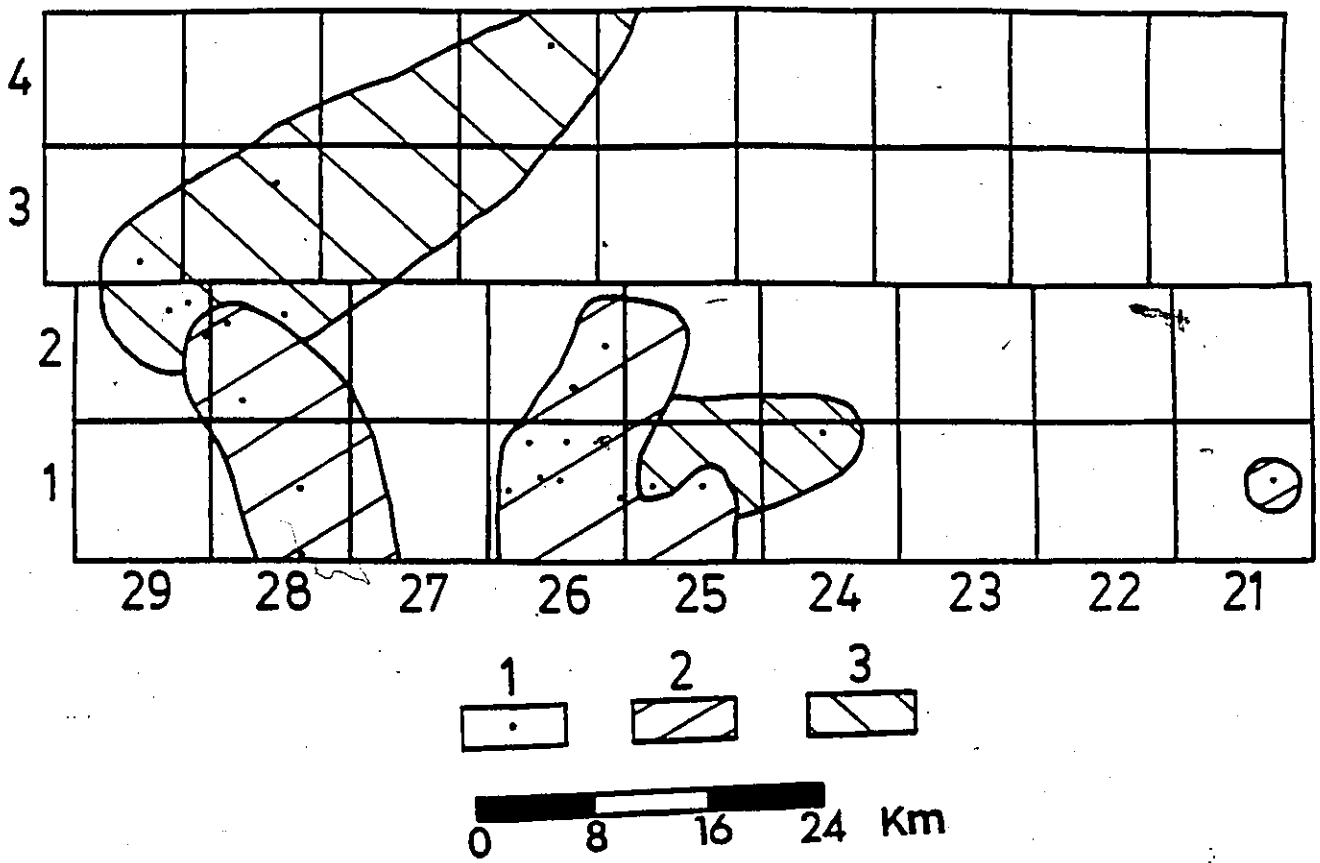

Fig. 38. Delineation of wet and dry zones for Spearfish Beds. 1) location of wells; 2) wet zone (pressure head more than 700 m); 3) dry zone (pressure head less than 700 m).

Lodgepole and Tilston Formations in the same area, the presence of prolific hydrocarbon accumulations within the Tilston Beds and the high permeability of the basal Lower Amaranth in this area as inferred from its wet property, appear to lend credence to the hypothesis concerning leaking of Mississippian oil as the origin of the Lower Amaranth accumulation.

The Coulter and South Pierson oil fields and the Lyleton area (Fig. 9) constitute Lower Amaranth oil targets (Galarnyk et al., 1984) and are located within the other tongue-shaped wet zone. The latter overlies directly the Charles Evaporite. Thus its wet condition is indicative of recharge through fracture systems of the evaporite from underlying Mississippian strata, most probably the MC3 carbonates. This view is strengthened by the presence of a synclinal flexure on the top of the Charles Evaporite in the vicinity of Township 1, Range 28WPM that might be indicative of partial salt removal in depth during post-Charles times.

The isolated wet locale in Township 1, Range 21WPM is located within the Lulu Lake oil field (Fig. 9), which produces from a Lodgepole anticline. The relatively wet nature of the Spearfish Beds around this site can probably be significant with respect to additional exploration directed at the Lower Amaranth. In contrast to the Spearfish Beds where zones of high permeability can be recognized, the Upper Amaranth beds that consist mainly of evaporites are characterized by relatively dry conditions as evidenced by pressure head values in the range 69 to 578 m.

4.4.2 Rest of the Jurassic strata

For hydrogeologic purposes, the rest of the Jurassic formations can be described as interbedded sandstones and shales at the top (Melita and Waskada Formations), underlain by the shales and oolitic-argillaceous limestones of the Reston Formation. Thus it becomes apparent that it is composed of lithologies that impart an overall heterogeneous nature to the entire post-Amaranth Jurassic succession. This in turn renders the assessment of the hydrogeologic environment a tenuous endeavour, since no information on particular formations exist.

The most striking feature on the potentiometric surface of the Jurassic (Fig. 39a) is the difficulty in distinguishing any regional pattern, mainly because of the presence of several anomalies. Two prominent potentiometric lows in the western part of the area appear to be located along a trend of abnormal thickening of the Upper Jurassic formations (Melita and Waskada) (Stott, 1955, Plate 7). This anomalous increase in thickness is not observed elsewhere in Jurassic strata and might indicate salt solution at depth, which may be linked to potentiometric lows.

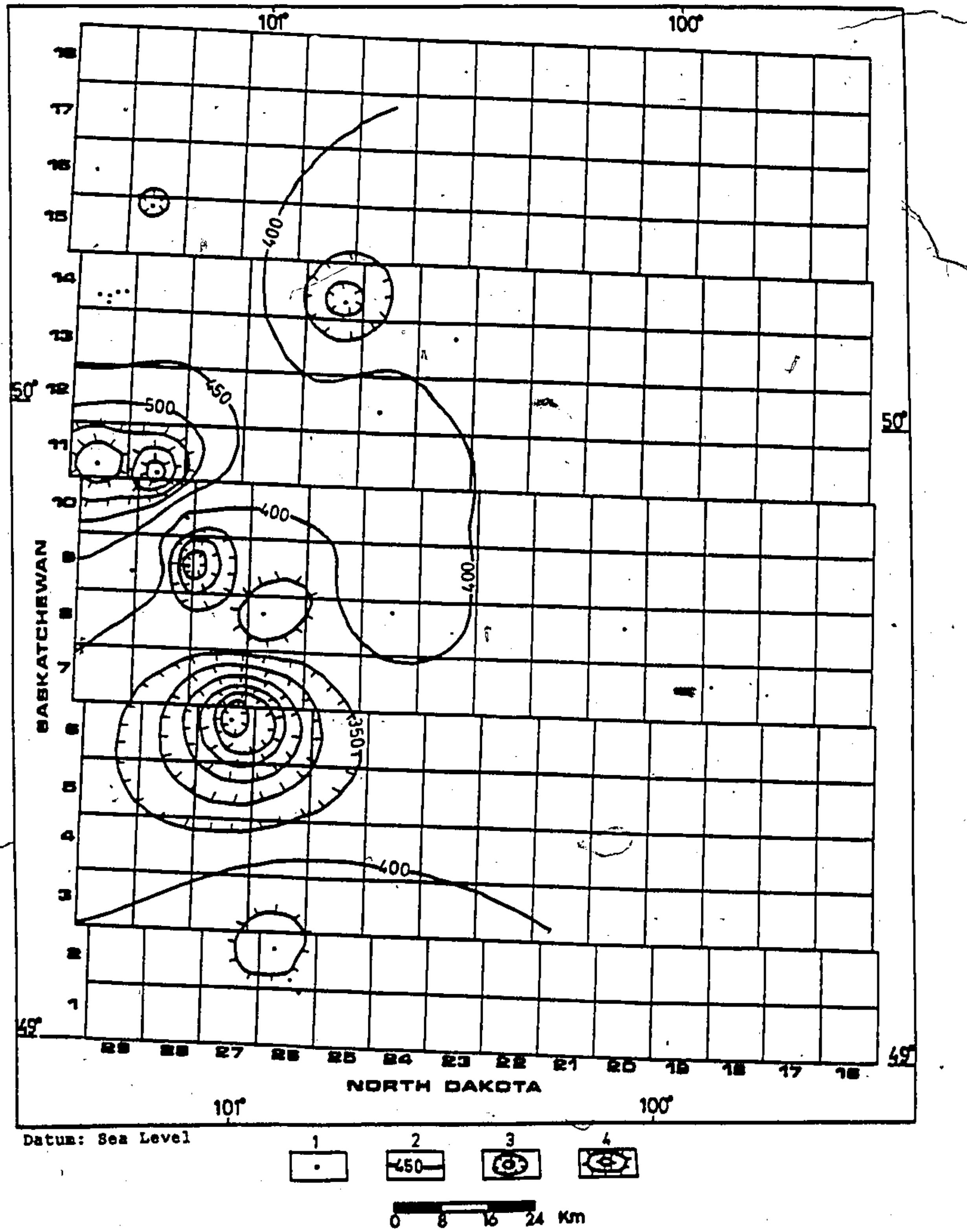

Fig. 39a. Potentiometric surface for Jurassic formations 1) location of wells; 2) equipotential lines (contour interval= 50 m); 3) potentiometric low; 4) potentiometric high.

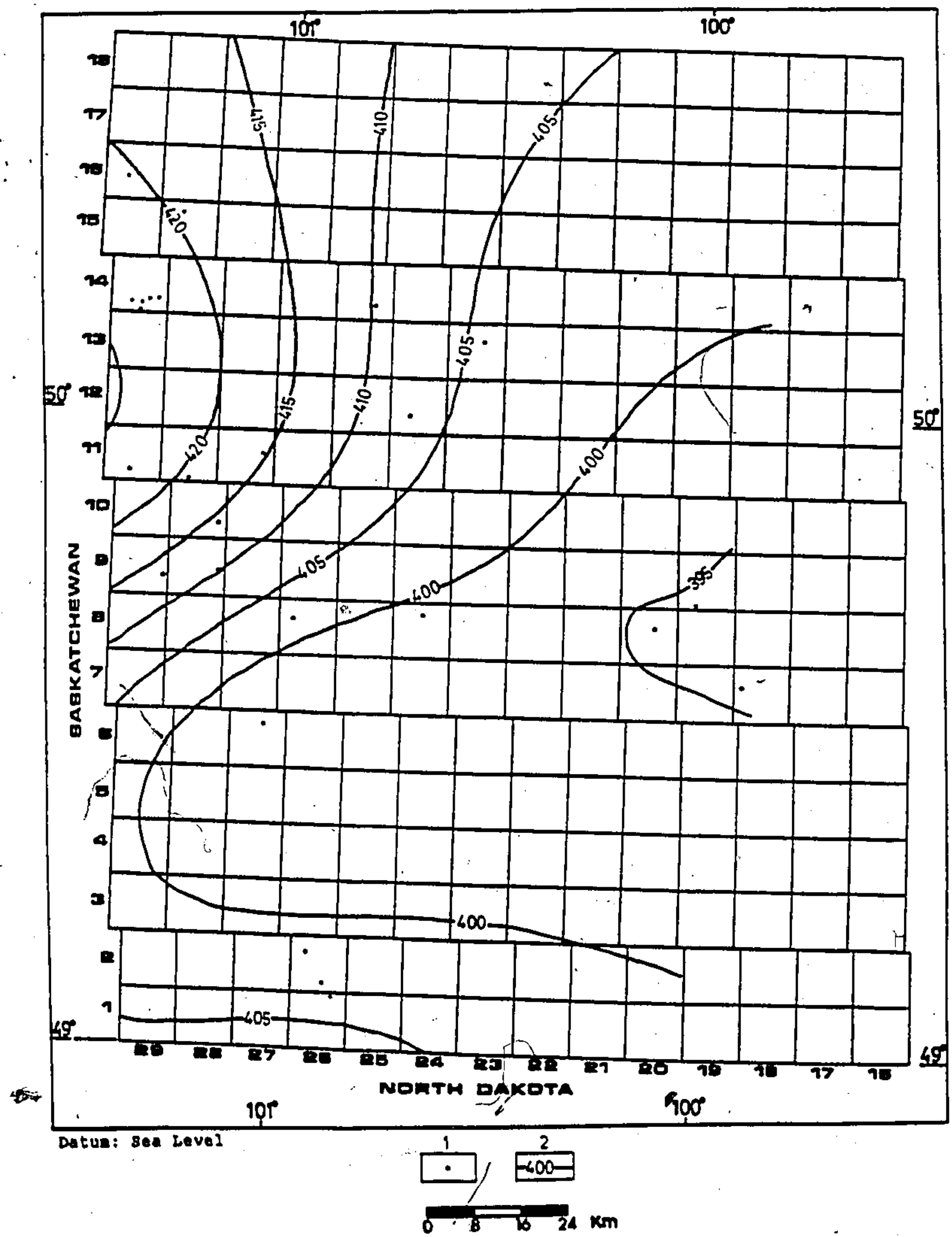

Fig. 39b. Potentiometric surface for Jurassic formations showing the regional trend. 1) location of wells; 2) equipotential lines (contour interval= 5 m).

Two more pronounced potentiometric highs occur in the vicinity of Township 11, Ranges 28 and 29WPM. This is especially reflected in the position of the Jurassic in the fluid-pressure profile relative to the other units in the lithologic column (Fig. 40), which is indicative of abnormally high pressures not derived from the underlying formations. Near the same locale, structural anomalies are evident on the pre-Mesozoic erosional surface (McCabe, 1971, Fig. 15), as well as in the Jurassic-Cretaceous Waskada Formation and Swan River Group (Bannatyne, 1970, Fig. 14). Further north in the vicinity of Township 12, Range 29WPM salt solution is known to have occurred at the top of the Prairie Evaporite (Norris et al., 1982) probably indicative of downward infiltration and cross-formational flow. Thus it is possible that later infilling of fracture systems that has occurred in pre-Jurassic formations restricted any further downward percolation of the formation waters, thus resulting in the abnormal pressurization of the Jurassic.

In an effort to eliminate the effect of anomalies, a potentiometric surface map showing the regional trend for the rest of the Jurassic was generated (Fig. 39b) by applying, through the software package, a low smoothing factor. Thus a dominantly eastward flow direction, exhibiting an average gradient of approximately 0.5 m/km, that appears to lead to the outcrop, becomes evident. The latter might be indicative of the presence of a recharge region further west of the study area.

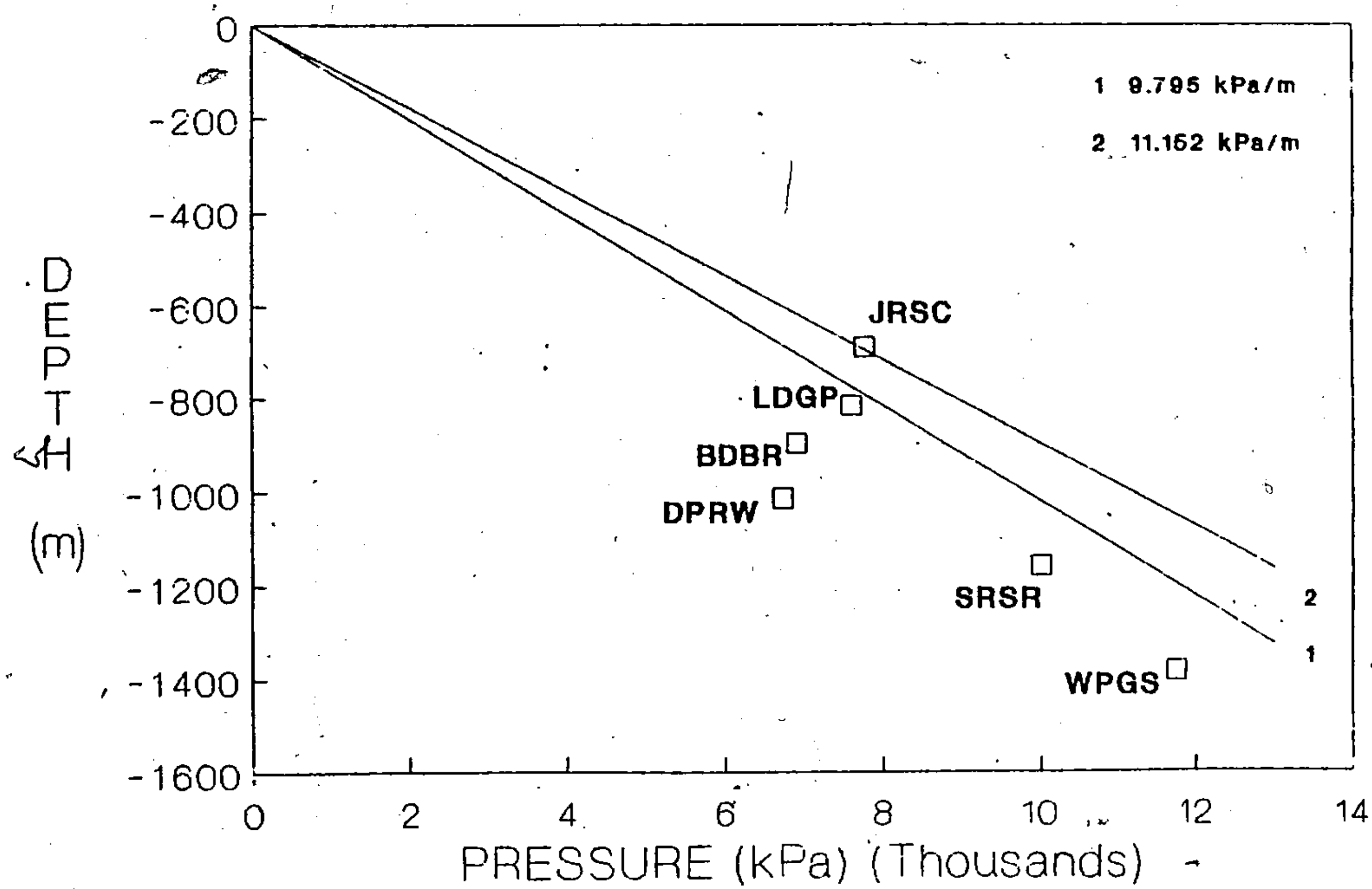

Fig. 40. Fluid pressure profile for Calstan Elkhorn 7A 8 11 29 well (LSD 07-08-11-29WPM). WPGS: Winnipegosis Formation; SRSR: Souris River Formation; DPRW: Duperow Formation; BDBR: Birdbear Formation; LDGP: Lodgepole Formation; JRSC: Jurassic formations.

The area around Township 8, Range 18WPM comprises a topographic high on the sub-Mesozoic unconformity (McCabe, 1971). In the adjacent region the Amaranth Formation is very thin between the Mississippian carbonates and the Jurassic formations (Stott, 1955), thus indicating the likelihood of hydraulic continuity. In fact, the latter is seen in Figure 11 by the position of the Jurassic relative to the normal hydrostatic gradient on the one hand, and the Dawson Bay and Winnipegosis Formations on the other hand. This can be accounted for by the presence of a distinct pressure system, with its continuity not interrupted by the thin Amaranth section. The same phenomenon can be expected to occur where the Amaranth Formation, and especially the upper part, is very thin.

4.4.3 Mannville Group

Overlying the Jurassic sediments are the quartzose sandstones and mudstones of the basal Cretaceous Mannville Group (Swan River Formation). The interfingering of sand and silt can be expected to impart an overall heterogeneous nature to this unit. There is a relatively large region in the central-western part of the area, from Township 6 to 12, Ranges 23 to 29WPM, from which the Swan River Formation is completely missing. In this area the Jurassic strata come directly into contact with shales of the Ashville Formation (Cretaceous), thus interrupting to a considerable extent the lateral continuity of the Mannville Group (Simpson _et al_., 1987, Fig. 13).

The above features are reflected in a hydrogeologic environment characterized by reservoir separation, as exemplified by the potentiometric map (Fig. 41). The difference in the gradient to the north and south of the area of the missing Mannville respectively is not accidental and can be best ascribed to the presence of two hydrogeologic systems separated by a permeability barrier. In the northern area a southeastward flow direction is observed with an average gradient of 4.0 m/km, with a steepening to the south, which is probably attributable to minor heterogeneities within this part of the reservoir. In the southern area the gradient turns mainly eastward at approximately 1.5 m/km. There is a general uniformity of potentiometric values in the same area, which might reflect a southward increase in sand content. For example, thick channel-fill deposits occur in the southwesternmost corner of the province.

The fluid potential pattern of the Mannville Group might be much more complicated than it appears. Thus, it is likely that the equipotential lines to the north and south of the area where Swan River sediments are missing, converge further west of the study area to give a dominantly eastward flow system which is deflected by the presence of the Jurassic strata and Ashville shales into a northern and southern system.

