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The Milk River Transboundary Aquifer in Southern Alberta

S. O'Connell

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Executive Summary

The Milk River transboundary aquifer is examined in a 330 township area of southern Alberta, adjoining the US and Saskatachewan borders. The Upper Cretaceous Milk River is divided into four members. In ascending order these are: the Telegraph Creek, the Virgelle, the Deadhorse Coulee, and the Alderson members. Large regional sandstone aquifers are present within the Virgelle and the Upper Alderson members.

The Virgelle aquifer covers 175 townships in the southeastern and central part of the study area, and is up to 69m thick. The Virgelle forms a continuous sand sheet that consists of a number of amalgamated, NW-SE trending shoreface units. The Virgelle aquifer is underlain by offshore marine shales of the Telegraph Creek Member, and overlain by the non-marine muds and coals of the Deadhorse Coulee Member.

The Virgelle aquifer is eroded at its northern and eastern edge along a regional unconformity surface. The overlying Alderson Member consists predominantly of offshore marine shales and low-permeability muddy fine-grained sands and silts, which hosts the Milk River gas fields. Within the upper part of the Alderson Member there are two large sand bodies which form the Upper Alderson aquifer. These sands extend over an area of 44 townships, and are up to 22m in thick. The Upper Alderson sand bodies were deposited in shoreface environments and parallel the underlying erosional edge of the Virgelle aquifer sands. The Virgelle and Upper Alderson aquifers are separated from each other by muddy sediments of the Alderson and Deadhorse Coulee members, but they are locally in contact at the Virgelle erosional edge and water flow between the two aquifers is likely.

Both the Virgelle and Upper Alderson sandstones terminate well to the south of the Milk River gas field. The aquifers have no direct lithological contact with the field which are entirely contained within the low permeability rocks of the Alderson Member.

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Virgelle Sand (V2) Isopach

Alderson Member Isopach

Upper Alderson Sandstone Isopach

Upper Alderson Sandstone 1 Isopach

Structure at the top of the Milk River

Other Appendices Accompanying this Report

The Mapping Database is provided as an excel spreadsheet

The Surfer mapping files are provided

Cross-sections Accompanying this Report

21 cross-sections are provided; these are printed at a scale of 1:1200

Introduction

The purpose of this study is to describe the geological characteristics of the Milk River transboundary aquifer in southern Alberta. The stratigraphy of the sandstones that host the aquifer is defined and the sandstone units are correlated and mapped. The sandstone geometries that are quantified in this report can be used for subsequent hydrogeological flow modelling

This report describes the Milk River Formation in a 330 township area in southern Alberta, covering some 30,000 square kilometers. The study area extends from T1 to T15, and from R1w4 to R22w4, and is bounded by the US border to the south and the Saskatchewan border to the east (figure 1).

Study Contents

- The study area contains approximately 45,800 oil and gas industry wells. A total of 2,207 of these wells were mapped for this study. The database with the Milk River tops is provided in an excel spreadsheet file.
- Twenty-one detailed cross sections were constructed; 16 stratigraphic dip sections and 5 stratigraphic strike sections (figure 2). These have been correlated and printed at a scale of 1:1,200. Three of the cross-sections have been synthesized and are included as page-sized summaries in this report.
- Nine maps have been constructed at a scale of 1:300,000. Page-sized versions of these maps are included in this report.

Regional Geology

The Santonian-to-Campanian Milk River Formation in southern Alberta and Saskatchewan forms a northward tapering sandy clastic wedge. Shoreline and coastal plain sediments of the Milk River Formation are exposed along the Milk River near the