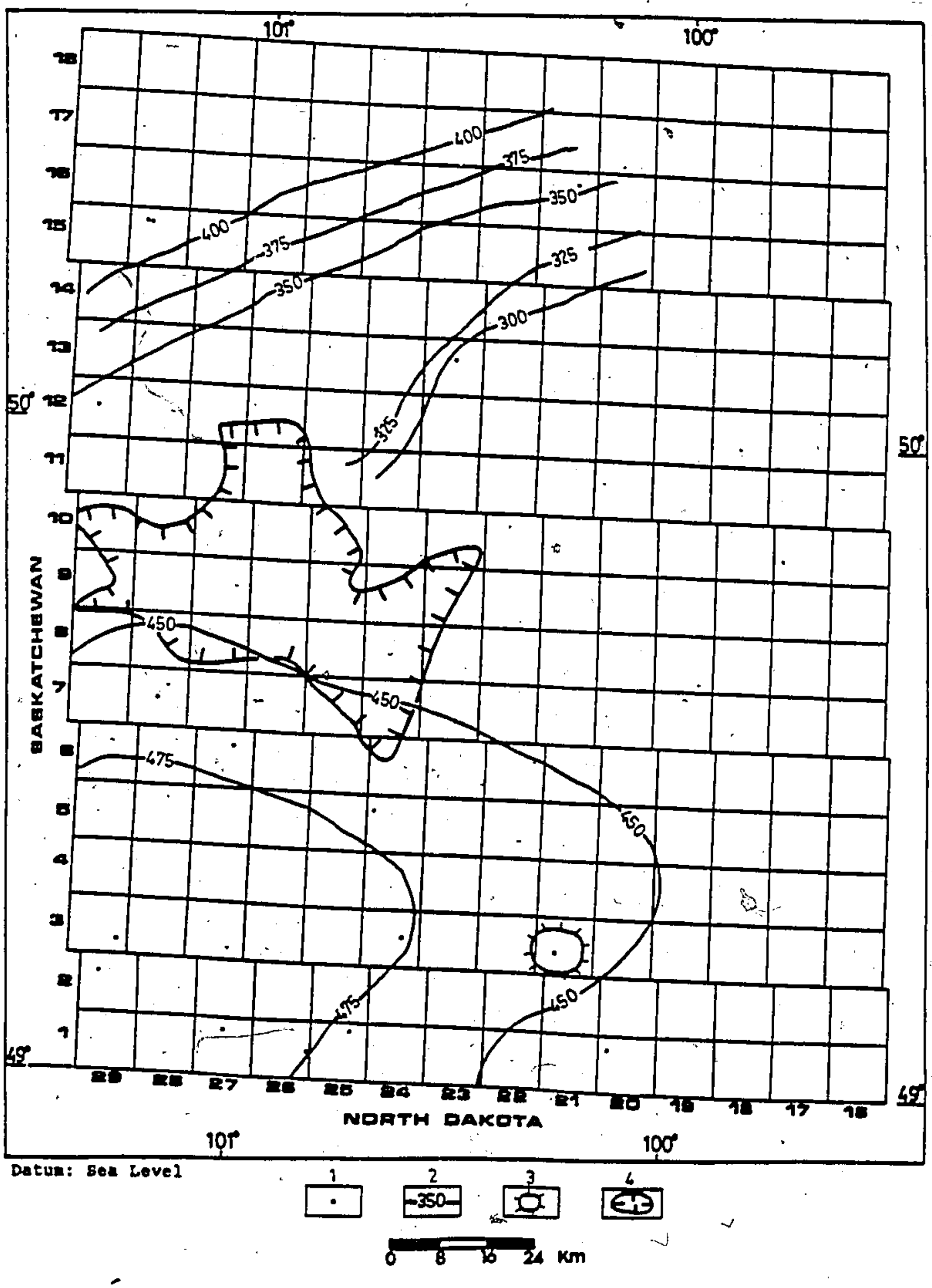

Fig. 41. Potentiometric surface for Mannville Group. 1) location of wells; 2) equipotential lines (contour interval= 25 m); 3) potentiometric high; 4) area where Mannville sediments are missing.

Credit: Simpson *et al.*, 1987.

4.4.4 Remaining of the Mesozoic strata

The rest of the Mesozoic succession is mainly shale with only subordinate siltstones and sandstones. The sparse well control largely precludes the possibility of understanding hydrogeologic conditions associated with aquitards.

Tests performed in the shales of the Joli Fou Formation (Lower Ashville shales) by the Cnd Superior Dome et al Tapp 7 22 well (LSD 07-22-11-26WPM) and Calstan South Harmsworth 6 25 11 26 well (LSD 06-25-11-26WPM) yielded relatively high potentiometric surfaces and pressure heads (403-317 m and 407-310 m respectively) mainly as a result of incorporation of the Viking Sandstone (Ashville Sand) interval. The latter comprises probably the most important aquifer within the Mesozoic sedimentary succession. The relatively narrow range of the potentiometric surfaces (from 360 to 408 m) exemplifies to a great extent its established homogeneity and purity. In some cases also, shut-in pressures are considerably lower than those expected for fresh water. The latter indicates the presence of subnormal pressure conditions. This is not surprising for a unit enveloped within shales and completely isolated from the surface (Dickey, 1986).

The Viking Sandstone is overlain by a moderately continuous shale sequence. Very sparse data on the Upper Ashville shale, the Fish Scale Marker and the Favel

Formation indicate potentiometric surfaces generally below ground level and relatively low pressure heads, which probably reflect their impermeable nature. Two tests, however, performed at the base of the Fish-Scale Marker, specifically the Pel-Tex C.H. No 5A SW-5-9-16 well (LSD 04-05-09-16WPM) and the McCarty and Coleman Routledge 6 33 well (LSD 06-33-09-25WPM), revealed the first a potentiometric surface corresponding to flowing artesian conditions and the second the highest pressure head. Also noteworthy is the fact that both sites are located near areas where the top of the Upper Ashville Shale appears to be structurally disturbed (Bannatyne, 1970, Fig. 20). For the latter case especially, a thickening of the Favel Formation is observed in the adjacent area (Bannatyne, 1970, Fig. 24), and most importantly it is located within the Virden field district for which evidence concerning salt-solution-induced structural disturbance up to Upper Cretaceous times has been cited.

4.4.5 Hydrostratigraphic units

In spite of the limited information, designation of hydrostratigraphic units within the upper clastic division is probably an easier task than in the rest of the sedimentary strata, mainly owing to the fact that the aquifers are laterally discontinuous and are more or less enclosed within shale aquitards. The lower sandy member of the Lower Amaranth Formation is included in the hydrostratigraphic unit defined by the underlying Mississippian carbonates. The rest of the Jurassic strata and the Swan River Formation are combined in one hydrostratigraphic unit because of the generally uniform eastwards flow pattern exhibited by them. It is likely that sand zones developed in the upper part of the Jurassic, as well as possible presence of conglomeratic material at the base of the Cretaceous as a result of the antecedent erosional interval, are effective in imparting a certain degree of hydraulic connection.

A distinct hydrostratigraphic unit is suggested to be represented by the undoubtedly isolated Viking Sandstone. However, the likelihood of a hydraulic connection between the distinct hydrostratigraphic units of the upper clastic division is not to be excluded, especially in view of the presence of structural and isopach anomalies probably relevant to salt removal. Hydraulic connection with hydrostratigraphic units of the carbonate-evaporite division might be expected to occur around Township 8, Range 18WPM, where the Amaranth Formation and Upper Amaranth Evaporite, are thin or entirely missing.

4.5 Discussion

Coincidence is observed in several instances, especially along the Birdtail-Waskada axis, between places where salt solution is known to have occurred and potentiometric lows or highs. The former are interpreted by the author of the present account as sealed fracture systems, the latter as active flow conduits.

Coincidence of anomalous potentiometric highs for different formations, especially in places where salt removal has taken place, implies the existence of cross-formational flow upwards or downwards, depending on the direction of the gradient. On the other hand, the coincidence of lows may reflect the presence of impermeable material and subsequent lack of cross-formational flow that might be of considerable significance in localizing oil accumulations.

The wet zones within impermeable intervals are of great importance since they include conduits for hydraulic connection between the underlying and overlying aquifers. The wet zone of the Lyleton-Bakken shale interval coincides with potentiometric anomalies on the overlying Lodgepole Formation and the wet zones of the Lower Amaranth are linked in several instances to hydrocarbon accumulations.

Heterogeneities within individual aquifers, as evidenced in several cases by core and drilling cutting descriptions, are reflected in the flow pattern by the presence of potentiometric lows.

4.6 Hydrodynamic Significance of Solution-Generated Collapse Structures

The effect of salt-solution-induced structures on the hydrogeologic environment is, in part, a function of the time of salt removal. Timing determined the vertical extent of both structural disturbance and possible hydraulic connection in the lithostratigraphic column. The fact that the pre-Mesozoic erosional interval was related to the most pronounced events of accelerated salt removal at depth, is also indicative of intense localized structural deformation of the pre-Jurassic formations.

The continuity or discontinuity of pressure systems depends mainly on the prevailing hydrogeologic conditions that follow the formation of solution-generated collapse features. Thus the new hydrogeologic environment and associated groundwater regime might either enhance the permeability of the fracture systems through continuous circulation, or even plug the conduits, thus interrupting the vertical hydraulic continuity. The former case was convincingly exhibited by the coincidence of pressure systems that incorporated a considerable number of distinct lithostratigraphic units with areas of known salt solution. At the same time, these areas comprise locales of anomalous highs on the potentiometric maps. Thus it appears that unsealed fracture systems resulting from salt-related tectonics have a dominant role in delimiting sites of upward and downward gradients that constitute the driving mechanism for cross-formational flow. The latter case, that corresponds to vertical hydraulic reservoir separation, was indicated by the position of individual formations in the fluid pressure profiles, as well as by the spatial coincidence of potentiometric lows.

The foregoing carry diverse and far-reaching implications for both natural-resources exploration and the injection of fluid wastes in the subsurface. Hydraulic continuity is of major significance from the standpoint of migration of hydrocarbon accumulations and injected fluid wastes, while hydraulic discontinuity from the viewpoint of hydrocarbon trapping mechanisms. Also noteworthy is that both cases were exhibited in the present account, as far as oil accumulations are concerned.

Those considerations, along with general observations concerning the hydrogeologic conditions inferred from the potentiometric maps and in some cases from fluid-pressure profiles, comprise the basis for a re-evaluation of the exploration and waste-disposal potential of southwestern Manitoba, which is attempted in the following chapter.

CHAPTER 5

ENVIRONMENTAL AND HYDROCARBON-RELATED IMPLICATIONS

5.1 General Remarks

It is evident that in light of the additional data derived from considerations of the prevailing hydrogeologic conditions within particular lithostratigraphic units, useful inferences concerning the exploration and waste-disposal potential of southwestern Manitoba can be drawn.

Simpson and Dennison (1975), in an account of the waste disposal potential of Saskatchewan, presented an evaluation for each of the three main sedimentary divisions. They pointed out the constraints on strategies for the subsurface disposal of fluid wastes, with special focus on the multiple conflicting objectives of private companies in the area and the presence of solution-generated collapse structures. Also noteworthy, is that they indicated that the Mannville Group is largely unsuitable as a potential disposal horizon, because of the artesian conditions probably associated with salt-related tectonics. They highlighted also the significance of the upper Paleozoic strata, truncated at the sub-Mesozoic unconformity, as waste disposal targets. The same factors apply to the somewhat similar sedimentary succession in southwestern Manitoba. Simpson et al. (1987, Fig. 16), on a detailed study on the subsurface waste disposal potential of Manitoba, proposed a designation scheme of potential disposal regions and units. They discussed the current subsurface utilization, that is mainly oil-field brine injection for subsurface confinement and containment or pressure maintenance operations at the oil-producing districts. They designated the southwesternmost part of Manitoba, that coincides approximately with the study area, as the most suitable region for waste injection because of the presence of confined aquifers. It is also important to note that, to date, the only operation of toxic substances injection has taken place from 1969 to 1975 to an abandoned oil well in the Maples oil district where caustic soda from refineries was injected into Mississippian strata (Simpson *et al*., in prep.)

Aspects related to the exploration for natural resources have been linked to Mississippian oil prospects, the only exception being the Lower Amaranth discovery. This resulted in a sparsity of fluid-related data for pre- and post-Mississippian strata that constitutes the major drawback in the effort to assess their hydrocarbon potential. Sporadic, somewhat inconclusive attempts have been made, such as those by Andrichuk (1959) for the lowermost Paleozoic formations and McCabe (1978) for the basal clastic unit. More important are the accounts concerned with post-Prairie formations that have been affected by salt-related tectonics. McCabe (1967) and Norris *et al*. (1982), on the basis of structural and isopach anomalies, probably indicative of development of sombrero anticlines, pointed out the likelihood for additional hydrocarbon discoveries along the Birdtail-Waskada axis, without any reference to any particular units. The most recent account by Galarnyk et al., (1984) focuses especially on the Amaranth prospect and the possible additional hydrocarbon potential of the Mission Canyon Formation.

5.2 Environmental-Related Implications

Simpson et al. (1987a) designated the possible disposal units in southwestern Manitoba in increasing potential as follows: lower zone of the carbonate-evaporite division (Red River through Souris River Formation); basal clastic unit and upper zone of the carbonate evaporite division. The re-evaluation of the waste disposal potential is attempted on the basis of the subdivision followed in the description of the hydrogeologic environment.

5.2.1 Basal clastic unit

Although Simpson et al. (1987a) casted doubt on the possibility of existence of any regional flow system through the predominantly shale facies of the Winnipeg Formation in most of the study area, the range of the sparsely distributed values, excluding those that correspond to subnormal pressures, as well as the distribution of the equipotential lines (Fig. 10b), indicate that such a pattern might exist. It might even reflect, as pointed out previously, the directional permeability within this formation. The likelihood that a regional pattern exists, along with the fact that the Winnipeg Formation is exposed at the outcrop belt of Lake Winnipeg, might impose several constraints on its possible use as a waste disposal target, since injected fluids might become a part of the regional flow system. The latter is of major importance if one considers the potential of this unit for disposal of waste potash brines (Simpson et. al., 1987).

To these problems should be added the possibility of cross-formational flow of the injected fluids towards the overlying formations in the areas of flowing artesian conditions along the Birdtail-Waskada axis. In the Brandon area, disposal of nitrogen-rich noxious waste is probably planned for the future (Simpson et al., 1987). It is noteworthy that this area is located relatively close to major potentiometric lows, corresponding to heterogeneities (Fig. 10a). It is possible that facies with high shale content might constitute barriers to waste migration in the vicinity of this area, thus rendering the subsurface disposal option for this case a viable alternative.

No accurate assessment of the disposal potential of the Winnipeg Formation can be made in light of the present data. More information relevant to the hydrogeologic environment is necessary before the initiation of any subsurface disposal operation in this unit. As far as the Brandon project is concerned, more drill stem tests should be carried out in the vicinity of this area in order to confirm the existence and areal extent of the low potentiometric surface values that probably will be indicative of the presence of shales and their effectiveness in preventing migration of the injected noxious substances.

5.2.2 Pre-Prairie carbonates

This zone includes all the unconfined pre-Prairie aquifers. From the descriptions of the potentiometric surface maps of the constituent formations, it became apparent that all the units are subject to regional flow of formation fluids. The fluid potential distribution appeared in all the cases to drop off towards the corresponding outcrop belts. The latter is especially exemplified by the discharge of the brine springs from the Winnipegosis reefs in the Devonian outcrop belt. Thus it is likely that fluid wastes injected in any of these formations might be incorporated into the regional groundwater regime and reappear at the near surface groundwater system. This is of major importance, especially in view of the designation of the Interlake Group as a possible future target for subsurface disposal of waste potash brines (Simpson *et al*., 1987). Of significance, however, is the presence or absence of a regional flow system in the biostromal Interlake deposits, west of the present salt edge. Indeed, there appears to be such a system, but note also that the equipotential contours have been extrapolated in this area because of paucity of data. Thus, detailed consideration of hydrodynamics is required in order to assess the disposal potential of the Interlake Group beds in this particular region.

Of special interest might be the Winnipegosis Formation in the area west of the Birdtail-Waskada axis, where low permeabilities that might restrict further up-dip migration of injected fluid wastes are probably present (Fig. 15a). The same region, however, is almost coincident with a trend of anomalies that was identified for the Devonian strata, probably indicative of salt-related tectonics. In light of the available data, the Red River Formation is not likely to represent a potential disposal target horizon, since first a regional system appears to occur and second the occurrences of evaporites that can be dissolved might even introduce additional hazards.

Simpson et al. (1987), made reference to the distance of the outcrop from the deeper parts of the Lower Paleozoic Formations in the southwestern corner of the province and the attendant extremely long time frame that would be recognized for possible reappearance of the injected fluids at the surface. From the present study, however, it becomes evident that, if a regional flow system exists at the southwesternmost part of the study area, its interception at the trend of the Birdtail-Waskada axis might induce, to a considerable extent, cross-formational flow that will tend to impel fluid wastes into stratigraphically younger strata. This was exhibited in at least one case in the vicinity of Township 5, Range 25WPM. The same phenomenon also might take place along the already discussed minor trend of magnetic anomalies in the northern part of the area.

Generally, in light of the present status of information, and more specifically the regional flow system and the likelihood of cross-formational flow, injection of noxious wastes into the pre-Prairie carbonates does not appear to represent the optimum alternative. Should such an approach be adopted, on the basis of the long distance to the outcrop belt, it should be limited to the eastern part of the study area east of the Birdtail-Waskada axis and the Hartney area, so that the possibility of upward deflection of the flow system at those locations can be excluded.

5.2.3 Post-Prairie carbonates

5.2.3.1 Unconfined aquifers

The waste disposal potential of the Dawson Bay and Souris River Formation is downgraded significantly by two factors: 1) as post-Prairie units they are affected by salt-related tectonics, even in the area within the present salt limit (Fig. 21); and 2) as unconfined systems they are likely to be subject to regional flow, as evidenced by the fluid-potential distribution (Figs. 19, 21). The latter becomes evident by the significant decrease in salinities towards the outcrop belt (Manitoba Department of Mines, 1971). In addition, the Souris River Formation has been used in the past as a brine supply aquifer (Simpson et al., 1987) and its possible future use has to be taken into account before the initiation of a disposal strategy. Also important is that the established presence of heterogeneities within these two units does not appear to affect in any way the fluid pattern, which is of regional scope and is moving towards the outcrop. It can be argued, therefore, that the Dawson Bay and Souris River Formations do not comprise potential disposal target horizons.

5.2.3.2 Confined aquifers

As in the case of the "open" carbonate aquifers, these strata also east of the salt solution edge have been probably subject to a certain degree of structural deformation subsequent to salt removal at depth (McCabe, 1967). Their significance, however, in terms of their potential for waste disposal, is strongly enhanced by the fact that they are overlain unconformably by the red beds of the Amaranth Formation. Once more, potentiometric anomalies were defined within the present salt limit, where most of the control points are concentrated that were attributed in several instances to salt solution. The effect of the latter is not very conspicuously imprinted on the hydrogeologic environment to the east of the same edge, because of the sparsity of data relative to the former area.

The effect of salt removal on the prevailing hydrogeologic environment becomes apparent on the fluid flow pattern on the rest of the Devonian units, namely the Duperow and Birdbear Formations, as in the case of the anomalies along the Birdtail-Waskada axis and the linear trend of anomalies that extends northwards from Township 5, Range 29WPM. Those areas should be automatically excluded from waste disposal practices. Use of the Duperow and Nisku Formations, also for noxious wastes containment and confinement, should be ruled out in the areas that coincide with the wet zones of the Lyleton-Bakken interval. There exists, as exhibited earlier, the likelihood of hydraulic continuity and hence cross-formational flow from the Devonian towards the overlying Mississippian strata.

It appears therefore that the disposal potential of these two Devonian units is narrowed down, to a major extent even within the present salt limit, to include a potential region further east of the salt solution edge. More specifically a prospective, future disposal area is in the carbonates of the Nisku Formation to the east of the Birdtail-Waskada axis from Townships 2 to 5, Ranges 18 to 22WPM. No major disruption of the hydrogeologic environment is apparent in this area (Fig. 26) and most important, relatively high salinity values are encountered (Manitoba

Department of Mines, 1971) that can be best accounted for by the complete isolation of the hydrogeologic system in this region. The only shortcoming in this case is represented by the possibility of multiple conflicting objectives, with respect to the hydrocarbon potential of the Nisku Formation which up to now, however, has not been shown to incorporate a potential hydrocarbon-bearing unit in southwestern Manitoba (Simpson et al., 1987a).

The Mississippian strata comprise oil-producing formations and this economic priority should not be endangered by waste injection. This applies especially to the Lodgepole Formation that includes the most prolific oil-bearing strata. The injection of industrial noxious wastes in the Lodgepole carbonates in an abandoned well in the Maples oil field (LSD 07-08-10-26WPM) has been considered by Simpson et al. (1987a, in prep.) as an outstanding example of reservoir isolation and reservoir depletion that allowed for its alternative use. The present study, however, reveals that even in this case the bottom seal (Lyleton-Bakken interval) is probably characterized by wet properties (Fig. 28). Hence the likelihood of downward infiltration of the injected fluids towards the Devonian Formations, as well as their possible up-dip migration along the pre-Jurassic unconformity, are not to be excluded. It is proposed through the present study that before the initiation of any waste disposal strategy into the carbonates of the Lodgepole Formation, the hydrogeologic properties of the underlying Lyleton-Bakken Formation be assessed in detail.

Also noteworthy is the fact that commercial hydrocarbon accumulations are linked in several instances to salt-related tectonics and this might impose additional hazards attendant upon waste injection. The northwestern part of the study area that coincides with the Lyleton-Bakken dry zone, where the Lodgepole formation is unconformably overlain by the Amaranth evaporites that provide the main cap seal, and to the east of Township 17, Range 29WPM where salt solution is known to have taken place, is likely to include potential sites for a Lodgepole waste disposal alternative. The Birdtail-Waskada axis and the salt-solution edge should comprise the eastern limit of this region, the significance of which is enhanced by its distant location relative to known hydrocarbon accumulations. Two minor drawbacks in this case are firstly the thin overlying sedimentary cover relative to the other areas in the south and secondly the occurrence of Winnipegosis reefs in the vicinity of this area (Fig. 15a)

The Mission Canyon Formation is limited at the southwestern extreme of the study area. This unit has been designated by Simpson et al. (1987a) as the most significant in terms of possible future demands concerning the containment and confinement of injected noxious wastes. This holds true especially for the MC3 Member which is truncated at the sub-Mesozoic unconformity, where it is overlain by the Amaranth Red Beds and is bounded at the top and the bottom by the Charles and MC2 Evaporites respectively. The complete encapsulation within these three aquitards occurs southwestwards of the subcrop erosional edge of the Charles Evaporite. The potentiometric maps of the Tilston and Alida Beds (Figs. 34, 36) augment to a major extent the contention expressed by the previously cited authors. More specifically, the apparent reversal in the gradients (predominantly southwestwards and westwards respectively) are indicative of a somewhat down-dip flow of the formation fluids. The latter is very important since, not only will the injected fluid wastes be entirely confined but, depending on their density and degree of miscibility with the water, they might move along with the formation fluids down-dip away from the disposal site.

The potential also of the Tilston Beds is not to be excluded, but a prominent anomaly in Townships 2 and 3, Ranges 27 and 28WPM, reflecting probably salt-related tectonics, ranks them as a second choice. The same region also should be excluded for waste-disposal practices into the Alida Beds, since the latter are characterized in the same area by a minor degree of structural disturbance (Manitoba Mineral Resources Division, 1976). Thus the most suitable area appears to comprise the MC3 Beds in the vicinity of Township 1, Ranges 27 to 29WPM. It should be limited, however, to Township 1, Range 29WPM, since the eastern part of the former is almost coincident with an area where the overlying Spearfish Beds are characterized by relatively high permeability (Fig. 38) and comprise also possible future hydrocarbon targets. It is important to note that, because of the direction of the gradient and the location of the optimum disposal area, problems of interprovincial (Manitoba-Saskatchewan) or even international (Manitoba-North Dakota) nature should be also taken into account.

5.2.4 Upper clastic division

The excessively sparse data constitute the main drawback to any attempt at re-appraisal of the waste-disposal potential of the upper clastic unit. In addition to that, the lateral variation of facies and the dominance of shales yields a relatively limited void space for containment and confinement of injected fluid wastes. The fluid potential pattern of the Jurassic formations and the Cretaceous Mannville Group (Figs. 39b, 41) gave an eastward flow direction.

Cretaceous and Jurassic strata outcrop in a small distance east of the study area in the Manitoba Escarpment and further eastwards, hence a possible incorporation of injected wastes into the near-surface hydrogeologic system should be taken into account. There is also a strong likelihood of excessively high pressures, relevant to salt solution phenomena, as in Jurassic strata of Township 11, Ranges 28 and 29WPM. Simpson et al. (1987) referred to the spatial coincidence between modern and ancient valley systems, related to salt solution; as excluding the upper clastic unit from the potential disposal target horizons. The only somewhat continuous aquifer, except for the near-surface Boissevain Formation, is the Ashville (Viking) Sand. Simpson (1983) argued that its abrupt increase in thickness (from 5 to 60 m approximately) might reflect in part basement- and salt-related tectonics. The author of the present account, however, suggests that the latter unit is likely to provide a potential disposal target horizon, because of its isolation , as discussed previously. The few cases where fluid pressures higher than those corresponding to normal hydrostatic gradient were registered, might be simply related to the over-pressuring of the formation subsequent to oil field brine injection observed by Simpson et al. (1987)

5.2.5 Summary of the results

The results from the preceding re-evaluation, are generally, in accordance with those discussed by Simpson et al. (1987a). Some new areas and units, however, were added to the list of the potential regions and formations for wastes disposal practices, the most significant being the carbonates of the Lodgepole and Birdbear Formations in the northwestern and southern part of the study area respectively, as well as the Ashville Sand body. The author suggests that a precise hierarchical evaluation of the proposed areas and units be subject first to more detailed and site-specific studies. However, pre-Prairie units further east of the of the Birdtail-Waskada axis should comprise the last alternative in the consideration of waste-disposal alternatives. A slight possibility of uncertainty accompanying the injection of industrial noxious wastes in the Maples oilfield was also indicated. Known and suspected areas of salt solution, as might be inferred from structural-isopach anomalies and potentiometric anomalies in the present study respectively, as well as the area in the vicinity of the Hartney structure, should be avoided. The same applies also to all the locales along and adjacent to the present salt solution edge and the Birdtail-Waskada axis. The presence of some other minor magnetic anomalies on the Precambrian basement in the western part of the study area should be also taken into account, even though their effects on the hydrogeologic environment are not conspicuous, probably because of the relatively sparse well control.

5.3 Hydrocarbon-Related Implications

From the standpoint of exploration for natural resources, post-Prairie units are apparently the most significant. Before the consideration of the latter however, a very brief evaluation of the pre-Prairie Formations will be attempted on the basis of the prevailing hydrogeologic conditions.

5.3.1 Pre-Prairie formations

Pre-Prairie units have not been proved to date to contain commercial hydrocarbon accumulations in southern Manitoba. Oil showings have been sporadically reported for the Winnipegosis Formation (Andrichuk, 1959; McCabe, 1978; Simpson et al., 1987). Andrichuk (1959) also made reference to oil showings in the Red River Formation. It is true, however, that pre-Prairie units have been relatively neglected, since the main interest is almost entirely focused on the oil bearing Mississippian strata. The new information derived from the hydrogeologic environment can probably account for, at least in part, their seemingly barren nature. More specifically, all the formations are characterized by regional flow systems that appear to lead toward the outcrop belt. In addition the salinity values for approximately all the units show a considerable decrease from the southwestern corner of the province towards the outcrop belts (Manitoba Department of Mines, 1971). A probable hydraulic connection with the surface indicates that, unless a favourable structural configuration was present, any possible oil accumulations might have been completely flushed out to escape at the surface. Since the trend of oil migration and that of the formation waters movement appear to nearly coincide, the effect of permeability pinch-outs in restricting further up-dip hydrocarbon migration becomes very questionable. Thus, in light of the present information, pre-Prairie formations do not appear to contain significant potential hydrocarbon prospects.

5.3.2 Post-Prairie formations

A starting point for the conceptualization of the control that salt solution exerts on hydrocarbon accumulations, as well as for the establishment of a rationale for locating possible new prospective targets, is the study of the spatial relationships between solution-generated collapse structures and known hydrocarbon accumulations. The latter is attempted in Figure 42, which shows known areas of salt solution corresponding in several instances to potentiometric anomalies, as well as areas of probable salt solution identified mainly by means of potentiometric anomalies.

Salt-solution structures become of vital importance in the exploration for hydrocarbons, where they intercept oil-bearing reservoir units, potential oil migration paths or hydrocarbon source rocks. In the study area, the main hydrocarbon-bearing units are the Mississippian carbonates

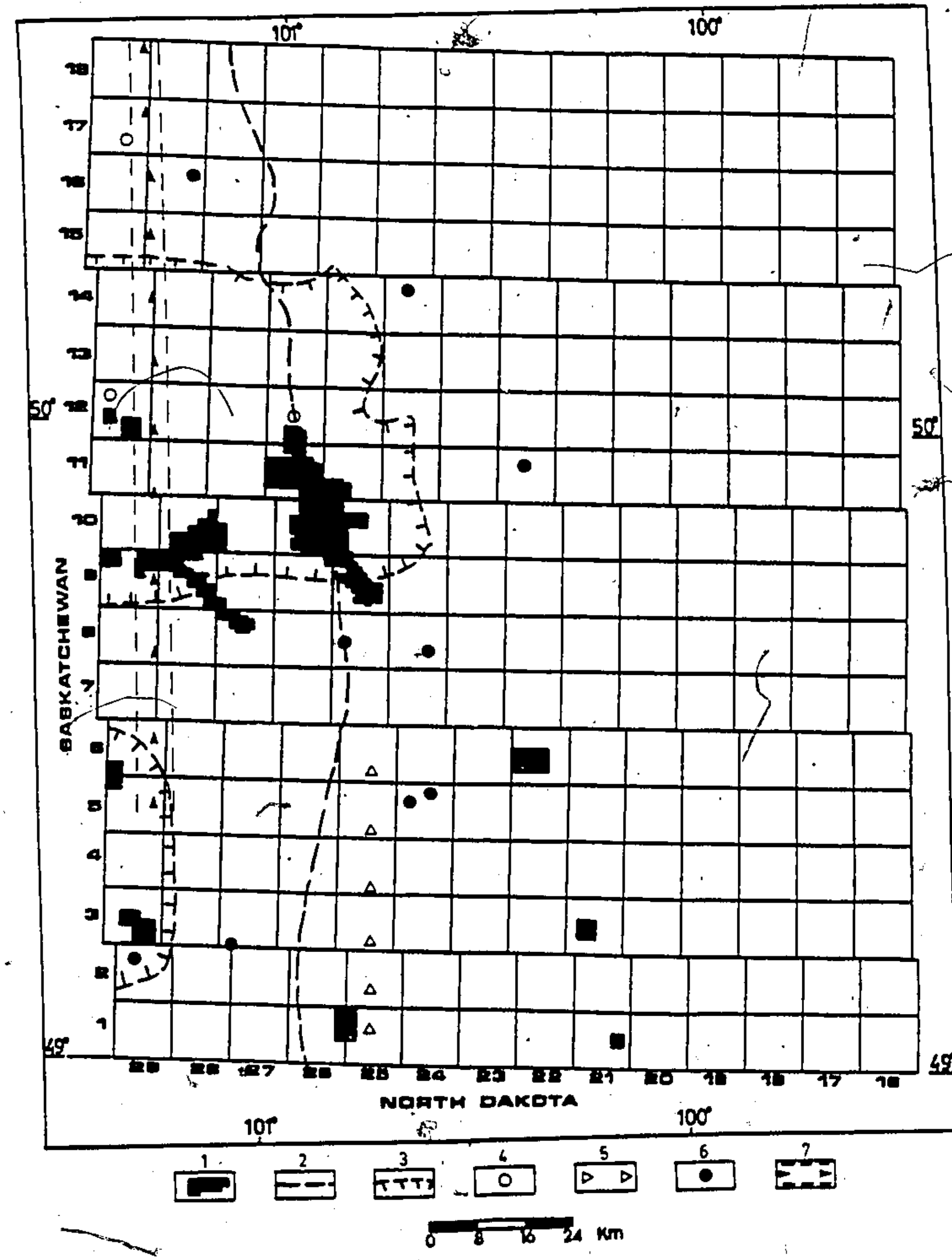

Fig. 42. Location of major oil fields related to distribution of solution-generated collapse structures. 1) oil field; 2) limit of Prairie Evaporite salt beds (solution edge); 3) Lyleton-Bakken wet zone; 4) known sites of salt solution and collapse; 5) known trend along which salt solution and collapse have occurred; 6) proposed sites of salt solution and collapse; 7) proposed trend along which salt solution and collapse have occurred.

Credits: McCabe, 1971.
Zahalon, 1980.
Norris *et al.*, 1982.
Simpson, 1983.

and the source rocks are most likely located in the deepest parts of the Williston basin in North Dakota. It appears, therefore, that the third case should be excluded. Simpson (1987b, 1988) discussed the potential for migration of hydrocarbons and formation waters with base metals in solution, in brecciated strata and along the fractures accompanying salt-related tectonics. His views are substantiated to an extent by the results of the present study, especially in the case of the Waskada oil field, where the possibility of upwards migration of hydrocarbons from the Lodgepole Formation towards the MC1 Member of the Mission Canyon Formation was indicated. Also noteworthy is the fact that regardless of the existence of cross-formational flow, salt solution by itself can lead to the formation of favourable structures for oil entrapment. Thus, the latter might be the case for several structures in the vicinity of the Daly and Virden oilfields, while in the Waskada field salt solution probably played a two-fold role: formation of the dome and enhancement of vertical migration.

The first observation to be made from Figure 42 is the location of the oil fields relative to the solution edge of the Prairie Evaporite. Most of the hydrocarbon accumulations are localized within the salt area. The eastern limit of the region where most of the hydrocarbon accumulations occur is the salt edge and the Birdtail-Waskada axis. The western limit is a trend of anomalies along the Saskatchewan-Manitoba border. It was drawn on the basis of known salt solution in Townships 12, 17 and 19, Range 29WPM, as well as of trends of potentiometric anomalies extending northward from Township 5, Ranges 28 and 29 WPM in the Devonian formations. It is not unlikely that the same features are indicative of a trend along which partial salt removal and collapse have occurred. It is significant to note its coincidence with a trend defined by oilfields in the same area. In the opinion of the author, the most striking feature in Figure 42 is the location of the Daly and Virden oilfields within the prominent Bakken-Lyleton wet zone that probably delimits areas of at least partial salt removal. It is also important to observe that two other prolific oil producing areas, the Pierson and Tilston oil fields, are located within the other wet zone of the same impermeable interval. The component of structural entrapment is apparent for both of them and it might be attributed to salt-related tectonics. The wet zones are likely to include additional potential prospects. This might be questionable for the most prominent zone, because of the intrinsic decrease in porosity and hence permeability northwestwards from the Daly and Virden oil fields. However, a secondary enhancement of these properties by salt removal and related collapse is not to be excluded. The area in the southern part of the Birdtail-Waskada axis offers potential Devonian prospects (Norris et al., 1982). Structural and isopach anomalies are present in the Devonian units from Township 1 to 6, Range

25WPM, and their hydrodynamic response was evidenced by the presence of anomalies on potentiometric surface maps along the same trend. In one case especially, an identical scenario to that observed in the Waskada area, as far as continuity of fluid pressure is concerned, is taking place in the carbonates of the Nisku Formation in the vicinity of Township 4, Range 25 WPM. The latter comprises probably the most potential prospective Devonian unit, especially if the possible presence of reefs in its upper part is taken into account.

The discussion concerning possible further exploration in southern Manitoba will be in the best case incomplete, unless some considerations on the potential for precipitation of base metals are included. Simpson (1988) referred to the case of the Mississippi Valley-type (MVT) lead-zinc deposits, as an example of precipitation of metals in solution to waters, that were subject to cross-formational flow. Norris et al. (1982) noticed the potential of Devonian units for lead-zinc mineralization. Most importantly, Davidson (1981) referred to the co-existence in the same anticlinal structure of hydrocarbon accumulations and copper mineralization, thus indicating their similar modes of migration. In southern Manitoba the possible presence of lead-zinc deposits might reflect either transportation from the glaciers from the north (Norris et al., 1982) or even upward migration of minerals that have been leached from the Precambrian basement. In that respect, the Birdtail-Waskada axis might be of considerable importance in localizing accumulations of base metals. Formation waters from the Lower Paleozoic units, such as the Winnipeg Formation, may have dissolved part of the base metals and transferred them through their high fluid pressures to overlying units, where they probably precipitated.

CONCLUDING REMARKS

1. Shut-in pressures from drill stem tests were employed for the construction of potentiometric surfaces and fluid-pressure profiles. These, with the aid of documented lithological descriptions, as well as structure contour and isopach maps, were related in turn mainly to the distribution of solution-generated collapse structures.

2. The presence of known solution-generated collapse structures is reflected in the fluid flow pattern as potentiometric anomalies. Areas of previously undocumented salt solution can be probably defined on the basis of potentiometric anomalies. Such a case might be represented by the linear trend of anomalies along the Saskatchewan-Manitoba border that was apparent in the Devonian units.

3. A definite relationship appears to exist between salt solution structures and the presence of continuous pressure systems, on the basis of their spatial coincidence. The latter provides the best evidence of cross-formational flow. They are reflected also in the potentiometric surfaces by the coincidence of high pressure cells. This might exert significant control on the migration of hydrocarbons and injected fluid wastes. The contribution of a distinct pressure system in inferring otherwise undocumented salt collapse, is highlighted in the case of Township 16, Range 28WPM.

4. Spatial coincidence of potentiometric lows might represent lack of cross-formational flow. This argument is augmented in several instances by the position of particular units on the fluid-pressure profiles. This correspondence is probably important in defining potential locales of hydrocarbon entrapment.

5. The waste disposal potential of southwestern Manitoba can probably be expanded to include the Lodgepole and the Birdbear Formations in the northwestern and southeastern parts of the study area respectively.

6. Mississippian carbonates, and especially the Lodgepole Formation, may comprise potential hydrocarbon target horizons within the Bakken-Lyleton wet zones. Additional potential is probably offered by the Devonian carbonates and most importantly the Nisku Formation in the southern part of the Birdtail-Waskada axis.

7. The boundary zone is likely to comprise a prospective area for exploration activities aimed at location of Mississippi Valley-type (MVT) lead-zinc mineral deposits.

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APPENDIX I

ELEVATIONS OF POTENTIOMETRIC SURFACES WITH RESPECT TO MEAN SEA LEVEL, COMPUTED AS METRES OF FRESH WATER FROM SHUT-IN BOTTOM HOLE PRESSURES (kPa).

WINNIPEG FORMATION (WNPG)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
WESTERN ORTHEZ 13-36	LSD.13-36-04-19W1	496.20	1376.20	1383.80	14617		605	
FRANCANA ET AL HARTNEY 6-34-5-24	LSD.06-34-05-24W1	438.90	1524	1575.50	16637	16637	562	562
AMERADA LAUDER PROV M F 9 35 5 25	LSD.09-35-05-25W1	434.30	1610.90	1639.80	17582	17347	589	566
ARCO SHILO PROV. 10 2 9 16	LSD.10-02-09-16W1	377.60	990.30	995.50	11383	11039	544	509
ARCO SHILO PROV. 10 24 9 16	LSD.10-24-09-16W1	373.10	967.70	979.90	1793	710	-424	-534
DOME BRANDON 3 5 9 19	LSD.03-05-09-19W1	418.50	1197.30	1200	1931		-584	
IMPERIAL BLOSSOM 3 17 12 24	LSD.03-17-12-24W1	472.70	1362.50	1375	13100		435	
NORCEN POR HARMSWORTH PRV. 15-11-12-26	LSD.15-11-12-26W1	454.20	1399	1406	14276	14276	506	506
DOME MINNEDOSA 16 26 14 18	LSD.16-26-14-18W1	556.30	611.10	618.10	3041		249	
DOME STRATHCLAIR 8 34 16 21	LSD.08-34-16-21W1	606.90	1160.40	1174.10	8825		334	

RED RIVER FORMATION (RDRV)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
AMERADA LAUDER PROV M F 9 35 5 25	LSD.09-35-05-25W1	434.30	1428.90	1450.80	15375	15348	553	550
FRANCANA ET AL E. TILSTON 8-13-5-29	LSD.08-13-05-29W1	489	1798	1815	18365	17634	549	474
DCL BRANDON 16 10 10 18	LSD.16-10-10-18W1	369.10	948.50	976	10377		453	
DOME HARDING 4 27 11 22	LSD.04-27-11-22W1	420.90	1051	1054.60	10273		415	
IMPERIAL BLOSSOM 3 17 12 24	LSD.03-17-12-24W1	472.70	1182.60	1191.80	9653		266	
DOME STRATHCLAIR 8 34 16 21	LSD.08-34-16-21W1	606.90	1075.90	1094.20	7308		259	
STRATH 6 23 17 23	LSD.06-23-17-23W1	567.80	1024.70	1032.70	7102		260	

INTERLAKE GROUP (IKGP)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT.	SURF.
CHEVRON COULTER PROV.	LSD.09-06-02-26W1	439.90	1596	1602	17069	15557	581	426
CALSTAN SOUTH NAPINKA 5 3 4 25	LSD.05-03-04-25W1	462.70	1446	1446	15375		586	
MADISON LAUDER 1 19 5 24	LSD.01-19-05-24W1	440.10	1138.70	1144.80	11514		471	
AMERADA LAUDER PROV M F 9 35 5 25	LSD.09-35-05-25W1	434.30	1269.50	1292.40	13693	13645	540	535
CAL STAN FINDLAY 9 26 7 25	LSD.09-26-07-25W1	433.10	1218	1236	12411		464	
DOME BRANDON 3 5 9 19	LSD.03-05-09-19W1	418.50	948.50	952.80	9653		451	
UNION GRISWOLD 13-4-10-22	LSD.13-04-10-22W1	422.80	969.30	975.40	10128	10073	481	476
B.A. MITCHELL 7 26 11 17	LSD.07-26-11-17W1	399.60	682.80	690.40	6550		378	
IMPERIAL BLOSSOM 3 17 12 24	LSD.03-17-12-24W1	472.70	1034.80	1048.50	9653		410	

WINNIPEGOSIS FORMATION (WPGS)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT.	SURF.
CALSTAN WASKADA 9-13-1-26	LSD.09-13-01-26W1	468.80	1541.10	1545.60	16030		560	
CHEVRON COULTER PROV.	LSD.09-06-02-26W1	439.90	1520	1535	16126	16146	551	553
CALSTAN SOUTH NAPINKA 5 3 4 25	LSD.05-03-04-25W1	462.70	1340.80	1373.40	13914	13914	510	510
SOYRIS VALLEY WARNEZ NO. 13 5	LSD.05-13-05-22W1	498.30	1150	1159.80	11445		507	
ROYALITE TRIAD ET AL EAST HARTNEY 1	LSD.07-27-05-24W1	442.90	1115	1125.90	13376		683	
FRANCANA ET AL HARTNEY 6-34-5-24	LSD.06-34-05-24W1	438.90	1094.20	1109.50	11342	11328	487	486
AMERADA LAUDER PROV M F 9 35 5 25	LSD.09-35-05-25W1	434.30	1232.60	1242.10	13059	12252	525	443
CAL STAN LINKLATER 2 21 7 28	LSD.02-21-07-28W1	493.20	1441.10	1447.50	10170		84	
DOME BRANDON 3 5 9 19	LSD.03-05-09-19W1	418.50	824.50	828.80	8032		410	
DCL BRANDON 16 10 10 18	LSD.16-10-10-18W1	369.10	664.50	701	7088	7129	392	396
CANADIAN IMPERIAL LENORE 2 20 11 24	LSD.02-20-11-24W1	457.80	994.60	1003.70	9687	9660	443	440
CALSTAN ELKHORN 7A 8 11 29	LSD.07-08-11-29W1	543.50	1373.70	1382.90	11721		357	
DOME ARROW RIUER 12 10 14 25	LSD.12-10-14-25W1	500.80	960.40	964.10	8308		385	
DOME STRATHCLAIR 8 34 16 21	LSD.08-34-16-21W1	606.90	822.40	828.10	5171		307	

DAWSON BAY FORMATION (DSBY)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
CALSTAN WHITEWATER 15-36	LSD.15-36-03-22W1	499.30	1148.20	1160.40	11369		500	
WESTERN ORTHEZ 13 36	LSD.13-36-04-19W1	496.20	945.80	951.90	8860		449	
AMERADA LAUDER PROV M F 9 35 5 25	LSD.09-35-05-25W1	434.30	1161.60	1173.80	12507	12183	537	504
DOME BRANDON 3 5 9 19	LSD.03-05-09-19W1	418.50	767.80	773.30	7308		391	
DOME BRANDON 16-27-9-19	LSD.16-27-09-19W1	405.10	699.80	705.60	6757		389	
CALSTAN SOUTH VIRDEN PROV. SWD 3-11	LSD.03-11-10-26W1	439.20	1017.40	1027.20	10763	10763	511	511
DOME HARDING 4 27 11 22	LSD.04-27-11-22W1	420.90	790.30	793.70	7584		401	
IMPERIAL BLOSSOM 3 17 12 24	LSD.03-17-12-24W1	472.70	917.40	925.10	8101		375	
DOME MINNEDOSA 16 26 14 18	LSD.16-26-14-18W1	556.30	647.40	656.50	4075		316	
APACHE ET AL CHUMAH 2-28-14-24	LSD.02-28-14-24W1	525.20	630.90	640	8039	7901	706	692
DOME STRATHCLAIR 8 34 16 21	LSD.08-34-16-21W1	606.90	762	772.70	4826		327	
PR POTASH ET AL MCAULEY PROV 13 2	LSD.13-02-16-29W1	469.70	906.80	952.50	2379	2172	-240	-261
STRATH 6 23 17 23	LSD.06-23-17-23W1	567.80	765.70	769.30	5736		384	

SOURIS RIVER FORMATION (SRSR)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT.	SURF.
CALSTAN WASKADA 9-13-1-26	LSD.09-13-01-26W1	468.80	1396.60	1403.30	12066		297	
LL & E WASKADA 15-20-3-25	LSD.15-20-03-25W1	468.50	1280.20	1292.40	13183	12852	522	488
ROYALITE TRIAD ET AL EAST HARTNEY 1	LSD.07-27-05-24W1	442.90	958	962.90	7929		289	
ROYALITE TRIAD ET AL EAST HARTNEY 1	LSD.07-27-05-24W1	442.90	903.10	907.70	8618		415	
L M IMP HARTNEY 1 29 5 24	LSD.01-29-05-24W1	434.30	1079	1090	11494	10094	518	375
FRANCANA ET AL HARTNEY 9-30-5-24	LSD.09-30-05-24W1	437	920	931	9806	9293	507	455
FRANCANA ET AL HARTNEY 9-30-5-24	LSD.09-30-05-24W1	437	1013	1021	10724	1083	511	-473
FRANCANA ET AL E. TILSTON 8-13-5-29	LSD.08-13-05-29W1	489	1442	1452	14993	14211	568	488
CAL STAN FINDLAY 9 26 7 25	LSD.09-26-07-25W1	433.10	1059.20	1072.30	10687		452	
CAL STAN LINKLATER 2 21 7 28	LSD.02-21-07-28W1	493.20	1149.40	1154.30	8618		219	
CAL STAN LINKLATER 2 21 7 28	LSD.02-21-07-28W1	493.20	1173.20	1178.10	9480		283	
CAL STAN LINKLATER 2 21 7 28	LSD.02-21-07-28W1	493.20	1225.90	1230.80	10342		318	
CALSTAN WAWANESA 3 1 8 18	LSD.03-01-08-18W1	415.70	701.30	703.20	6412		367	
DOME BRANDON 16-27-9-19	LSD.16-27-09-19W1	405.10	670.90	674.20	6474		392	
CALSTAN WOODNORTH PROV. 5 18 9 27	LSD.05-18-09-27W1	487.10	1105.80	1111.30	10687		467	
CHEVRON DALY 14-13-9-28	LSD.14-13-09-28W1	488.60	1280	1300	12590	12780	474	493
CALSTAN SOUTH VIRDEN PROV. SWD 3-11	LSD.03-11-10-26W1	439.20	990.60	1000.40	11080	10218	570	482
B A UNION GROSE SWD 7-27-10-26	LSD.07-27-10-26W1	442	986.30	996.70	9825		448	
DALY GAS # 10-7-10-27	LSD.10-07-10-27W1	489.20	1079	1083.90	10418	10983	469	527
DALY GAS 7-18-10-27	LSD.07-18-10-27W1	496.20	1071.40	1079	10659	10563	505	496
CALSTAN DALY 15 18 10 27	LSD.15-18-10-27W1	491.90	1066.50	1070.20	11032		548	
CDN SUP DALY SWD NO 1	LSD.12-04-10-28W1	512.40	1083.90	1099.70	8274		257	
CALSTAN DALY 8-14-10-28	LSD.08-14-10-28W1	498.70	1095.80	1104.90	10687		465	
B.A. MITCHELL 7 26 11 17	LSD.07-26-11-17W1	399.60	530.40	534.90	4757		350	
DOME HARDING 4 27 11 22	LSD.04-27-11-22W1	420.90	757.10	761.70	7102		384	
CALSTAN ELKHORN 7A 8 11 29	LSD.07-08-11-29W1	543.50	1155.80	1160.10	9997		404	

IMPERIAL BLOSSOM 3 17 12 24	LSD.03-17-12-24W1	472.70	798.60	810.80	6205		295	
IMPERIAL BLOSSOM 3 17 12 24	LSD.03-17-12-24W1	472.70	885.40	897.60	7584		349	
CALSTAN HARMSWORTH PROV. 6A 24 12 26	LSD.06-24-12-26W1	455.40	954	963.20	5109		14	
HOCKINS 3 19 13 15	LSD.03-19-13-15W1	392	420.60	424.30	2856		259	
DOME MINNEDOSA 16 26 14 18	LSD.16-26-14-18W1	556.30	626.40	632.50	3771		309	
DOME MINNEDOSA 16 26 14 18	LSD.16-26-14-18W1	556.30	611.10	618.10	3041		249	
APACHE ET AL CHUMAH 2-28-14-24	LSD.02-28-14-24W1	525.20	836.70	848.90	7364	7198	428	411
DYPONT 14 25 16 28	LSD.14-25-16-28W1	479.10	829.70	833.30	7260		387	
STRATH 6 23 17 23	LSD.06-23-17-23W1	567.89	730.30	737.60	4688		309	

DUPEROW FORMATION (DPRW)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT.	SURF.
IMP CALSTAN HERNEFIELD 1 30	LSD.01-30-01-25W1	472.40	1266.40	1275.60	13100	12376	534	460
CALSTAN WASKADA 9-13-1-26	LSD.09-13-01-26W1	468.80	1267.10	1273.10	12238		445	
CALSTAN WHITEWATER 15-36	LSD.15-36-03-22W1	499.30	998.20	1008.90	8901		399	
LL & E WASKADA 15-20-3-25	LSD.15-20-03-25W1	468.50	1130.50	1138.70	10025	8487	353	196
WESTERN ORTHEZ 13 36	LSD.13-36-04-19W1	496.20	730	736.10	5757		348	
CALSTAN SOUTH NAPINKA 5 3 4 25	LSD.05-03-04-25W1	462.70	1070.80	1070.80	11238		539	
CHEVRON ET AL HARTNEY 1-28-5-24	LSD.01-28-05-24W1	441.40	544	555	5794		478	
FRANCANA ET AL HARTNEY 9-30-5-24	LSD.09-30-05-24W1	437	685	691	7301	7297	491	491
FRANCANA ET AL HARTNEY 6-34-5-24	LSD.06-34-05-24W1	438.90	871.10	875.40	9039	8901	486	472
HB S. PIPESTONE PROV. 4-25-6-26	LSD.04-25-06-26W1	436.20	945	956	5835	4474	76	-63
PPI HAMOIL SINCLAIR PROV 12 32 6 28	LSD.12-32-06-28W1	490.70	1060.70	1069.80	10721	9749	515	416
CAL STAN FINDLAY 9 26 7 25	LSD.09-26-07-25W1	433.10	923.50	928.10	9653		491	
CAL STAN LINKLATER 2 21 7 28	LSD.02-21-07-28W1	493.20	1128.10	1132.90	9653		346	
CANADIAN SUPERIOR ROUNTHWAITE 10 17	LSD.10-17-08-17W1	389.50	496.20	502.30	3689		264	
DOME HAYFIELD 12 22 8 20	LSD.12-22-08-20W1	444.70	598.90	615.70	710		-99	
B.A. UNION WOODNORTH 9 28 8 27	LSD.09-28-08-27W1	470.60	982.70	989.10	9653		467	
AMERADA CROWN M.E. 13 11	LSD.13-11-09-16W1	374.60	429.80	443.50	3447		283	
CALSTAN WOODNORTH PROV. 5 18 9 27	LSD.05-18-09-27W1	487.10	954	967.40	8963		435	
CITIES SERVICE DOWNIE 2 4 10 17	LSD.02-04-10-17W1	377	434.60	442.60	3054		246	
SPRUCE WOODS S.T. NO 1	LSD.13-12-10-17W1	384	423.70	431.30	2758		234	
PEACOCK EXPLORATION KEMNAY NO 1	LSD.13-04-10-20W1	425.20	563	582.20	4895		343	
UNION GRISWOLD 13-4-10-22	LSD.13-04-10-22W1	422.80	670	720.20	7033	6612	421	378
CALSTAN SOUTH VIRDEN PROV. SWD 3-11	LSD.03-11-10-26W1	439.20	838.20	846.10	8377		448	
B A UNION GROSE AND SWD 7-27-10-26	LSD.07-27-10-26W1	442	842.80	853.40	7929		398	
DALY GAS 7-18-10-27	LSD.07-18-10-27W1	496.20	929.60	941.80	9542	9267	529	500
CALSTAN DALY 15 18 10 27	LSD.15-18-10-27W1	491.90	915.90	919.90	8274		417	

APACHE DARLING DALY 15-18-10-27	LSD.15-18-10-27W1	495.30	907.70	920.50	9349	9211	529	515
CALSTAN DALY 16 20 10 27	LSD.16-20-10-27W1	488	925.10	929.60	8618		438	
CDN SUP DALY SWD NO 1	LSD.12-04-10-28W1	512.40	989.10	1000	8963	9136	427	445
CALSTAN DALY 8-14-10-28	LSD.08-14-10-28W1	498.70	948.80	952.50	8618		426	
DOME HARDING 4 27 11 22	LSD.04-27-11-22W1	420.90	673.60	678.20	9239		686	
CDN SUP DOME ET AL WHITEFORD 8 28	LSD.08-28-11-26W1	463.90	827.20	840.30	7481		387	
CALSTAN ELKHORN 7A 8 11 29	LSD.07-08-11-29W1	543.50	1010.40	1015	6722		215	
IMPERIAL BLOSSOM 3 17 12 24	LSD.03-17-12-24W1	472.70	694.90	701.30	5516		335	
CALSTAN HARMSWORTH PROV. 6A 24 12 26	LSD.06-24-12-26W1	455.40	774.20	788.20	4592		136	
PARADISE MAXFIELD TWO CREEKS 10 33	LSD.10-33-12-26W1	457.20	773.90	799.20	7453	7033	419	376
B.A. UNION BRAZZELL 2 7	LSD.02-07-14-20W1	556	579.70	598	1165	3344	77	299
APACHE ET AL CHUMAH 2-28-14-24	LSD.02-28-14-24W1	525.20	656.50	662	5447	5323	419	407
DOME ARROW RIVER 12 10 14 25	LSD.12-10-14-25W1	500.80	714.50	719.30	5274		320	
DOME STRATHCLAIR 8 34 16 21	LSD.08-34-16-21W1	606.90	576.10	594.10	3068		326	
DOME BIRTLE 14 35 16 27	LSD.14-35-16-27W1	521.20	674.80	681.20	4523		302	
DYPONT 14 25 16 28	LSD.14-25-16-28W1	479.10	684.90	691.60	5550		354	
STRATH 6 23 17 23	LSD.06-23-17-23W1	567.80	588.30	595.60	3537		333	
APACHE ET AL SOLSGIRTH 2-7-18-25	LSD.02-07-18-25W1	548.60	610.50	615.70	4275	4413	369	383
ANGLO AMERICAN BIRDTAIL 4 30 18 26	LSD.04-30-18-26W1	551.40	618.70	640.10	207		-68	

BIRDBEAR FORMATION (BDBR)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
ROYALITE TRIAD ET AL LULU LKE NO 1	LSD.16-14-01-21W1	699.80	1138.70	1141.80	7584		332.27	
CLEARY FLOSSIE LAKE 10 21	LSD.10-21-01-23W1	655.60	1232	1244.20	10280		460.92	
DEKALB ET AL WASKADA 10-23-1-25	LSD.10-23-01-25W1	474.30	1169.20	1176.80	11997	11880	522.31	510.36
IMP CALSTAN HERNEFIELD 1 30	LSD.01-30-01-25W1	472.40	1176.50	1187.50	12169	11893	527.27	499.09
CALSTAN WASKADA 9-13-1-26	LSD.09-13-01-26W1	468.80	1203	1207.90	12238		510.31	
MURPHY ET AL N. WASKADA 8-32-2-25	LSD.08-32-02-25W1	478.40	1138	1151	10912	10270	441.44	375.89
LL & E MELITA PROV 2-30-2-26	LSD.02-30-02-26W1	438	1173.80	1179.60	12569	12514	541.61	535.99
LL & E CANSO COULTER 9-15-2-27	LSD.09-15-02-27W1	435	1207.30	1211	12528	12417	503.02	491.69
CALSTAN PIERSON PROV 2-29-2-29	LSD.02-29-02-29W1	481	1328.90	1333.50	13169		491.96	
CALSTAN SOUTH NINGA 9-6-3-18	LSD.09-06-03-18W1	521.20	774.20	783.30	6640		415.80	
BAYSEL CALSTAN BOISSEVAIN 3-20-3-19	LSD.03-20-03-19W1	514.80	807.10	819.90	7067		416.39	
CALSTAN WHITEWATER 15-36	LSD.15-36-03-22W1	499.30	885.40	894.60	8060		427.57	
WESTERN ORTHEZ 13 36	LSD.13-36-04-19W1	496.20	697.40	707.10	5654		366.33	
DOME HARRIS COX WHITEWATER LAKE 4 4	LSD.04-04-04-22W1	503.80	926.60	932.70	8343	2275	422.86	-196.64
CALSTAN SOUTH NAPINKA 5 3 4 25	LSD.05-03-04-25W1	462.70	1007.70	1007.70	10066		482.67	
FRONTIER NAPINKA 3 22 4 25	LSD.03-22-04-25W1	455.10	987.20	1009.50	10753	10232	543.41	490.21
IMP CALIFORNIA STANDARD EUNOLA 4 28	LSD.04-28-04-29W1	492.60	1223.80	1237.50	11997		479.91	
GRT PLNS NINETTE PROV. 2 27 5 17	LSD.02-27-05-17W1	457.20	552.30	582.20	4185	3385	302.26	220.58
U.S. SMELTING 3 30 DRAPER	LSD.03-30-05-21W1	476.40	780.30	794.30	7253		422.58	
IMP CANADIAN SUPERIOR ARGUE 5-33	LSD.05-33-05-23W1	443.50	844.30	855	8874		494.47	
FRANCANA ET AL HARTNEY 6-34-5-24	LSD.06-34-05-24W1	438.90	771.10	780.90	8053	8060	480.15	480.87
CALSTAN LAUDER 9 14 5 25	LSD.09-14-05-25W1	440.10	917.40	924.80	9453		480.38	
TILSTON A NO 1	LSD.05-12-05-29W1	483.10	1158.20	1189	12169		536.47	
MCCARTY COLEMAN FORBES 1 31 6 22	LSD.01-31-06-22W1	439.50	736.40	747.40	7653		473.42	
MCCARTY AND COLEMAN MORRICE 12 28	LSD.12-28-06-23W1	432.80	767.80	774.50	7998		474.84	
U.S. SMELTING 1 35 ALSTON	LSD.01-35-06-23W1	436.20	751.30	755.60	7653		461.92	

SAPPHIRE EAST GRANDE CLARIERE NO.1	LSD.14-16-06-24W1	435.60	833.60	841.90	8743		486.30	
PERRY FULK 6 36	LSD.06-36-06-27W1	452.90	958	962.60	9136		423.02	
FPI HAMOIL SINCLAIR PROV 12 32 6 28	LSD.12-32-06-28W1	490.70	1030.20	1039.40	10397		512.76	
CAL. STANDARD TILSTON PROVINCE 4 3	LSD.04-03-06-29W1	501.40	1161.90	1166.50	10618		418.92	
DOME NESBITT 11 19	LSD.11-19-07-18W1	445.60	546.20	551.70	4082		310.64	
GRT PLNS NESBITT 5 26 7 18	LSD.05-26-07-18W1	417.60	482.50	502.30	4578	4495	382.68	374.21
DOME NACO PLUM LAKE 16 34 7 24	LSD.16-34-07-24W1	434.60	737.60	745.80	7791	7501	484.21	454.60
CAL STAN LINKLATER 2 21 7 28	LSD.02-21-07-28W1	493.20	981.80	986.60	6722		192.87	
CALSTAN WAWANESA 3 1 8 18	LSD.03-01-08-18W1	415.70	458.70	478.50	3275		271.55	
DOME HAYFIELD 12 22 8 20	LSD.12-22-08-20W1	444.70	562.70	576.10	4144		291.67	
CALSTAN SOUTH RALSTON 5 34 8 23	LSD.05-34-08-23W1	435.90	672.10	681.20	5957		362.87	
CALSTAN EAST OAK LAKE PROV. 11 28	LSD.11-28-08-24W1	433.10	705.60	714.80	6881		420.80	
SCURRY GARVEY BELLEVIEW 2-3-8-26	LSD.02-03-08-26W1	438.90	855	870.50	8777	8246	464.47	410.26
AGNEW 13 27 8 26	LSD.13-27-08-26W1	434.60	810.80	841.20	7929	8687	402.89	480.28
GUYER LAURENCE EBOR PROV 3 4 8 28	LSD.03-04-08-28W1	501.10	964.40	974.40	9542	9101	500.87	455.85
GUYER LAURENCE SOUTH EBOR PROV 5 24	LSD.05-24-08-29W1	518.50	979.90	990.60	9625	9025	510.54	449.29
GRT PLNS SAM BERESFORD 2-15-9-20	LSD.02-15-09-20W1	424.30	509	524.30	4399	4344	349.11	343.49
MCCARTY COLEMAN OAK LAKE 13-6-9-24	LSD.13-06-09-24W1	436.20	730.60	737	6895		403.13	
MCCARTY COLEMAN PLAISIER 4-24	LSD.04-24-09-25W1	437.40	741	747.10	7584		464.57	
CALSTAN ROUTLEDGE PROV. 13-29-9-25	LSD.13-29-09-25W1	437.10	738.80	743.10	7412		450.71	
MCCARTY AND COLEMAN DEGALLEY 12 35	LSD.12-35-09-25W1	430.10	734	738.20	7171		424.01	
SOURIS VALLEY ET AL JEFFREY 1 22	LSD.01-22-09-26W1	440.70	764.40	773	7343		417.37	
CALSTAN WOODNORTH PROV. 5 18 9 27	LSD.05-18-09-27W1	487.10	846.40	854	8274		477.82	
CALSTAN DALY 1-30-9-28	LSD.01-30-09-28W1	515.40	903.70	914.40	8446		463.28	
CDN SUPERIOR WELCH 12 18 10 25	LSD.12-18-10-25W1	439.20	729.70	744.90	7239		433.35	
CALSTAN SOUTH VIRDEN 1-12-10-26	LSD.01-12-10-26W1	439.50	729.10	733	6619		382.25	
WILLIAMS 12-14-10-26	LSD.12-14-10-26W1	437.40	729.40	740.10	7584		471.57	
B A UNION GROSE SWD 7-27-10-26	LSD.07-27-10-26W1	442	730	740.70	7239		440.35	
BAY CANADIAN SUPERIOR HORN 4 12	LSD.04-12-10-27W1	464.20	786.40	797.10	7501		432.90	

APACHE DARLING DALY 15-18-10-27	LSD.15-18-10-27W1	495.30	795.50	823	8108		500.07	
DOME NACO SOUTH WEST HARGRAVE 15 31	LSD.15-31-10-27W1	494.40	836.70	842.80	5985		262.63	
CDN SUP DALY SWD NO 1	LSD.12-04-10-28W1	512.40	879	887.60	8274	8274	469.52	469.52
CALSTAN DALY 8-14-10-28	LSD.08-14-10-28W1	498.70	828.40	836.40	7826		461.28	
SAPPHIRE NORTH WEST BUTLER NO 1	LSD.04-16-10-29W1	533.10	929.90	941.80	7929		400.79	
CALSTAN VIRDEN 16 7 11 25	LSD.16-07-11-25W1	442	675.10	696.50	7426	7391	503.64	500.07
BUTTES ET AL VIRDEN EAST PROV 3-20	LSD.03-20-11-25W1	375.50	598.30	605.90	6702	6702	453.83	453.83
PARADIISE LENORE 15-23-11-25	LSD.15-23-11-25W1	459.90	657.10	672.10	6412		442.42	
CALSTAN SOUTH HARMSWORTH 6 25 11 26	LSD.06-25-11-26W1	452.90	681.20	687.30	5516		328.74	
CDN SUP DOME ET AL WHITEFORD 8 28	LSD.08-28-11-26W1	463.90	697.40	717.20	6743		435.11	
MCCARTY AND COLEMAN 3 24 FOSTER	LSD.03-24-11-27W1	477.90	759.60	770.80	7274		449.72	
CALSTAN ELKHORN 7A 8 11 29	LSD.07-08-11-29W1	543.50	888.20	896.70	6895		350.73	
QUEEN CITY CDN SUPERIOR NO 4 36	LSD.04-36-11-29W1	520.90	862.60	890.60	7722		418.66	
IMPERIAL BLOSSOM 3 17 12 24	LSD.03-17-12-24W1	472.70	611.10	620.30	3447		204.31	
DOME HARRIS COX HARMSWORTH 1-10	LSD.01-10-12-26W1	456.30	690.70	694.30	6550		430.71	
NORCEN POR HARMSWORTH PRV. 15-11-12-26	LSD.15-11-12-26W1	454.20	680	693	6665	6701	441.65	445.32
DOME NACO TWO CREEKS 1 19	LSD.01-19-12-26W1	471.20	693.70	704.70	5895		368.34	
DOME HARRIS COX TWO CREEKS 4 32	LSD.04-32-12-26W1	465.40	708.40	714.80	6557	6185	420.02	382.04
PARADISE MAXFIELD TWO CREEKS 10 33	LSD.10-33-12-26W1	457.20	661.10	671.80	6440	6150	442.88	413.27
CALSTAN KIRKELLA 13-4-12-29	LSD.13-04-12-29W1	532.80	863.60	874.80	7584		432.27	
SASKOIL W. KIRKELLA PROV. 6-18-12-29	LSD.06-18-12-29W1	539.40	871	879	8147	7917	492.15	468.67
CALSTAN KIRKELLA 5 21 122 29	LSD.05-21-12-29W1	527	842.80	850.40	6550		345.31	
SAPPHIRE WEST MINIOTA NO 1	LSD.04-20-13-27W1	477	648.60	657.80	3599		186.63	
LAURENCE ET AL REEDER PROV 6 14	LSD.06-14-13-28W1	487.10	691.60	705.60	6647	6288	460.11	423.46
PEACOCK EXPLORATION W BURNBANK 11 2	LSD.11-02-13-29W1	506.90	768.70	778.80	6550		396.81	
CHAMPLIN BIRDTAIL CREEK PROV 1-29	LSD.01-29-14-26W1	467	602.30	609.60	5295	5302	397.98	398.70
CALSTAN TREAT PROV 15 29 15 28	LSD.15-29-15-28W1	471.50	589.80	608.10	4137		285.76	
RIFE ET AL MCAULEY 5-8-15-29	LSD.05-08-15-29W1	526.20	715	727	6144	5482	426.46	358.87
PARADISE BIRDTAIL 3 3 16 27	LSD.03-03-16-27W1	480.40	556.30	564.80	4688		394.21	

CALSTAN BIRDTAIL 9 8 16 27	LSD.09-08-16-27W1	480.40	549.60	562.10	4806	4640	408.96	392.01
DOME BIRTLE 14 35 16 27	LSD.14-35-16-27W1	521.20	581.30	591.90	4461		384.74	
DYFONT 14 25 16 28	LSD.14-25-16-28W1	479.10	546.80	553.50	4482		383.18	
DOME BIRTLE 16 17	LSD.16-17-17-27W1	521.80	583.70	590.70	4413		381.64	

LODGEPOLE FORMATION (LDGP)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
GREEN HILLS KILLARNEY 13 36 1 18	LSD.13-36-01-18W1	559.90	783.30	798.60	5550		328	
AMERADA TURTLE MTN PROV MA 16 4	LSD.16-04-01-20W1	673.90	982.10	988.50	7826	7067	484	407
DOME CAL TURTLE MTN 9 6 1 20	LSD.09-06-01-20W1	685.50	1033.30	1038.10	7722		436	
CITIES SERVICE EAST MAX LAKE NO 1	LSD.14-29-01-20W1	680.60	984.20	987.60	6481		355	
ROYALITE TRIAD ET AL LULU LKE NO 1	LSD.16-14-01-21W1	699.80	1002.80	1008.30	5688		272	
GEOG CHAGOS LULU LAKE PROV. 16 23	LSD.16-23-01-21W1	712	1013.80	1032.10	8350	7901	532	487
ROYALITE TRIAD ET AL LULU LAKE 6 24	LSD.06-24-01-21W1	697.40	1010.10	1013.20	8101		511	
ANDEX LULU LAKE PROV. 15-25-1-21	LSD.15-25-01-21W1	685.50	992	996	7729	7729	479	479
ANDEX LULU LAKE PROV. 10-27-1-21	LSD.10-27-01-21W1	702.10	1009	1014	8020	7712	507	475
ANDEX LULU LAKE PROV. 2-28-1-21	LSD.02-28-01-21W1	690.10	1007	1014	8052	8058	498	499
ANDEX GORDON LAKE PROV. 14-29-1-21	LSD.14-29-01-21W1	687.30	1008	1015	8131	7973	502	486
WHITEWATER ET AL LULU LAKE PROV. 2-3	LSD.02-34-01-21W1	703.40	1013.50	1020	7752	7568	475	456
BAYSEL CALSTAN SHARPE LAKE 3 27	LSD.03-27-01-22W1	665.40	1005.80	1014.40	8274		496	
OMEGA WASKADA PROV. 7-30-1-25	LSD.07-30-01-25W1	471.50	916.80	930.90	15327	15065	1105	1079
ANGLO ET AL SOURIS VALLEY CR 16-18	LSD.16-18-01-26W1	435.60	1043	1051.30	10418		448	
CLEARY SOURIS VALLEY-WHITE NO 5-34	LSD.05-34-01-29W1	484.60	1158.20	1167.70	11204	11390	461	480
CHEVRON MAX LAKE 4-7-2-20	LSD.04-07-02-20W1	644.30	938.80	947.90	8143	7274	528	439
ROXY-CLARION ET AL MOUNTAINSIDE	LSD.13-16-02-21W1	599.80	894	905	7916	7916	503	503
ROXY-ANDEX MOUNTAINSIDE 1-20-2-21	LSD.01-20-02-21W1	591.10	890	894	7714	7424	485	455
CLARION ET AL HAZELDEAN 14-17-2-22	LSD.14-17-02-22W1	575.60	912	918	8267	8249	502	500
MIDWEST IMP. LIEGE 2-3-2-23	LSD.02-03-02-23W1	648.90	987.60	994.60	8267	8005	498	472
CHAUVNO ET AL DELORAINE 13-29-2-23	LSD.13-29-02-23W1	505	835	851	8033	8025	474	473
CALSTAN DELORAINE 10-31-2-23	LSD.10-31-02-23W1	501.70	832.10	838.20	8026	8026	483	483
ROXY-ANDEX ET AL DELORAINE 12-32-2-2	LSD.12-32-02-23W1	502.20	825	833	8092	8092	495	495
CALSTAN IMPERIAL SOUTH ELVA 13 30	LSD.13-30-02-27W1	456.90	1033.60	1067.10	11238		537	
BAYSEL CALSTAN BOISSEVAIN 3-20-3-19	LSD.03-20-03-19W1	514.80	766.90	774.20	6550		409	

ROXY ANDEX WHITEWATER 9-2-3-21W1	LSD.09-02-03-21W1	539.20	812	817	7558	7571	494	495
ROXY ANDEX WHITEWATER 9-3-3-21	LSD.09-03-03-21W1	534.80	811	816.50	7434	7434	477	477
ROXY ANDEX WHITEWATER 5-12-3-21	LSD.05-12-03-21W1	519.70	787	790.50	7235	6932	468	437
SAM GRT PLNS E. WHITEWATER PROV 9-14	LSD.09-14-03-21W1	506.30	780.30	792.80	7350	5723	464	298
MADISON WHITEWATER 4 16 3 21	LSD.04-16-03-21W1	508.40	779.40	784.30	7584		498	
CALSTAN WHITEWATER 12-16-3-21	LSD.12-16-03-21W1	507.20	765.40	768.70	3275	-	73	
CALSTAN WHITEWATER 10 17 3 21	LSD.10-17-03-21W1	502	768.10	776.60	6860		426	
CALSTAN WHITEWATER PROV. 2 20 3 21	LSD.02-20-03-21W1	499.30	769	776.60	6964		434	
NORTHERN WHITEWATER 4-21-3-21	LSD.04-21-03-21W1	501.70	759	765	4482		194	
CALSTAN-WHITEWATER 15-36	LSD.15-36-03-22W1	499.30	767.80	772.40	7295		472	
VALLAT DELORAINE 13-4-3-23	LSD.13-04-03-23W1	499.60	818.10	847.30	8288	8246	498	494
DACOTA CASSAN NO 5-23	LSD.05-23-03-24W1	485.20	840.90	856.50	8274		473	
BARON KIDD SAMBROOK 15 25 3 25	LSD.15-25-03-25W1	474.90	833	850.40	7619	7239	402	364
IMPERIAL PIERSON 13-2-3-29	LSD.13-02-03-29W1	476.10	1090.90	1100.90	10342		431	
IMP CON SUP PIERSON 8-26-3-29	LSD.08-26-03-29W1	477.60	1056.10	1066.80	10535		486	
WESTERN ORTHEZ 13 36	LSD.13-36-04-19W1	496.90	631.90	641.60	448		-99	
COPPERHEAD S REGENT 5 7 4 21	LSD.05-07-04-21W1	502.60	765	770.50	7584	7584	506	506
DOME HARRIS COX WHITEWATER LAKE 4 4	LSD.04-04-04-22W1	503.80	795.20	798.30	7653		487	
IMPERIAL REGENT 12 10 4 22	LSD.12-10-04-22W1	505.10	787.90	794.30	7722	7860	499	513
B AND F SOUTH REGENT PROV 15 14 4 22	LSD.15-14-04-22W1	506.30	772.70	779.40	7308		473	
BISON OREGAN SECURITY DAND 13 19	LSD.13-19-04-22W1	501.10	764.70	778.50	7958	7495	535	488
MURPHY HATHAWAY 15-20-4-22	LSD.15-20-04-22W1	502.60	768.10	781.80	7474	7433	484	480
IMPERIAL REGENT 15 21 4 22	LSD.15-21-04-22W1	505.70	777.20	783.30	7501		488	
SASKOIL GNOL REGENT 14-27-4-22	LSD.14-27-04-22W1	502.30	758	770	7080	7107	455	458
DOME NACO SOUTH REGENT 1 34 4 22	LSD.01-34-04-22W1	503.80	755.90	762	5985		353	
IMP DAND 1 13 4 23	LSD.01-13-04-23W1	503.20	791	807.70	7308		442	
CALSTAN IMPERIAL NAPINKA 2 7 4 25	LSD.02-07-04-25W1	452	856.50	883.90	9025		489	
HB NAPINKA 10-28-4-25	LSD.10-28-04-25W1	442.70	800	805	7855	7585	440	412
IMP WEST BRENDA 13 17 4 26	LSD.13-17-04-26W1	447.80	906.80	912.90	9032		457	

IMP CALIFORNIA STANDARD EUNOLA 4 28	LSD.04-28-04-29W1	492.60	1038.10	1050	10308	9377	495	400
CLARION ET AL ELGIN 4-19-5-21	LSD.04-19-05-21W1	483.90	683	695	6569	8176	460	624
U.S. SMELTING 3 30 DRAPER	LSD.03-30-05-21W1	476.40	671.80	680.30	5219		329	
CLARION ET AL REGENT 3-1-5-22	LSD.03-01-05-22W1	502.50	736.50	740	6049	6827	380	459
ROXY-CLARION ET AL W. REGENT 4-3	LSD.04-03-05-22W1	503.20	752	760	7134	6088	472	365
IMP UNDERHILL 4 8 5 22	LSD.04-08-05-22W1	497.10	756.50	759.60	7763	7763	530	530
IMP CANADIAN SUPERIOR ARGUE 15 13	LSD.15-13-05-23W1	484.30	742.20	748.30	7102		461	
IMP CANADIAN SUPERIOR ARGUE 5 33	LSD.05-33-05-23W1	443.50	723.90	729.10	7564	7377	487	468
FRANCANA ET AL HARTNEY 6-34-5-24	LSD.06-34-05-24W1	438.90	661.40	695.20	6922	6922	450	450
CALSTAN LAUDER 9 14 5 25	LSD.09-14-05-25W1	440.10	775.50	800.10	8074		464	
CALSTAN IMPERIAL RUTH 1 17 5 26	LSD.01-17-05-26W1	443.20	841.20	864.10	8281		425	
B.A. MCIVER BROOMHILL PROV 15 29	LSD.15-29-05-27W1	458.40	844.30	858	8729	8467	492	465
FRONTIER BROOMHILL PROV. 9 32 5 27	LSD.09-32-05-27W1	459.30	839.40	851.90	9604	9535	588	581
FRANCANA ET AL E. TILSTON 8-13-5-29	LSD.08-13-05-29W1	489	980	1000	9268	8781	435	385
PEACOCK MOFFAT 13 6 6 22	LSD.13-06-06-22W1	453.20	676	681.50	6378		423	
TEXACO SOURIS 13 8 6 22	LSD.13-08-06-22W1	449.90	645.90	650.70	6895		503	
CALSTAN HARTNEY 14 9 6 22	LSD.14-09-06-22W1	453.20	654.40	661.10	6743	5971	481	402
TEXACO B.A. SOURIS 13 15 6 22	LSD.13-15-06-22W1	452.30	637.30	641.90	6915	4282	516	248
TEXACO SOURIS 4 16 6 22	LSD.04-16-06-22W1	452.90	671.20	690.40	7129	7129	490	490
TEXACO SOURIS 8 17 6 22	LSD.08-17-06-22W1	450.20	650.10	652.90	6619	5957	473	405
MCCARTY COLEMAN FORBES 1 31 6 22	LSD.01-31-06-22W1	439.50	639.50	647.70	6883		495	
AMERADA CROWN. M.B. 15 27	LSD.15-27-06-25W1	437.10	778.80	789.40	8101		475	
HB S. PIPESTONE PROV. 4-25-6-26	LSD.04-25-06-26W1	436.20	725.10	730	7839	7501	507	472
KCL ET AL BROOMHILL 16 3 6 27	LSD.16-03-06-27W1	451.10	813.80	832.10	8439	8315	481	468
LARIO BROOMHILL 10-4-6-27	LSD.10-04-06-27W1	456	838.20	843.70	8501	7998	480	429
CALSTAN NORTH BROOMHILL 9 5 6 27	LSD.09-05-06-27W1	459	848.60	851.90	8567	7979	492	422
NEW SCOPE ET AL BROOMHILL 12-9-6-27	LSD.12-09-06-27W1	458.80	836.50	845	7864	7879	417	418
CALSTAN RESTON 7 27 6 27	LSD.07-27-06-27W1	452	808.90	815.30	7929		446	
PERRY FULK 6 36	LSD.06-36-06-27W1	452.90	784.30	795.20	7929		467	

SASKOIL JECCO S. LINKLATER PROV. 3-2	LSD.03-22-06-28W1	483.40	873	886	8388	8263	454	441
HAMOIL SINCLAIR PROV 15 36 6 29	LSD.15-36-06-29W1	501.40	878.70	883.90	8646	8618	500	497
CALSTAN DELEAU 14 31 7 23	LSD.14-31-07-23W1	432.50	625.40	642.80	6853	6660	489	470
CALSTAN PLUM LAKE PROV 10 32 7 24	LSD.10-32-07-24W1	434.60	667.50	677.60	7081	8136	480	588
DOME NACO PLUM LAKE 16 34 7 24	LSD.16-34-07-24W1	434.60	629.10	657.10	7067	6881	499	480
CAL STAN FINDLAY 9 26 7 25	LSD.09-26-07-25W1	433.10	681.80	689.50	7584		518	
MARIGOLD DELLEVIEW 6 36 7 26	LSD.06-36-07-26W1	438.90	734.90	744	7860		497	
NORTHERN RUSTIN 2 16 7 27	LSD.02-16-07-27W1	454.20	807.10	815.30	8446		501	
CAL STAN LINKLATER 7 20 7 28	LSD.07-20-07-28W1	493.50	834.20	837.30	8274		501	
CAL STAN LINKLATER 2 21 7 28	LSD.02-21-07-28W1	493.90	832.70	840.60	7929		463	
SASKOIL W. SINCLAIR 6-18-7-29WPM	LSD.06-18-07-29W1	534	936	945	8764	8764	484	484
HOMESTEAD ET AL W SINCLAIR 2 19	LSD.02-19-07-29W1	535.80	931.20	946.40	8860	8860	494	494
CORP. ETAL W. SINCLAIR PR. 10-20-7-29	LSD.10-20-07-29W1	520.90	906.50	909.50	7202	1636	347	-222
NORTHERN WEST SINCLAIR 2 28 7 29	LSD.02-28-07-29W1	525.50	901.90	911	9032		537	
SOCONY MOBIL JACKSON CK PROV 11 30	LSD.11-30-07-29W1	540.40	935.70	943.70	7508		363	
CALSTAN SOUTH RALSTON 5 34 8 23	LSD.05-34-08-23W1	435.90	623.30	630.90	3896		203	
CALSTAN EAST OAK LAKE PROV. 11 28	LSD.11-28-08-24W1	433.10	593.80	598	6343		483	
AMERADA CROWN M C 2 12	LSD.02-12-08-25W1	433.70	662.90	676.70	7260		498	
DOME HARRIS COX BELLEVIEW 16 1	LSD.16-01-08-26W1	436.50	733.30	736.40	7632		479	
SCURRY GARVEY BELLEVIEW 2-3-8-26	LSD.02-03-08-26W1	438.90	719.30	740.70	7639	7632	478	477
ROYALITE TRIAD ET AL SCARTH NO 1	LSD.14-19-08-26W1	451.40	731.20	734.30	5516		280	
CALSTAN NORTH EAST AGNEW PROV 10 25	LSD.10-25-08-26W1	435.60	684.90	697.10	7136		467	
WEST AGNEW 14 1	LSD.14-01-08-27W1	456.60	755.90	762	5364		242	
CLEARY WATT 3 16 8 27	LSD.03-16-08-27W1	474	811.70	832.20	7853	7715	444	429
CALSTAN WOODNORTH PROV 2 28 8 27	LSD.02-28-08-27W1	471.80	747.70	752.20	7550		490	
CALSTAN WOODNORTH PROV 4 28 8 27	LSD.04-28-08-27W1	474	754.40	758.30	7584		490	
B.A. UNION WOODNORTH 14 28 8 27	LSD.14-28-08-27W1	472.70	751.60	754.70	7757		510	
CALSTAN WOODNORTH PROV 9 29 8 27	LSD.09-29-08-27W1	475.80	756.20	759.30	7584		491	
LANDA DALY 15 31 8 27	LSD.15-31-08-27W1	483.10	762.90	773.30	7695	7695	495	495

CALSTAN WOODNORTH 2 33 8 27	LSD.02-33-08-27W1	470	758.60	760.20	7929		519	
PENNANT ET AL EWART 13 3 8 28	LSD.13-03-08-28W1	496.20	789.40	807.70	3778	965	74	-213
GUYER LAURENCE EBOR PROV 3 4 8 28	LSD.03-04-08-28W1	501.10	819.60	830.30	8060	8060	494	494
CALSTAN CROMER PROV 8 27 8 28	LSD.08-27-08-28W1	471.50	783.90	799.20	6033		288	
BECKWITH 5 29	LSD.05-29-08-28W1	508.70	786.70	809.50	7033		417	
CLEARY SCHELZ 6 36 8 28	LSD.06-36-08-28W1	475.80	765	770.20	8267		550	
SOCONY MOBIL N. JACKSON CREEK 1 6	LSD.01-06-08-29W1	532.50	917.10	918.70	8570		489	
GUYER LAURENCE SOUTH EBOR PROV 5 24	LSD.05-24-08-29W1	518.50	838.50	842.20	7046	6578	396	348
MCCARTY COLEMAN OAK LAKE 13-6-9-24	LSD.13-06-09-24W1	436.20	643.70	648.60	6688		470	
DOME COX ALGAR 1-13-9-24	LSD.01-13-09-24W1	432.50	668.40	682.80	6550		418	
DOME COX NORTH OAK LAKE 4-17-9-24	LSD.04-17-09-24W1	436.20	624.80	633.10	6619		479	
SAMEDAN WEST ROUTLEDGE 12 2 9 25	LSD.12-02-09-25W1	431.90	645.60	647.40	6619	6481	460	446
CALSTAN WEST ROUTLEDGE CPR 16 3 9 25	LSD.16-03-09-25W1	433.40	638.60	643.70	6909	6164	495	419
PARADISE PASCAR S ROUTLEDGE 16-4	LSD.16-04-09-25W1	434	646.20	649.20	5178		313	
PARADISE PASCAR S ROUTLEDGE 8 9 9 25	LSD.08-09-09-25W1	433.70	628.20	630.60	6516	6398	468	456
CALSTAN SOUTH ROUTLEDGE PROV 4-10	LSD.04-10-09-25W1	433.40	626.40	632.20	6578	5095	473	321
FARGO SAMEDAN S ROUTLEDGE PROV 7 11	LSD.07-11-09-25W1	435.90	633.40	640.10	6660	6433	476	453
MCCARTY AND COLEMAN MAON 12 15	LSD.12-15-09-25W1	435.90	634.90	638.60	6067		417	
CALSTAN SOUTH ROUTLEDGE PROV 8 16	LSD.08-16-09-25W1	435.30	639.50	648.90	6653		466	
HOFCO VANDERSCHAEGHE 13-17-9-25	LSD.13-17-09-25W1	437.40	641.60	645.30	6998		507	
CALSTAN ROUTLEDGE PROV. 16-18-9-25	LSD.16-18-09-25W1	436.20	646.50	649.20	6943	6902	496	492
CALSTAN WEST ROUTLEDGE PROV. 4-20	LSD.04-20-09-25W1	437.10	644.30	647.10	6964	7239	501	529
PARADISE ROUTLEDGE 11 21 9 25	LSD.11-21-09-25W1	434.60	629.40	637.60	6688		480	
HOFCO FILLION 6 22 9 25	LSD.06-22-09-25W1	438.30	631.20	643.10	6274		436	
CALSTAN ROUTLEDGE 15-28-9-25	LSD.15-28-09-25W1	437.70	629.40	632.50	6550		474	
CALSTAN ROUTLEDGE PROV. 13-29-9-25	LSD.13-29-09-25W1	437.10	638.90	640.70	6895		500	
CALSTAN SOUTH VIRDEN 6 31	LSD.06-31-09-25W1	444.10	645.30	661.70	6205		416	
IMPERIAL ROUTLEDGE 8-32M-9-25	LSD.08-32-09-25W1	438.90	626.40	637.90	6550		470	
MCCARTY AND COLEMAN ROUTLEDGE 6 33	LSD.06-33-09-25W1	436.20	625.80	630.90	6481		467	

MCCARTY AND COLEMAN DEBALLEY 12 35	LSD.12-35-09-25W1	430.10	629.70	639.20	6619		467	
BASCO SCARTH 5 17	LSD.05-17-09-26W1	449.60	710.80	722.40	7239	7136	466	456
B.A. HUDSONS BAY S MAPLES 2 26 9 26	LSD.02-26-09-26W1	441	648.60	657.80	6757		473	
MARIGOLD MAPLES 14 29	LSD.14-29-09-26W1	449.90	655.30	662.90	6412		442	
TRI-WEST SUMMIT S VIRDEN 10-33-9-26	LSD.10-33-09-26W1	439.50	634	643.70	6846	5985	495	407
MCCARTY AND COLEMAN LAING 9 35	LSD.09-35-09-26W1	438	644	647.10	6550		460	
CALSTAN SOUTH VIRDEN 1 36	LSD.01-36-09-26W1	440.10	643.70	646.20	6550		463	
GARVEY EAST DALY 4 5 9 27	LSD.04-05-09-27W1	478.20	763.80	775.40	8012	7860	521	505
LANDA DALY 6-6-9-27	LSD.06-06-09-27W1	483.70	768.10	774.20	7963	7481	522	473
PEACOCK WOODNORTH NO 1	LSD.13-11-09-27W1	465.70	720.90	734.60	7515		498	
CALSTAN WOODNORTH PROV. 5 18 9 27	LSD.05-18-09-27W1	487.10	724.50	736.70	5861		349	
W.H. MCKENZIE N. WOODNORTH 4-21-9-27	LSD.04-21-09-27W1	477.30	739.10	750.10	7370	6977	480	440
CANADIAN SUPERIOR KOOL 14-1-9-28	LSD.14-01-09-28W1	486.80	766	769.60	7722		506	
GARVEY SCURRY S CROMER PROV 5-4-9-28	LSD.05-04-09-28W1	490.40	783.30	793.70	7777	7777	491	491
SCURRY GARVEY CROMER 9-9-9-28	LSD.09-09-09-28W1	477.90	761.40	771.10	855	7612	-206	484
SCURRY GARVEY CROMER PROV 11-10-9-28	LSD.11-10-09-28W1	475.20	757.40	765	7639	7632	490	489
CALSTAN EAST CROMER PROV 16 11 9 28	LSD.16-11-09-28W1	491.90	762.60	776.60	7860		518	
CALSTAN EAST CROMER PROV 5 12 9 28	LSD.05-12-09-28W1	488.90	761.10	774.50	7791		510	
CALSTAN EAST CROMER PROV 12 14 9 28	LSD.12-14-09-28W1	496.80	784.60	786.10	7922		519	
SOURIS VALLEY RUTLEDGE GOULTER 14 15	LSD.14-15-09-28W1	502.30	784.30	785.80	7722		505	
SCURRY-GARVEY CROMER 1-16-9-28	LSD.01-16-09-28W1	492.60	763.50	787.90	8267	3599	549	72
SCURRY-GARVEY S EBOR 7-18-9-28	LSD.07-18-09-28W1	505.70	807.70	816.90	7750	7750	480	480
B.A. UNION GLINZ 15 21 9 28	LSD.15-21-09-28W1	510.50	776.60	781.80	4344		172	
CLEARY KING 4 23 9 28	LSD.04-23-09-28W1	498	756.50	763.20	5861		333	
CLEARY JOPCO 6 24 9 28	LSD.06-24-09-28W1	489.50	744	748.30	6709		426	
CALSTAN DALY PROV 5 29 9 28	LSD.05-29-09-28W1	516.90	794	797.10	7446		480	
CALSTAN DALY 1-30-9-28	LSD.01-30-09-28W1	515.40	795.50	800.10	7929		525	
PEACOCK EXPLORATION EBOR NO 1	LSD.03-02-09-29W1	527.60	838.50	841.90	8012		504	
DOME HUDSONS BAY WEST EBOR 1-8-9-29	LSD.01-08-09-29W1	529.10	842.20	847.60	7895		488	

DOME ET AL WEST EBOR 13-9-9-29	LSD.13-09-09-29W1	535.50	838.20	841.20	4999	4888	205	193
MADISON EBOR 11 12 9 29	LSD.11-12-09-29W1	519.40	822	827.50	8405		550	
GARVEY EBOR 1 13 9 29	LSD.01-13-09-29W1	519.70	799.80	823.90	8067	1262	519	-175
G.STONEHOUSE 4 16 9 29	LSD.04-16-09-29W1	538.90	813.50	832.40	7239		446	
CALSTAN EBOR 15 23 9 29	LSD.15-23-09-29W1	525.20	830.90	835.50	7929		499	
T.MCDOUGALL 4 26 9 29	LSD.04-26-09-29W1	532.50	823	826	6033		322	
CALSTAN WEST BUTLER 13 29 9 29	LSD.13-29-09-29W1	542.80	812.30	855	2654		-41	
CALSTAN WEST BUTLER 8-31-9-29	LSD.08-31-09-29W1	544.70	850.70	857.70	7860		489	
PARADISE EBOR 9-35-9-29	LSD.09-35-09-29W1	527.30	782.10	792.80	6860	2599	435	0
TEXAS CRUDE OIL COMPANY EBOR 2-36	LSD.02-36-09-29W1	524.30	775.40	780.90	6247	2765	381	26
CALSTAN SOUTH VIRDEN 7 7 10 25	LSD.07-07-10-25W1	438.30	628.80	634.90	6378		455	
HUDSONS BAY SOUTH VIRDEN 5-8	LSD.05-08-10-25W1	441	629.40	634.90	5557		373	
DOME HARRIS COX N ROUTLEDGE 3-13	LSD.03-13-10-25W1	370.30	543.80	549.20	5861		419	
CAN SUPERIOR WELCH 13-18-10-25	LSD.13-18-10-25W1	440.10	623	627.60	6136		439	
CANADIAN ET AL ROSELEA 9-19-10-25	LSD.09-19-10-25W1	430.40	605.30	612.60	4999		328	
M WELSH 13-20-10-25	LSD.13-20-10-25W1	374.60	545	552.90	5481		381	
CALSTAN EAST VIRDEN PROV. 5 28 10 25	LSD.05-28-10-25W1	423.10	590.10	596.20	6033		443	
ROSELEA 10-30-10-25	LSD.10-30-10-25W1	420.60	566	574.50	4482		304	
J P OWEN-BEKKER 13 32 10 25	LSD.13-32-10-25W1	371.90	532.80	536.10	4999		346	
TRANS EMPIRE-SIGNAL E VIRDEN 3-33	LSD.03-33-10-25W1	432.50	605	626.40	5585		376	
CAN PROSPECT S VIRDEN 7-1-10-26	LSD.07-01-10-26W1	439.50	633.40	641.90	6033		414	
MCCARTY & COLEMAN 16-2 NICOL	LSD.16-02-10-26W1	437.40	627.90	635.80	5929		407	
CALSTAN SOUTH VIRDEN 15 3 10 26	LSD.15-03-10-26W1	436.50	636.10	639.20	5929		403	
R CHAPMAN 13 4 10 26	LSD.13-04-10-26W1	444.70	636.70	647.10	6584		470	
IMPERIAL VIRDEN 8 8 10 26	LSD.08-08-10-26W1	446.80	652.90	654.40	6550		461	
IMPERIAL VIRDEN 5 9 10 26	LSD.05-09-10-26W1	444.40	653.80	662.90	7136		510	
FARGO BA UNION VIRDEN 15 10	LSD.15-10-10-26W1	439.50	637	639.50	6412		455	
CALSTAN S VIRDEN PROV 2-11	LSD.02-11-10-26W1	440.10	611.70	614.80	379		-136	
CALSTAN SOUTH VIRDEN 1-12-10-26	LSD.01-12-10-26W1	439.50	637.90	642.50	6826		494	

CNN PROSPECT VIRDEN 7-13-10-26	LSD.07-13-10-26W1	441	623.90	626.40	6205		448	
WILLIAMS 4 14 10 26	LSD.04-14-10-26W1	440.40	633.40	638.90	6067		421	
THINDERBIRD ET AL HUGHES 2-15-10-26	LSD.02-15-10-26W1	438	633.40	641	6550		466	
CALSTAN ROSELEA 16-21-10-26	LSD.16-21-10-26W1	444.40	630.30	636.40	6619		484	
PONDER B.A.-VIRDEN 12-22-10-26	LSD.12-22-10-26W1	440.70	641	643.10	6447		456	
CDN DEVONIAN HEPBURN 13-23	LSD.13-23-10-26W1	440.40	615.70	623.60	6033		433	
CDN PROSPECT GARLICK 2-24-10-26	LSD.02-24-10-26W1	441.70	632.50	637.60	5102		325	
CALSTAN VIRDEN 6 26 10 26	LSD.06-26-10-26W1	445.60	622.40	630	6584		488	
B A UNION GROSE 12-27-10-26	LSD.12-27-10-26W1	443.20	635.80	636.70	6722		493	
ROSSEN EUREKA 3-28-10-26	LSD.03-28-10-26W1	450.20	641.60	645.30	6550		474	
CALSTAN WEST VIRDEN PROV 13 29	LSD.13-29-10-26W1	457.80	648.60	651.70	310	6447	-162	464
CALSTAN VIRDEN 16 30 10 26	LSD.16-30-10-26W1	459	652.90	655.60	6378		455	
PEACOCK GARDINER NO 1	LSD.09-31-10-26W1	459.90	653.80	654.10	6378		457	
SCALLION 4 32	LSD.04-32-10-26W1	458.40	649.50	654.10	6205		438	
TALON ROSELEA 1 34 10 26	LSD.01-34-10-26W1	443.80	621.50	625.80	5516		381	
HAUK 1-35-10-26	LSD.01-35-10-26W1	447.80	630.90	643.70	6336		451	
CAN SUP ET AL MCDOUGALL 2 36 10 26	LSD.02-36-10-26W1	435.90	585.20	599.50	4757		322	
HALLIS VIRDEN 12 25 10 27	LSD.12-25-10-27W1	471.50	666.60	671.20	6722		487	
DOME NACO SOUTH WEST HARGRANE 15 31	LSD.15-31-10-27W1	494.40	720.20	728.50	6991		480	
CAL. STAN DALY 13 1 10 28	LSD.13-01-10-28W1	498	715.40	740.10	4826		251	
M AND H 16 5 10 28	LSD.16-05-10-28W1	515.10	770.50	780.30	4482	5171	192	263
APACHE BRALORNE DALY 4 7 10 28	LSD.04-07-10-28W1	523.30	773	797.40	7343	6026	476	341
CALSTAN DALY 1-9-10-28	LSD.01-09-10-28W1	511.10	754.70	773	6205		372	
CALSTAN DALY PROV 5 12 10 28	LSD.05-12-10-28W1	496.50	720.50	743.70	6378		404	
CALSTAN DALY 13-14-10-28	LSD.13-14-10-28W1	503.60	722.40	742.20	2758		43	
CENTOBA WEST DALY 14-19-10-28	LSD.14-19-10-28W1	520.60	746.20	770.50	5971		360	
GARVEY FERGUSON NORTH DALY 8-22	LSD.08-22-10-28W1	509.60	737	752.60	7157	5399	488	308
SOURIS VALLEY YOUNGE DALY 10-23	LSD.10-23-10-28W1	499.30	767.20	771.10	6067		348	
GARNEY DALY 6-25-10-28	LSD.06-25-10-28W1	484	728.50	739.10	6778	5674	437	324

MURPHY NORTH DALY 13-27-10-28	LSD.13-27-10-28W1	509.60	743.70	774.20	7315	6102	482	358
NEW SCORE ET AL COULTER A7-21-1-27	LSD.04-28-10-28W1	517.90	776.50	787.70	7668	7668	513	513
TUNDRA KILL. W. DALY PROV. 1-29-10-28	LSD.01-29-10-28W1	518.60	755	760	8367	7127	613	486
CALSTAN NORTH BUTLER PROV 8-11-10-29	LSD.08-11-10-29W1	523.60	799.50	814.70	7584	7584	483	483
KYWAN GNOL WEST DALY 10-14-10-29	LSD.10-14-10-29W1	525.70	789	796	3209	3071	57	43
SAPPHIRE NORTH WEST BUTLER NO 1	LSD.04-16-10-29W1	533.10	831.20	834.80	7860		501	
CALSTAN VIRDEN 4-5-11-25	LSD.04-05-11-25W1	437.40	590.40	596.50	4447	3861	295	235
CALSTAN VIRDEN 7-6-11-25	LSD.07-06-11-25W1	439.20	595.90	598.90	5309	5240	382	375
PARADISE VIRDEN 3-7-11-25	LSD.03-07-11-25W1	443.50	591	600.20	5068		361	
SHELL LENORE 14-15	LSD.14-15-11-25W1	449	597.40	604.10	5805	5006	438	356
CALSTAN SCALLION 14-2-11-26	LSD.14-02-11-26W1	452	618.40	624.50	5343		373	
CDN DEV STEPHENSON 5 5 11 26	LSD.05-05-11-26W1	464.80	660.50	666	5792	5792	390	390
DOME NASO EAST HARGRAVE 13-7-11-26	LSD.13-07-11-26W1	471.50	655.30	656.80	5929		420	
DOME HUMBER NORTH VIRDEN 15-8-11-26	LSD.15-08-11-26W1	462.70	645.90	652.30	5654		388	
CALSTAN SCALLION 1-10-11-26	LSD.01-10-11-26W1	456.90	622.70	627.30	5654		407	
CALSTAN SCALLION PROV. 4-11-11-26	LSD.04-11-11-26W1	454.80	609.60	620	5240		370	
CALSTAN SCALLION 7 13 11 26	LSD.07-13-11-26W1	449.60	591.30	604.70	931	2310	-60	81
W. MILNE 5 14 11 26	LSD.05-14-11-26W1	456.30	618.40	625.10	5654		408	
CALSTAN SCALLION 3 15 11 26	LSD.03-15-11-26W1	458.10	619.70	625.80	6771		524	
CALSTAN SCALLION 6 16 11 26	LSD.06-16-11-26W1	460.90	627	633.10	6378		479	
W CANADIAN-MILL CITY SCALLION 16-17	LSD.16-17-11-26W1	464.20	640.10	645	6033		435	
WEST CDN SCALLION 9 18 11 26	LSD.09-18-11-26W1	469.10	647.70	653.80	6274		456	
FARGO VALLAT BA UNION N.L TAPP 9 19	LSD.09-19-11-26W1	467.90	632.20	638.60	5654	4999	407	340
C NICKOL 10 20	LSD.10-20-11-26W1	463.90	650.70	656.80	5688		388	
G CLARKE 5 21 11 26	LSD.05-21-11-26W1	465.10	632.80	640.10	6033		441	
T.L. TAPP 10 22 11 26	LSD.10-22-11-26W1	458.40	614.20	620.90	6033		453	
E HUTCHISON 4 23	LSD.04-23-11-26W1	454.80	634.30	637.30	5929		423	
DOME CDN SUPERIOR 3 24 11 26	LSD.03-24-11-26W1	450.50	587.70	605.60	5481	6102	404	468
CALSTAN SOUTH HARMSWORTH 6 25 11 26	LSD.06-25-11-26W1	452.90	595.90	598.90	5792		445	

P.J. TAPP 5 26 11 26	LSD.05-26-11-26W1	456.90	622.10	624.50	5861		431	
W.C. TAPP 15 27 11 26	LSD.15-27-11-26W1	497.60	611.40	615.10	6033		460	
CALSTAN SCALLION PROV 1 29 11 26	LSD.01-29-11-26W1	464.20	636.40	654.70	4688		288	
CLEARFIELD IMPERIAL 11 30	LSD.11-30-11-26W1	471.50	650.70	654.40	5861		415	
HEAMAN 1 32	LSD.01-32-11-26W1	465.10	648	654.40	5447		367	
B.A. UNION MILNE 4 34 11 26	LSD.04-34-11-26W1	462.40	620.60	628.50	5516		397	
LAURENCE ET AL HARGRAVE PROV 4 2	LSD.04-02-11-27W1	487.10	695.90	704.40	6474	6343	444	430
RUNDLE ET AL HARGRAVE 12 9 11 27	LSD.12-09-11-27W1	497.40	705.60	712.30	6453	5798	444	377
CALSTAN HARGRAVE 15 12 11 27	LSD.15-12-11-27W1	475.80	663.20	666.30	6481		471	
DOME NACO HARGRAVE 2-13-11-27	LSD.02-13-11-27W1	476.10	662.60	664.50	6453		470	
BAYSEL CALSTAN HARGRAVE 13 15	LSD.13-15-11-27W1	492.90	651.10	679.40	2758		95	
BAYSEL CALSTAN HARGRAVE 15 16A 11 27	LSD.15-16-11-27W1	491	653.20	678.20	6205		446	
W CANADIAN MILL CITY HARGRAVE 6 18	LSD.06-18-11-27W1	498.70	723.60	737.30	6447		420	
MCCARTY AND COLEMAN 3 24 FOSTER	LSD.03-24-11-27W1	477.90	677	679.10	6653		478	
TRANS EMPIRE WEST SCALLION 1 25	LSD.01-25-11-27W1	474	666.30	670.90	5895	5516	405	366
SAPPHIRE REAPER NO 1	LSD.12-36-11-28W1	502.30	696.50	714.80	5516		351	
CALSTAN ELKHORN 7A 8 11 29	LSD.07-08-11-29W1	543.50	793.10	817.50	7584		500	
GARNEY S KIRKELLA PROV 10-22-11-29	LSD.10-22-11-29W1	527.90	763.80	776	7219	7219	489	489
GARNEY S KIRKELLA PROV 6-28-11-29	LSD.06-28-11-29W1	533.40	762.60	769.60	6971	6971	475	475
DOME HUMBER PROSPECT HARMSWORTH 5 3	LSD.05-03-12-26W1	463.60	609.30	612.60	5585		421	
CALSTAN NORTH SCALLION 13 4 12 26	LSD.13-04-12-26W1	466.30	602.30	612.60	5654		431	
CANADIAN PROSPECT SCALLION 1 5	LSD.01-05-12-26W1	466.60	623.30	627.60	5861		437	
BLACKPATCH KORMYLO SCALLION 2 8	LSD.02-08-12-26W1	466.60	614.20	618.40	4385		296	
DOME HARDIS COX HARMSWORTH 1-10	LSD.01-10-12-26W1	456.30	593.80	598	5550		425	
DOME HARRIS COX TWO CREEKS 4 32	LSD.04-32-12-26W1	465.40	584.90	592.50	5667		451	
CALSTAN TWO CREEKS 9 22 12 27	LSD.09-22-12-27W1	479.10	574.20	577	5357		449	
LAURENCE ET AL TWO CREEKS PROV 13 29	LSD.13-29-12-27W1	488.60	602.30	617.50	5647	5626	448	445
CDCOG ET AL KIRKELLA 9-28-12-28	LSD.09-28-12-28W1	503.80	624.20	627.90	5833	5833	471	471
RIDEAU E. KIRKELLA SWD 15-1-12-29	LSD.15-01-12-29W1	513.40	720	736.50	7400	7400	532	532

DILLMAN KIRKELLA 16-3-12-29	LSD.16-03-12-29W1	522.40	740.70	749.80	6998	6909	487	478
CALSTAN KIRKELLA 13-4-12-29	LSD.13-04-12-29W1	532.80	758	759.60	7446		533	
RIDEAU ET AL W. KIRKELLA 16-6-12-29	LSD.16-06-12-29W1	536.20	749	773	5809	2969	356	66
SASKOIL ET AL W. KIRKELLA 14-7-12-29	LSD.14-07-12-29W1	541.50	750	763	6959	6948	489	488
RIDEAU W. KIRKELLA 12-8-12-29	LSD.12-08-12-29W1	533.50	731	742.50	6978	6178	503	422
DILLMAN WEST KIRKELLA 11-9-12-29	LSD.11-09-12-29W1	526.70	740.10	746.20	7171		513	
DILLMAN KIRKELLA PROV. 11 10 12 29	LSD.11-10-12-29W1	522.70	728.80	734.60	6791	5240	481	323
DILLMAN KIRKELLA PROV 6 11 12 29	LSD.06-11-12-29W1	522.10	712.30	739.10	6853	5840	483	379
RIDEAU PIPESTONE E. KIRKELLA 6 11 12 29	LSD.06-12-12-29W1	509.30	719	729	6698	6661	464	460
WEST KIRKELLA 3 17 12 29	LSD.03-17-12-29W1	534.10	743	749	6849	6821	484	481
SASKOIL WEST KIRKELLA 13-18-12-29	LSD.13-18-12-29W1	539.90	731	741	7370	6595	551	472
RIDEAU W. KIRKELLA 2-19-12-29	LSD.02-19-12-29W1	538.50	745	753	6813	6468	481	446
CALSTAN KIRKELLA 5 21 12 29	LSD.05-21-12-29W1	527	711.70	722.40	3378		149	
ASM-BTO ET AL KIRKELLA PROV 16-29	LSD.16-29-12-29W1	524.60	763.80	771.10	7019	7033	470	472
SASKOIL W. KIRKELLA PROV. 6-30-12-29	LSD.06-30-12-29W1	535.80	722	733.50	6488	6111	465	426
MOBIL BIRDTAIL 6 33 13 27	LSD.06-33-13-27W1	470.30	534.60	540.10	4909		431	
LAURENCE ET AL REEDER PROV 6 14	LSD.06-14-13-28W1	487.10	579.70	598.30	5530	5530	453	453
CHAMPLIN BIRDTAIL CREEK 16-1-14-27	LSD.16-01-14-27W1	460.90	495.30	513.60	4440	4433	401	400
HOMESTEAD BIRDTAIL 10 8	LSD.10-08-15-27W1	467.90	487.40	501.70	4633		439	
GRT PLNS BIRDTAIL 10 28 15 27	LSD.10-28-15-27W1	464.20	463.30	474	3992	3992	398	398
CALSTAN TREAT PROV 15 29 15 28	LSD.15-29-15-28W1	471.50	492.90	497.70	3999		382	
RIFE ET AL MCAULEY	LSD.05-08-15-29W1	526.20	597	606	5406	5406	472	472
CALSTAN BIRDTAIL 9 8 16 27	LSD.09-08-16-27W1	480.40	487.70	499.90	4192	4089	408	398
DOME BIRTLE 14 35 16 27	LSD.14-35-16-27W1	521.20	531	538.60	4068		398	
DYPONT 14 25 16 28	LSD.14-25-16-28W1	479.10	469.40	476.10	3992		411	
ROCANVILLE LAZARE PROV 2 16 17 28	LSD.02-16-17-28W1	478.20	455.70	464.80	3868	3723	408	393

TILSTON BEDS (TLSN)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT.	SURF.
CLEARY FLOSSIE LAKE 10 21	LSD.10-21-01-23W1	655.60	1021.70	1028.70	7715		415	
ROXY-ANDEX ET AL S. GOODLANDS 4-5-1-24	LSD.04-05-01-24W1	484.10	911	914.50	8855	8842	474	472
OMEGA S. GOODLANDS PROV. 11-6-1-24	LSD.11-06-01-24W1	479	906	909	8811	8768	470	465
PLAZA SOUTH GOODLANDS 1 28 1 24	LSD.01-28-01-24W1	498.70	891.50	896.70	8867	8205	507	440
MIDWEST IOE WATERLOO 8 33 1 24	LSD.08-33-01-24W1	496.50	882.40	884.50	8784	8805	509	511
A & B RESOURCES ET AL GOODLANDS 10-3	LSD.10-33-01-24W1	494.70	877	894	8800	8863	499	506
GEOG CRANMER 13 1 1 25	LSD.13-01-01-25W1	470.60	911.40	918.10	9439	9060	516	477
WILDMOUNT ET AL WASKADA 14-3-1-25	LSD.14-03-01-25W1	472.10	920	929	8538	8354	415	396
ROXY-ANDEX ET AL S. WASKADA 15-5-1-25	LSD.15-05-01-25W1	470.80	935.50	945	8989	8603	444	404
CHEVRON WASKADA 10-7-1-25	LSD.10-07-01-25W1	469.10	950	955.40	10011	10011	536	536
NEW SCOPE SOUTH WASKADA 13-7-1-25	LSD.13-07-01-25W1	468.60	930	948	9725	9659	513	507
DEKALB IOE WASKADA 16 8 1 25	LSD.16-08-01-25W1	470.90	936	939.70	9777	9473	529	498
ROXY-ANDEX ET AL E. WASKADA 11-10-1-25	LSD.11-10-01-25W1	474.40	918	928	8972	8816	462	446
ROXY-CLARION ET AL CRANMER 1-13-1-25	LSD.01-13-01-25W1	477.60	901	906	9215	9239	512	515
ANGLO ET AL SOURIS V. MEGGISON 10 14	LSD.10-14-01-25W1	477.60	919.60	925.70	8963		467	
DEKALB ET AL WASKADA 16-15-1-25	LSD.16-15-01-25W1	474.60	905.30	916.80	8756	4102	452	-23
TRI-WEST ET AL WASKADA PROV 11-16	LSD.11-16-01-25W1	474	924.20	928.40	9356	9356	501	501
J.P. OWEN LEE NO.1	LSD.13-18-01-25W1	470.60	933	938.20	10204		574	
COPPERHEAD TRI-WEST WASKADA 14-19-1-25	LSD.14-19-01-25W1	472.70	924.50	934.80	5536	1682	103	-290
DEKALB ET AL WASKADA 2-22-1-25	LSD.02-22-01-25W1	474.90	911.40	922	9315	9108	504	483
DEKALB ET AL WASKADA 14-23-1-25	LSD.14-23-01-25W1	473.70	903.10	908.60	9273	8901	512	474
ROXY-ANDEX ET AL E. WASKADA 8-26-1-25	LSD.08-26-01-25W1	474.80	902	909	9018	9102	486	495
VOYAGER EASTLAND WASKADA 2-27-1-25	LSD.02-27-01-25W1	476.50	903	908	9055	9180	493	506
ROXY-CLARION ET AL WASKADA PROV.	LSD.04-28-01-25W1	475	920	929.50	8572	8615	421	425
IMP CALSTAN HERNEFIELD 1 30	LSD.01-30-01-25W1	472.40	918.70	925.10	9618	9549	529	522
OMEGA WASKADA 6 30 1 25	LSD.06-30-01-25W1	471.20	928.10	934.20	9797	9011	537	457

OMEGA WASKADA 4-31-1-25	LSD.04-31-01-25W1	471.20	926.60	938.80	9770	8798	530	431
DOME PROVO WASKADA PROV 1-10-1-26	LSD.01-10-01-26W1	463.30	962.30	965.60	9370	9349	454	452
OMEGA S. WASKADA A16-13-1-26	LSD.16-13-01-26W1	469.30	922	934	9364		491	
ANGLO ET AL SOURIS VALLEY CR 16-18	LSD.16-18-01-26W1	435.60	964.10	973.20	9563		439	
IOE ARTHUR 5-22-1-26	LSD.05-22-01-26W1	464.80	932.10	937	9370	8929	484	439
OMEGA WASKADA 15-23-1-26	LSD.15-23-01-26W1	467.50	923	929	8817	8582	439	415
I H C WASKADA B 25 1 26	LSD.08-25-01-26W1	471.80	932.70	943.40	7860		331	
HUDSON SOUTH DALNY 1 32 1 26	LSD.01-32-01-26W1	459.30	932.40	937	6619		198	
OMEGA DALNY 3-34-1-26WPM	LSD.03-34-01-26W1	464.50	930	942	10778	9225	623	464
OMEGA WASKADA	LSD.02-35-01-26W1	467.10	925.50	935	469	884	-420	-378
OMEGA WASKADA 2-36-1-26	LSD.02-36-01-26W1	470.90	934.50	943.90	434	152	-429	-457
TJB COULTER 4-1-1-27	LSD.04-01-01-27W1	455.80	995	1010	9729	9606	439	427
POPLAR GAS EX ADMIRAL ANTLER NO 1	LSD.08-15-01-29W1	468.80	1111.90	1115.60	10604		436	
ROXY-CLARION ET AL LIEGE 13-3-2-23	LSD.13-03-02-23W1	611.60	953	957	7318	6670	402	336
CLARION ET AL DELORAINE 8-31-2-23	LSD.08-31-02-23W1	502.40	827	842	6492	8144	323	492
DOME DELORAINE	LSD.11-32-02-23W1	504.40	830	837	8052	8010	489	485
OMEGA WASKADA 13-8-2-25	LSD.13-08-02-25W1	475.20	897.50	902.50	8928	8860	484	477
OMEGA WASKADA 11-9-2-25	LSD.11-09-02-25W1	478.10	897	905	9043	9067	496	499
VOYAGER ET AL CRANMER 10-12-2-25	LSD.10-12-02-25W1	481	881	886.50	8761	8943	489	508
ROXY-ANDEX ET AL N. CRANMER 4-13-2-25	LSD.04-13-02-25W1	479.60	880	884	8911	8893	505	504
MURPHY ET AL N. WASKADA 8-32-2-25	LSD.08-32-02-25W1	478.40	880	890	8943	8925	501	500
OMEGA WASKADA	LSD.03-03-02-26W1	465.60	927.50	932.50	8514	8140	402	364
GNDL MMR DALNY 6-4-2-26	LSD.06-04-02-26W1	463.30	942.40	947.60	9529	8839	489	418
ROXY ET AL DALNY 1-9-2-26	LSD.01-09-02-26W1	462.40	923.50	940	9467	8962	489	437
CALSTAN IMPERIAL DALNY 8-10-2-26	LSD.08-10-02-26W1	467.30	964.40	969.60	12307	9756	754	494
GRIZZLY ET AL WASKADA 15.14 2 26	LSD.15-14-02-26W1	467.90	938.80	944	9563	9411	500	485
MIDWEST IMP. DALNY 6-16-2-26	LSD.06-16-02-26W1	463	960.10	973.80	9956	9928	506	503
ROXY ET AL N. WASKADA 2-35-2-26	LSD.02-35-02-26W1	469.10	885	892	8883	8962	484	492
CALSTAN IMPERIAL SOUTH ELVA 13 30	LSD.13-30-02-27W1	456.90	970.20	980.50	9735	9067	470	402

ANGLO ET AL SOURIS VALLEY SHANNON	LSD.01-22-02-28W1	459	1021.10	1032.10	10583	10528	507	502
CALSTAN IMPERIAL N GOODLANDS 16-9	LSD.16-09-03-24W1	473.70	843.70	847.30	8370	8274	481	471
CLEARY-MCCALLUM 4-32	LSD.04-32-03-26W1	443.50	860.80	870.20	7860		376	
SKELTON 4-14	LSD.14-04-03-27W1	452.90	935.40	950.70	8618		382	
SASKO ET AL S. MELITA 12-12-3-27	LSD.12-12-03-27W1	457.20	918	923	9158	9324	469	486
CLEARY SOURIS VALLEY INNES 4-17	LSD.04-17-03-27W1	465.10	944.60	952.20	10108		545	
IMPERIAL PIERSON NO 6-7	LSD.06-07-03-28W1	472.40	1011.90	1015	9997		478	
RIO PRADO SOURIS GIBSON 2-14-3-28	LSD.02-14-03-28W1	466	968.30	972	9997		515	
TACOMA N PIERSON 14-16-3-28	LSD.14-16-03-28W1	470.90	972.90	982.70	9246	6971	432	200
KR ET AL N PIERSON 3-20-3-28	LSD.03-20-03-28W1	473.40	977.80	986.90	9349		441	
TACOMA N PIERSON 2-21-3-28	LSD.02-21-03-28W1	469.10	968.70	976.90	9825	9273	495	439
QUEST PIERSON A4-22-3-28	LSD.04-22-03-28W1	469.20	966	979.50	6042	5855	107	87
QUEST ELVA 4-25-3-28	LSD.04-25-03-28W1	464.60	946	952	9398	9313	472	463
ROBLIN 2-27-3-28	LSD.02-27-03-28W1	467.30	966.50	971.40	8791		393	
TEXACO-MCCALL-GRAHAM CREEK A-4-29	LSD.04-29-03-28W1	473.70	982.70	988.20	9653		471	
IMPERIAL PIERSON 13-2-3-29	LSD.13-02-03-29W1	476.10	1067.40	1072.60	9997		424	
ANGLO ET AL SOURIS VALLEY-WICKS 1-8	LSD.01-08-03-29W1	484	1061.60	1065.30	10845		526	
TACOMA N PIERSON 2 24 3 29	LSD.02-24-03-29W1	474	986	995.80	9887	9363	488	434
IMP CDN SUP PIERSON 8-26-3-29	LSD.08-26-03-29W1	477.60	991.50	997.60	9653		466	
CEGO CANADIAN PROSPECT CAYUGA 13-31	LSD.13-31-03-29W1	498.30	1015.60	1029.30	9273		416	
CALSTAN IMPERIAL NAPINKA 2 7 4 25	LSD.02-07-04-25W1	452	831.80	834.50	8481	8343	483	469
IMP WEST BRENDA 13 17 4 26	LSD.13-17-04-26W1	447.80	860.50	876.30	8791	8550	469	444
B.A. MOORE BEDE 5-33-4-26	LSD.05-33-04-26W1	445.30	837.90	854.40	8880	8494	497	458
B.A. MCLEAN PROV. 2 11 4 28	LSD.02-11-04-28W1	472.40	934.50	940.60	8805	6750	431	221
IMP CALIFORNIA STANDARD EUNOLA 4 28	LSD.04-28-04-29W1	492.60	981.50	987.60	9653	8963	491	420
CALSTAN IMPERIAL RUTH 1 17 5 26	LSD.01-17-05-26W1	443.20	820.50	827.50	8777	7763	512	408
B.A. TWEED BEDE 13 13 5 27	LSD.13-13-05-27W1	448.10	833.60	849.50	8487	7543	465	369
B.A. GERVIN BROOMHILL 1 20 5 27	LSD.01-20-05-27W1	453.20	861.40	877.20	9046	8446	500	438
SASKOIL BROOM HILL 8-33-5-27	LSD.08-33-05-27W1	454.50	837	843.50	8545	8275	483	456

TILSTON A NO 1	LSD.05-12-05-29W1	483.10	933	942.10	8356		394	
CLEARY ROWBOTTOM ET AL 3 19 5 29	LSD.03-19-05-29W1	508.10	961.90	966.50	9653	9756	527	538
TUNDRA ET AL TILSTON PROV. 3-30-5-29	LSD.03-30-05-29W1	512.90	950	954.50	9417	9401	520	518
NORTHERN TILSTON NO 9 31	LSD.09-31-05-29W1	512.40	944.90	947.90	9136		497	
SASKOIL JECCO S. LINKLATER 3-13-6-28	LSD.03-13-06-28W1	473.90	854	862.50	8427	8427	472	472
KISSINGER ET AL RESTON 7 35 6 28	LSD.07-35-06-28W1	479.50	862.30	866.20	8701	6709	502	298
CAL. STANDARD TILSTON PROVINCE 4 3	LSD.04-03-06-29W1	501.40	943.10	949.10	8618		432	
MANNING KRANZ TILSTON 4 5 6 29	LSD.04-05-06-29W1	506.30	939.10	953.10	9205		493	
MANDAK POPE TILSTON 1 6	LSD.01-06-06-29W1	510.50	935.10	935.40	8791		473	
NEW SCOPE ET AL TILSTON 5-9-6-29	LSD.05-09-06-29W1	511.40	932	940	8737	8416	463	431
CHEVRON RESTON 5-33-7-27	LSD.05-33-07-27W1	451.80	775	778	6559	6006	343	287

ALIDA BEDS (ALID)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT.	SURF.
VOYAGER BLACKROCK S. CRANMER 8-1-1-25	LSD.08-01-01-25W1	474.60	908	916	8103	7657	386	340
ROXY-ANDEX ET AL S. WASKADA 15-5-1-25	LSD.15-05-01-25W1	470.80	929	935.50	9374	9353	492	388
CHEVRON S. WASKADA 10-1-1-26	LSD.10-01-01-26W1	468.80	938	944	8262	8530	368	396
NORTH AMERICAN ARTHUR 2-20 1 26	LSD.02-20-01-26W1	454.80	919.90	937.30	10859	10135	626	552
AMERAN WASKADA DIR 8-32-1-26	LSD.08-32-01-26W1	461	950	956	9022	8864	426	410
RIO PRADO SOURIS DOWNEY 12-9-1-27	LSD.12-09-01-27W1	459.90	987.60	990.60	10170		508	
GRT NO. CARBON & CHEM CO WESTOVER 1	LSD.08-21-01-27W1	455.70	972.30	975.40	8963		395	
VOYAGER BLACKROCK COULTER PR. 5-22	LSD.05-22-01-27W1	454	975	979	9712	9884	467	484
KODIAK DUNNING NO 1	LSD.16-28-01-27W1	456.60	969.30	976.60	9308		430	
CLEARY SOURIS VALLEY-MOORE 11-13	LSD.11-13-01-28W1	451.40	994.60	1011.90	10404		502	
RIO PRADO SOURIS FENTON 5-17-1-28	LSD.05-17-01-28W1	463	1040.30	1043.90	3241		-250	
RIDEAU PIPESTONE LYLETON 9-27-1-28	LSD.09-27-01-28W1	459.40	997	1003	10145	9918	492	469
CALSTAN LYLETON 3 33 1 28	LSD.03-33-01-28W1	464.50	1008.90	1019.90	10666	10666	534	534
POPLAR GAS EX ADMIRAL ANTLER NO 1	LSD.08-15-01-29W1	468.80	1060.70	1065.30	10804		507	
IMPERIAL COPLEY 11-18	LSD.11-18-01-29W1	479.80	1111.30	1119.50	10721		455	
OMEGA WASKADA 6-3-2-26W1	LSD.06-03-02-26W1	468.20	928	934	8207	8164	372	368
CHEVRON COULTER PROV.	LSD.09-06-02-26W1	439.90	916	930	9908	9166	521	446
CALSTAN IMPERIAL DALNY 8-10-2-26	LSD.08-10-02-26W1	467.30	942.40	946.10	9997	9756	542	517
ROXY-ANDEX ET AL WASKADA 4-13-2-26	LSD.04-13-02-26W1	468.50	909	923	8733	7683	437	330
CHANDLER COULTER 8-5-2-27	LSD.08-05-02-27W1	454.20	958.30	965.60	9942	9011	504	409
GNOL HMR LYLETON 10-6-2-27	LSD.10-06-02-27W1	458.70	972.30	979	9970	9522	498	452
ANGLO ET AL SOURIS VALLEY SHARP 2 18	LSD.02-18-02-27W1	457.80	970.80	978.40	8322		329	
MIDWEST IMP. COULTER 1 19 2 27	LSD.01-19-02-27W1	442.30	940.60	958.90	9908	9460	495	449
CHEVRON ET AL DALNY 15-24-2-27	LSD.15-24-02-27W1	453.30	926	932	9248	9321	465	473
BANF ET AL LYLETON 15 5 2 28	LSD.15-05-02-28W1	463.60	1013.80	1018	10639	10363	532	504
RIO PRADO SOURIS HILL 16 9 2 28	LSD.16-09-02-28W1	461.50	994.60	999.10	10046		488	

KISSINGER ET AL PIERSON 14 20	LSD.14-20-02-28W1	465.10	990.60	997.30	10225	8370	512	322
ANGLO ET AL SOURIS VALLEY SHANNON	LSD.01-22-02-28W1	459	975.40	979.70	9384		437	
CHANDLER E PIERSON 15 27 2 28	LSD.15-27-02-28W1	461.80	978.40	984.50	9784	9687	476	466
GNOL ET AL E PIERSON 10-28-2-28	LSD.10-28-02-28W1	465.40	977.20	987.60	9439	9080	441	405
DOME PROVO CALSTAN ELVA PROV 16-29	LSD.16-29-02-28W1	467.60	985.40	992.10	9901	9680	486	464
COBRA ET AL W. PIERSON 2-30-2-28	LSD.02-30-02-28W1	467.40	995	1000	9864	9449	474	432
PLAZA NORTH ANTLER 4-34-2-28	LSD.04-34-02-28W1	464.20	972.30	982.70	9970	8612	499	361
MURPHY S. PIERSON #11-8	LSD.11-08-02-29W1	480.60	1043	1053	10487	4872	498	-75
MURPHY ET AL S. PIERSON PR. 16-11-2-29	LSD.16-11-02-29W1	469	1020	1027	10373	10270	501	490
COBRA ET AL S. PIERSON 9-24-2-29	LSD.09-24-02-29W1	465.90	1000	1004	9169	9801	398	463
COBRA ET AL S. PIERSON 12-26-2-29	LSD.12-26-02-29W1	471	1005	1013	8339	9476	309	425
CALSTAN PIERSON PROV 2-29-2-29	LSD.02-29-02-29W1	481	1036	1039.70	10273		490	
HANDLER E. PIERSON 15 32 2 29	LSD.15-32-02-29W1	481.90	1021.10	1030.20	10087	9825	482	455
COLGAS ET AL PIERSON 14-6-3-28	LSD.14-06-03-28W1	471.80	992.50	996	8310	8091	324	302
KR ET AL PIERSON 15-7-3-28	LSD.15-07-03-28W1	470	979.60	993	9797	9570	477	454
TACOMA E PIERSON 12-10-3-28	LSD.12-10-03-28W1	468.50	970.50	979.60	9777	8625	487	369
IMPERIAL EDWARD 4-16-3-28	LSD.04-16-03-28W1	470.60	977.20	981.50	10425	10108	553	521
KR ET AL PIERSON 13-17-3-28	LSD.13-17-03-28W1	473	979.90	990.60	10004	9570	504	459
KR ET AL PIERSON 9-18-3-28	LSD.09-18-03-28W1	470.60	980.80	988.80	9880	9680	490	470
TACOMA N PIERSON 2-19-3-28	LSD.02-19-03-28W1	472.40	980.20	987.90	9556	9149	460	419
OAKLAND ET AL PIERSON 5-20-3-28	LSD.05-20-03-28W1	474.90	979.20	984.80	7489	7516	255	257
TACOMA N PIERSON 4-21-3-28	LSD.04-21-03-28W1	470.60	969.30	981.50	9115	7150	420	219
KR CANSO EAST PIERSON 2-22-3-28	LSD.02-22-03-28W1	471.20	965.60	969.90	9701	4826	492	-6
TEXACO-MCCALL-GRAHAM CREEK A-4-29	LSD.04-29-03-28W1	473.70	969.30	975.40	3447		-150	
TUNDRA PIERSON 12-1-3-29	LSD.12-01-03-29W1	473.40	998	1003.50	7921	7173	279	202
IMPERIAL PIERSON 13-2-3-29	LSD.13-02-03-29W1	476.10	1004.90	1007.70	9653		454	
CHANDLER W PIERSON 6-3-3-29	LSD.06-03-03-29W1	479.80	1013.50	1021.40	9956	9777	475	457
CHANDLER W. PIERSON 2 4 3 29	LSD.02-04-03-29W1	482.20	1026.60	1031.40	10342	9791	507	450
CHANDLER W PIERSON 13-8-3-29	LSD.13-08-03-29W1	488.90	1017.70	1024.40	10170	7708	503	251

SWEET GRASS PIERSON PROV 9 10 3 29	LSD.09-10-03-29W1	477.90	1004.90	1011.30	7584		241	
NORTHERN DEVELOPMENT PIERSON 2 11	LSD.02-11-03-29W1	476.10	1001.90	1003.70	10170		511	
IMPERIAL PIERSON 12 12 3 29	LSD.12-12-03-29W1	473.40	1001.30	1007.40	9308		416	
TACOMA N PIERSON 12 13 3 29	LSD.12-13-03-29W1	474	989.10	1004.90	9991	9453	489	434
DOME PIERSON PROV. 7-14-3-29	LSD.07-14-03-29W1	475.40	997.50	1001	10023	9990	498	493
RIDEAU PIERSON PROV. 11-16-3-29	LSD.11-16-03-29W1	482.80	1002	1010	9506	9214	443	413
CDR IMP N PIERSON 8-21-3-29	LSD.08-21-03-29W1	482.20	1002.80	1006.40	9997	6640	496	154
TACOMA N PIERSON 8-24-3-29	LSD.08-24-03-29W1	475.50	985.40	995.20	8701	8136	369	311

JURASSIC FORMATIONS (JRSC)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
OMEGA CHEVRON WASKADA 11-34-1-26	LSD.11-34-01-26W1	467	831	839	7530	7543	396.76	398.09
OMEGA ET AL WASKADA 14-4-2-26W1	LSD.14-04-02-26W1	464.90	841	849	8183	8261	451.33	459.29
CLEE MELITA PROV. 2-30-2-26	LSD.02-30-02-26W1	438	790.30	800.70	8205	8212	474.97	475.69
CALSTAN RESTON 7 27 6 27	LSD.07-27-06-27W1	452	669	673.60	2827		67.02	
DOME NESBITT 11 19	LSD.11-19-07-18W1	445.60	395.90	399.30	3385		391.89	
DOME HAYFIELD 12 22 8 20	LSD.12-22-08-20W1	444.70	481.60	484.60	4130		381.74	
CALSTAN EAST OAK LAKE PROV. 11 28	LSD.11-28-08-24W1	433.10	525.50	546.80	5240		421.27	
ROYALITE TRIAD ET AL SCARTH NO 1	LSD.14-19-08-26W1	451.40	527.90	531.60	5102		440.68	
DOME BRANDON 3 5 9 19	LSD.03-05-09-19W1	418.50	342.90	354.20	3103		381.09	
CHEVRON DALY 14-13-9-28	LSD.14-13-09-28W1	488.60	715.20	729.50	4083	1989	175.95	-37.84
GARNET EBOR 1 13 9 29	LSD.01-13-09-29W1	519.70	694.30	699.80	6116	6109	444.30	443.59
CALSTAN DALY PROV 13 11 10 28	LSD.13-11-10-28W1	504.70	670.60	675.10	1379	5516	-29.61	392.74
POLARIS TECK COLONIAL DALY 9A-5	LSD.09-05-11-28W1	518.20	680.30	687	9391	6819	687.86	527.37
CALSTAN ELKHORN 7A 8 11 29	LSD.07-08-11-29W1	543.50	686.70	691.60	7757		643.83	
IMPERIAL BLOSSOM 3 17 12 24	LSD.03-17-12-24W1	472.70	472.40	483.10	4309		429.52	
IMPERIAL NORMAN 4 27 13 23	LSD.04-27-13-23W1	513.90	499.90	509	3585		370.90	
DOME ARROW RIVER 12 10 14 25	LSD.12-10-14-25W1	500.80	445	452.60	2434		295.69	
GORDON MANSON 9 5 14 29	LSD.09-05-14-29W1	507.80	539.50	541.30	4592	4171	435.31	392.33
WEST CAN MANSEN 8 7 14 29	LSD.08-07-14-29W1	507.80	538	550.20	4075		373.63	
JASPER H B MANSON 8-8-14-29	LSD.08-08-14-29W1	509	535.80	539.80	4461	4454	424.64	423.92
COCOG ET AL MANSON 9-9-14-29	LSD.09-09-14-29W1	505.70	521.20	530.40	4992	4220	484.95	406.13
GARNET MANSON PROV. 5 11 14 29	LSD.05-11-14-29W1	503.20	566.90	579.10	4923	4944	426.70	428.85
PR POTASH ET AL MCAULEY 4 32 15 28	LSD.04-32-15-28W1	474.30	442	460.20	3723		394.19	
TROY ST. LAZARE 13-17-16-29	LSD.13-17-16-29W1	476.60	450	455	3818	3818	411.39	411.39

MANNVILLE GROUP (MNVL)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED*		SHUT-IN PRES.		POTENT. SURF.	
CITIES SERVICE EAST MAX LAKE NO 1	LSD.14-29-01-20W1	680.60	732.70	740.70	4240		373	
DEKALB ET AL WASKADA 4-35-1-25	LSD.04-35-01-25W1	477	668.70	673.60	6343	5861	451	402
CALSTAN WASKADA 9-13-1-26	LSD.09-13-01-26W1	468.80	659.90	662.90	6550		475	
KODIAK DUNNING NO 1	LSD.16-28-01-27W1	456.60	646.80	652.90	6688		485	
CALSTAN PIERSON PROV. 2-29-2-29	LSD.02-29-02-29W1	481	686.70	694.30	5757		477	
CALSTAN WHITEWATER 12-16-3-21	LSD.12-16-03-21W1	507.20	519.10	543.20	5171		492	
DAKOTA CASSAN NO 5-23	LSD.05-23-03-24W1	485.20	560.80	570	5516		478	
CALSTAN PIERSON PROV 10 11	LSD.10-11-03-29W1	475.20	709.30	719.90	7405		511	
FRANCANA ET AL HARTNEY 9-30-5-24	LSD.09-30-05-24W1	437	487	495	5144	5198	457	473
CALSTAN RESTON 7 27 6 27	LSD.07-27-06-27W1	452	499.60	515.40	5171		465	
CAL STAN LINKLATER 2 21 7 28	LSD.02-21-07-28W1	493.20	562.70	569.70	5309		456	
IMPERIAL BLOSSOM 3 17 12 24	LSD.03-17-12-24W1	472.70	381	388.60	2413		530	
CALSTAN KIRKELLA 5 21 12 29	LSD.05-21-12-29W1	527	514.80	525.50	3378		346	
IMPERIAL NORMAN 4 27 13 23	LSD.04-27-13-23W1	513.90	401.70	405.40	1724		285	
CALSTAN TREAT PROV 15 29 15 28	LSD.15-29-15-28W1	471.50	391.10	422.80	3585		415	
PR POTASH ET AL MCAULEY 4 32 15 28	LSD.04-32-15-28W1	474.30	380.10	398.40	3103		393	
DOME STRATHCLAIR 8 34 16 21	LSD.08-34-16-21W1	606.90	399.30	414.50	1586		354	

ASHERN FORMATION (ASRN)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES		POTENT. SURF.	
CAL STAN FINDLAY 9 26 7 25	LSD.09-26-07-25W1	433.10	1172.60	1191.50	11032		368	

PRAIRIE EVAPORITE (PRVR)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
CHEVRON W. OAK LAKE 1-18-8-25	LSD.01-18-08-25W1	435.50	1148	1160	12037	12067	504	507

FIRST RED BEDS (FRRD)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
DALY GAS 7-18-10-27	LSD.07-18-10-27W1	496.20	1080.50	1104.90	10577	10604	471	474
CDN SUP DALY SWD NO 1	LSD.12-04-10-28W1	512.40	1135.10	1146	10687	10687	457	457

JOLI FOU SHALE (JLFU)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
CND SUPERIOR DOME ET AL TAPP 7 22	LSD.07-22-11-26W1	458.10	361.20	371.90	3103		403	
CALSTAN SUPERIOR HARMSWORTH 6 25 11 26	LSD.06-25-11-26W1	452.90	351.40	356	2620	3034	364	407

VIKING FORMATION (VKNG)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
CANADIAN SUPERIOR ROUNTHWAITE 10 17	LSD.10-17-08-17W1	389.50	238.40	247.50	2482		395	
SCURRY-WECO-FREEHOLD C.H. SW-27	LSD.04-27-10-21W1	440.20	309.10	315.20	2772	2772	408	403
SCURRY-WECO-FREEHOLD C.H. SW-13	LSD.04-13-11-22W1	371.30	231	237.10	2648	2641	405	404
ARCO HARDING STH NO 1 4-8-12-23	LSD.04-08-12-23W1	452	338.30	341.10	2627	2627	379	379
IMPERIAL BLOSSOM 3 17 12 24	LSD.03-17-12-24W1	472.70	349	352	2344		360	
DOME HARRIS COX HARMSWORTH 1-10	LSD.01-10-12-26W1	456.30	336.80	341.40	2758		396	

BASE OF FISH SCALE MARKER (BFS)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.
FEL-TEX C.H. NO 5A SW-5-9-16	LSD.04-05-09-16W1	364.50	203	209.40	2420		402
MCCARTY AND COLEMAN ROUTLEDGE 6 33	LSD.06-33-09-25W1	436.20	361.20	378	3172		382
DOME HARRIS COX WEST LENMORE 2 32A	LSD.02-32-11-25W1	447.80	344.70	348.70	1724		275
IMPERIAL NORMAN 4 27 13 23	LSD.04-27-13-23W1	513.90	369.40	374.60	2206		365

LOWER COLORADO (LCLD)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
FEL-TEX C.H. NO 5A SW-5-9-16	LSD.04-05-09-16W1	364.50	182	188.40	1351		314	
SCURRY-WECO-FREEHOLD CH NE-26-9-20	LSD.16-26-09-20W1	416	251.50	257.60	2075	2075	370	370

SECOND WHITE-SPECKLED SHALE (SSPK)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		POTENT. SURF.	
OMEGA WASKADA 16-36-1-26	LSD.16-36-01-26W1	471.40	485	495	1458	922	125	71
NSM-BIO ET AL KIRKELLA PROV 16-29	LSD.16-29-12-29W1	524.60	353.60	378	800	572	228	205

APPENDIX II

PRESSURE HEAD VALUES, COMPUTED AS METRES OF FRESH WATER FROM SHUT-IN BOTTOM HOLE PRESSURES (kPa).

LYLETON-BAKKEN SHALE INTERVAL (BKKN)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		PRESSURE HEAD	
CALSTAN WASKADA 9-13-1-26	LSD.09-13-01-26W1	468.80	1151.20	1158.80	3103		317	
CALSTAN PIERSON PROV 2-29-2-29	LSD.02-29-02-29W1	481	1280.50	1287.80	10273		1049	
CPOG NAPINKA 10 22 4 26	LSD.10-22-04-26W1	431.60	993.60	999.70	4164	1820	425	186
CAL. STANDARD TILSTON PROVINCE 4 3	LSD.04-03-06-29W1	501.40	1113.70	1118.30	7171		732	
CAL STAN LINKLATER 2 21 7 28	LSD.02-21-07-28W1	493.20	936.30	941.20	4654		475	
DOME HARRIS COX WEST EWART 12 15	LSD.12-15-08-29W1	525.20	962.90	966.20	1379		141	
CALSTAN ROUTLEDGE PROV. 13-29-9-25	LSD.13-29-09-25W1	437.10	704.40	709.30	6033		616	
CALSTAN WOODNORTH PROV. 5 18 9 27	LSD.05-18-09-27W1	487.10	803.80	814.40	4137		422	
CALSTAN EAST CROMER PROV 13 14 9 28	LSD.13-14-09-28W1	497.10	833.60	839.70	7102		725	
CALSTAN DALY 1-30-9-28	LSD.01-30-09-28W1	515.40	873.30	876.30	7377		753	
CALSTAN WEST BUTLER 1-31-9-29	LSD.01-31-09-29W1	543.80	917.80	923.80	6895		704	
DOME HARRIS COX N ROUTLEDGE 3-13	LSD.03-13-10-25W1	370.30	588.30	594.10	5929		605	
CALSTAN NORTH BUTLER PROV 8-11-10-29	LSD.08-11-10-29W1	523.60	855.90	871.70	7584	3241	774	331
TUNDRA MOGC DALY PROV. 11-11-10-29	LSD.11-11-10-29W1	526.10	863	871	4676	6108	477	624
SAPPHIRE NORTH WEST BUTLER NO 1	LSD.04-16-10-29W1	533.10	892.80	899.80	7929		809	
NEWSCOPE OPINAC DALY 13-21-10-29	LSD.13-21-10-29W1	536.20	875.50	882	8580	8280	876	845
NEWSCOPE OPINAC DALY 8-30-10-29	LSD.08-30-10-29W1	540.10	882	892.50	819	8215	84	839
QUEEN CITY CDN SUPERIOR NO 4 36	LSD.04-36-11-29W1	520.90	824.50	830.60	6136		626	
MCBRIDE ALCON HARGRAVE 1 3 12 27	LSD.01-03-12-27W1	487.40	693.40	701	6447		658	
BASCO KANAGE 13 21	LSD.13-21-12-28W1	499.60	716.30	726	6722	6343	686	648
DILLMAN KIRKELLA 16-3-12-29	LSD.16-03-12-29W1	522.40	804.10	813.20	6302		643	
CALSTAN KIRKELLA 13-4-12-29	LSD.13-04-12-29W1	532.80	822.70	829.10	6722		686	
CALSTAN KIRKELLA 5 21 12 29	LSD.05-21-12-29W1	527	787.30	795.80	5861		598	
ASN-BTO ET AL KIRKELLA PROV 16 29	LSD.16-29-12-29W1	524.60	774.80	781.50	7150	6750	730	689
SAPPHIRE WEST MINIOTA NO 1	LSD.04-20-13-27W1	477	611.40	615.40	5764		588	

CDCOG ET AL WILLEN 3-13-14-29	LSD.03-13-14-29W1	491.60	638.60	649.20	5543	5419	566	553
GRT PLNS BIRDTAIL 10 28 15 27	LSD.10-28-15-27W1	464.20	514.50	519.70	4399	3771	449	385
CALSTAN TREAT PROV 15 29 15 28	LSD.15-29-15-28W1	471.50	547.10	551.40	3585		366	
PARADISE BIRDTAIL 3 3 16 27	LSD.03-03-16-27W1	480.40	525.80	533.40	4068		415	
CALSTAN BIRDTAIL 9 8 16 27	LSD.09-08-16-27W1	480.40	518.50	524	4309	3640	440	372
DOME BIRTLE 14 35 16 27	LSD.14-35-16-27W1	521.20	545.60	557.20	4226		431	
ASM-BTO ET AL FT ELLICE PROV 2-14	LSD.02-14-16-28W1	389.80	438.90	444.40	4392	4247	448	434
DYPONT 14 25 16 28	LSD.14-25-16-28W1	479.10	506	512.70	4240		433	
TROY ST. LAZARE 1-21-16-29	LSD.01-21-16-29W1	474.70	528	541	4667	4543	476	464
TROY ST. LAZARE PROV. A4-22-16-29	LSD.04-22-16-29W1	475.30	532	541	4231	4278	432	437
DOME BIRTLE 16 17	LSD.16-17-17-27W1	521.80	548	552.90	4185		427	
CALSTAN LAZARE 11 30 17 28	LSD.11-30-17-28W1	476.40	481.90	495	3944	3509	403	358

SPEARFISH BEDS (SFRF)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		PRESSURE HEAD	
GEOG CHAGOS LULU LAKE PROV 6 23 1 21	LSD.06-23-01-21W1	699.80	986	1012.90	8736	7288	892	744
A & B RESOURCES ET AL GOODLANDS 10-3	LSD.10-33-01-24W1	494.70	848	858	189	262	19	27
CHEVRON WASKADA PROV. 4-20-1-25	LSD.04-20-01-25W1	475	918	925	3106	2076	317	212
SASKO PCV ET AL E. WASKADA 3-22-1-25	LSD.03-22-01-25W1	475.40	882	909	8202	7514	837	767
OMEGA WASKADA PROV. 9-32-1-25	LSD.09-32-01-25W1	475.50	843	874	1454	1151	148	118
CALSTAN WASKADA 9-13-1-26	LSD.09-13-01-26W1	468.80	892.50	898.60	7239		739	
ANGLU ET AL SOURIS VALLEY CR 16-18	LSD.16-18-01-26W1	435.60	914.70	922.60	10066		1028	
NORTH AMERICAN ARTHUR 6 21 1 26	LSD.06-21-01-26W1	461.50	920.50	933.90	9770	9018	997	921
IOE ARTHUR 5-22-1-26	LSD.05-22-01-26W1	464.80	915.60	927.80	9694	9122	990	931
HUDSON SOUTH DALNY 1 32 1 26	LSD.01-32-01-26W1	459.30	910.70	929	6929	3861	707	394
OMEGA DALNY 3-34-1-26WPM	LSD.03-34-01-26W1	464.50	908	919	10322	8970	1054	916
CHAMPLIN LYLETON 1-3-1-28	LSD.01-03-01-28W1	458.10	1006.40	1018	11694		1194	
RIDEAU PIPESTONE LYLETON 16-15-1-28	LSD.16-15-01-28W1	459.70	988	1012	11238	9256	1147	945
CALSTAN IMPERIAL DALNY 8-10-2-26	LSD.08-10-02-26W1	467.30	906.50	913.20	10239		1045	
ROXY-CLARION ET AL N. WASKADA PROV.	LSD.05-24-02-26W1	472.30	893	905	8901	8819	909	900
COBRA SHELL LYLETON 14-5-2-28	LSD.14-05-02-28W1	466.30	988	1004	9994	784	1020	80
COBRA OIL AND GAS LTD.	LSD.12-27-02-28W1	464	958	970	1534	4699	157	480
COBRA ET AL W. PIERSON 2-30-2-28	LSD.02-30-02-28W1	467.40	965.50	984	5044	7563	515	772
COBRA ET AL S. PIERSON 9-24-2-29	LSD.09-24-02-29W1	465.90	973.50	992	10189		1040	
COBRA ET AL S. PIERSON 12-26-2-29	LSD.12-26-02-29W1	410	984	1002.30	4164	1200	425	123
TUNDRA S. PIERSON PROV. 4-36-2-29W1	LSD.04-36-02-29W1	469.10	973	987	388	574	40	59
QUEST LEVA 4-26-3-28	LSD.04-26-03-28W1	469.70	925	950	6007	5953	613	608
IMPERIAL PIERSON 13-2-3-29	LSD.13-02-03-29W1	476.10	978.40	1002.30	2206		225	
NEW SCOPE ET AL NAPINKA 12-26-4-26	LSD.12-26-04-26W1	446.80	808	821	2871	5136	~~293~~	524

UPPER AMARANTH FORMATION (AMRN)

WELL NAME	WELL LOCATION	KB	INTERVAL TESTED		SHUT-IN PRES.		PRESSURE HEAD	
OIL ET AL E PIERSON 4-1-3-28	LSD.04-01-03-28W1	462.50	878	890	2398	2548	245	260
TUNDRA VIRDEN PROV. 6-29-10-26	LSD.06-29-10-26W1	458.40	620	630	679	339	69	35
CALSTAN DALY 16 20 10 27	LSD.16-20-10-27W1	488	659	662.90	5516		563	
WESTMIN SASKOIL ELKHORN PROV. 13-24-11-28	LSD.13-24-11-28W1	499.30	648	652	5622	5658	574	578
NORCEN POR HARMSWORTH PRV. 15-11-12-26	LSD.15-11-12-26W1	454.20	551	564	4488	4410	458	450
PARADISE MAXFIELD TWO CREEKS 10 33	LSD.10-33-12-26W1	457.20	549.90	564.50	4544	4192	464	428
CHAMPLIN BIRDTAIL CREEK PROV 1-29	LSD.01-29-14-26W1	467	524.30	536.40	4647	4647	474	474

VITA AUCTORIS

Ioannis Bacopoulos

Born: June 8, 1961.
Status: Single.

Education:

1972-1978
Graduated with Apolytirion of Gymnasium.
19th Gymnasium of Athens, Athens, Greece.

1981-1985
Graduated with Diploma in Geological Sciences.
National University of Athens, Athens, Greece.
Thesis entitled "Well-site Geology".

1986-1988
Graduated with M.Sc. in Geology.
University of Windsor, Windsor, Ontario, Canada.
Thesis entitled "Solution-generated collapse (SGC) structures and formation-fluid hydrodynamics in southern Manitoba".

Work Experience in Geology:

Summer 1984
Well site geologist with Public Petroleum Corporation of Greece (PPC).

1986-1988
Teaching Assistant, University of Windsor.