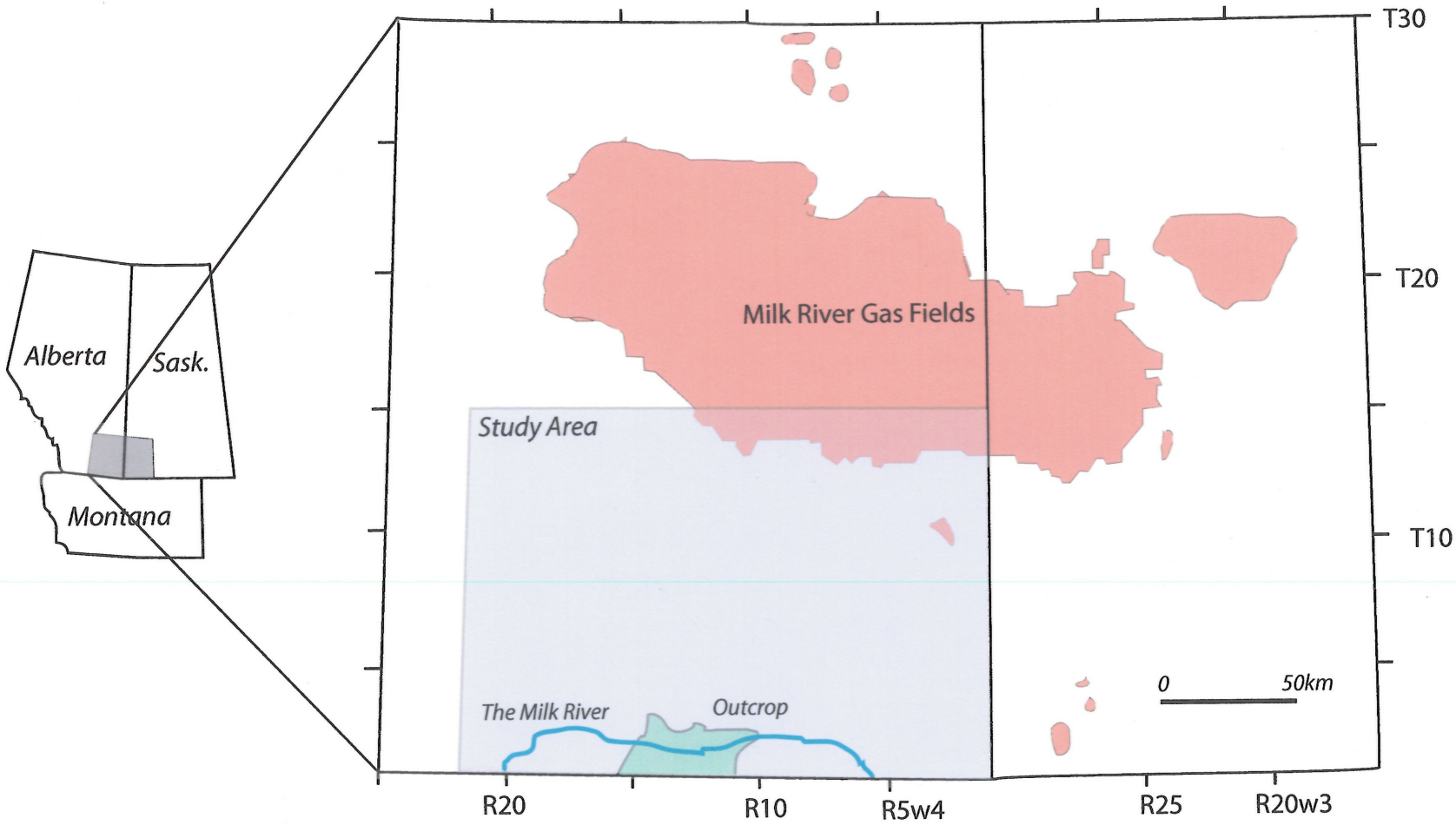


Figure 1

Study Area
Township 1 to Township15; Range 1 to Range 22w4

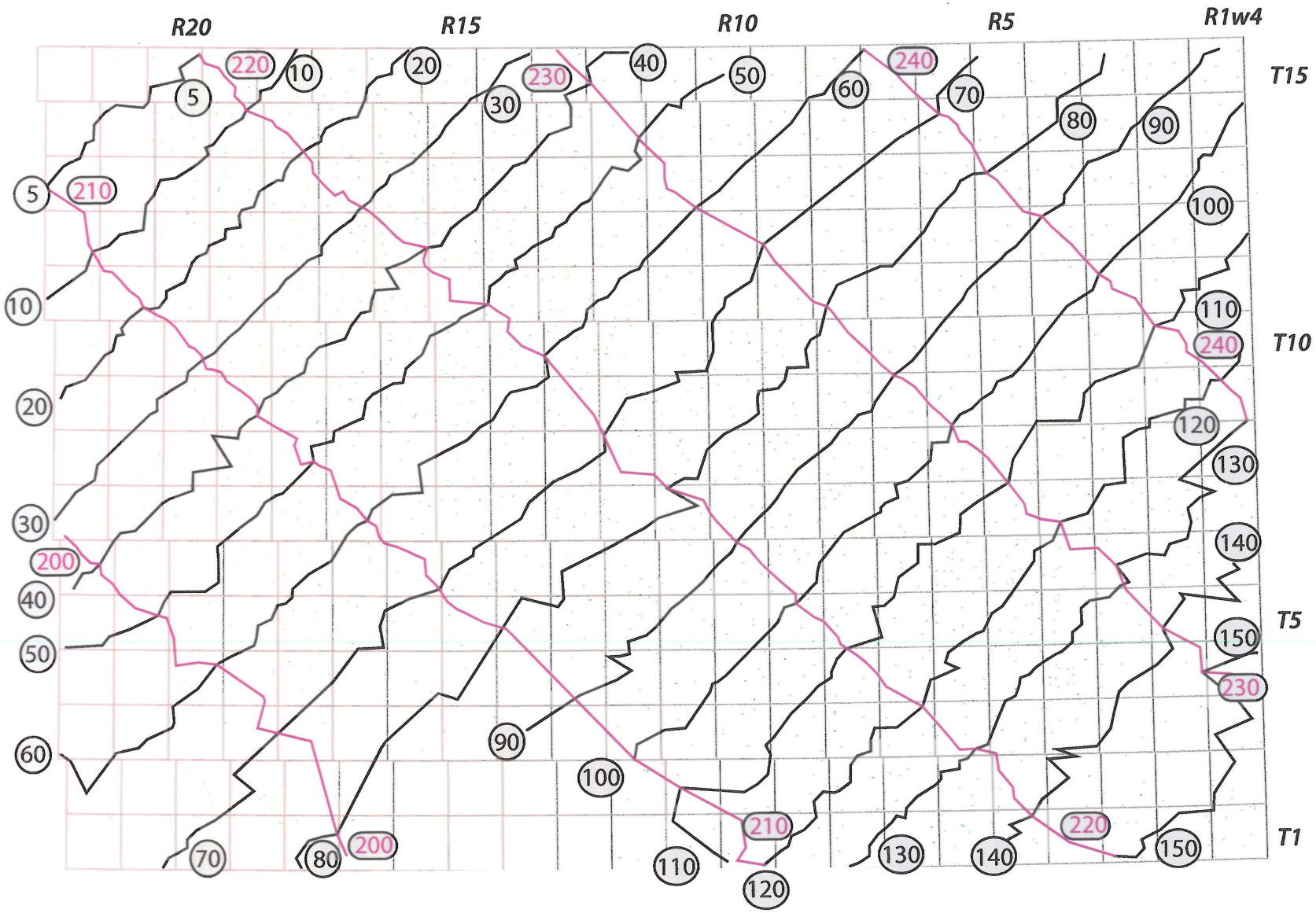


Figure 2 *Study area with cross-section lines and location of wells used for mapping*

US border. These pass northwards into offshore marine shales, siltstones and fine-grained sandstones of the Alderson Member which hosts the Milk River gas field (figure 3).

In outcrop the Milk River Formation comprises three members; the Telegraph Creek, Virgelle, and Deadhorse Coulee members (figure 4). Together these form a shallowing-upward facies succession from offshore sands and shales to shoreface and tidal-inlet sandstones, estuarine channel complexes, and hererolithic coal-bearing coastal plain deposits. The Virgelle Member sandstones and the non-marine Deadhorse Coulee Member together formed shoreline complexes that had NW-SE shoreline trends, with many local variations. The Milk River shorefaces downlap onto the flat-lying sediments of the First White Speckled shale. The Milk River Formation is overlain by marine shales of the Pakowki Formation. Stratigraphically the Milk River succession is interpreted as a northeasterly prograding systems tract of probable third order frequency (O'Connell *et al.,* 1992).

There is extensive gas production from the Virgelle sandstones in northern Montana, mainly from large Laramide structural complexes. In southern Alberta, Virgelle Member sands are water-bearing and there is no significant gas production. The Virgelle and Deadhorse Coulee Members are not present in Saskatchewan.

O'Connell *et al.* (1992), Payenberg (2002) and Mumpy *et al.* (2009) demonstrate that there is a major unconformity separating the shoreline sediments of the Milk River Formation from the offshore marine deposits of the Alderson Member. The Alderson Member is younger than the Telegraph Creek, Virgelle and Deadhorse Coulee members of the Milk River Formation, and is separated from them by a large time-gap. The surface separating the Alderson Member from the underlying Milk River members is referred to as the Milk River Sequence Boundary in this report.

The Alderson Member of the Milk River Formation consists of muddy very fine-grained sandstones, siltstones and shales. Most of the Alderson Member lithologies were deposited in offshore marine settings, but there are a series of sandstone units in the

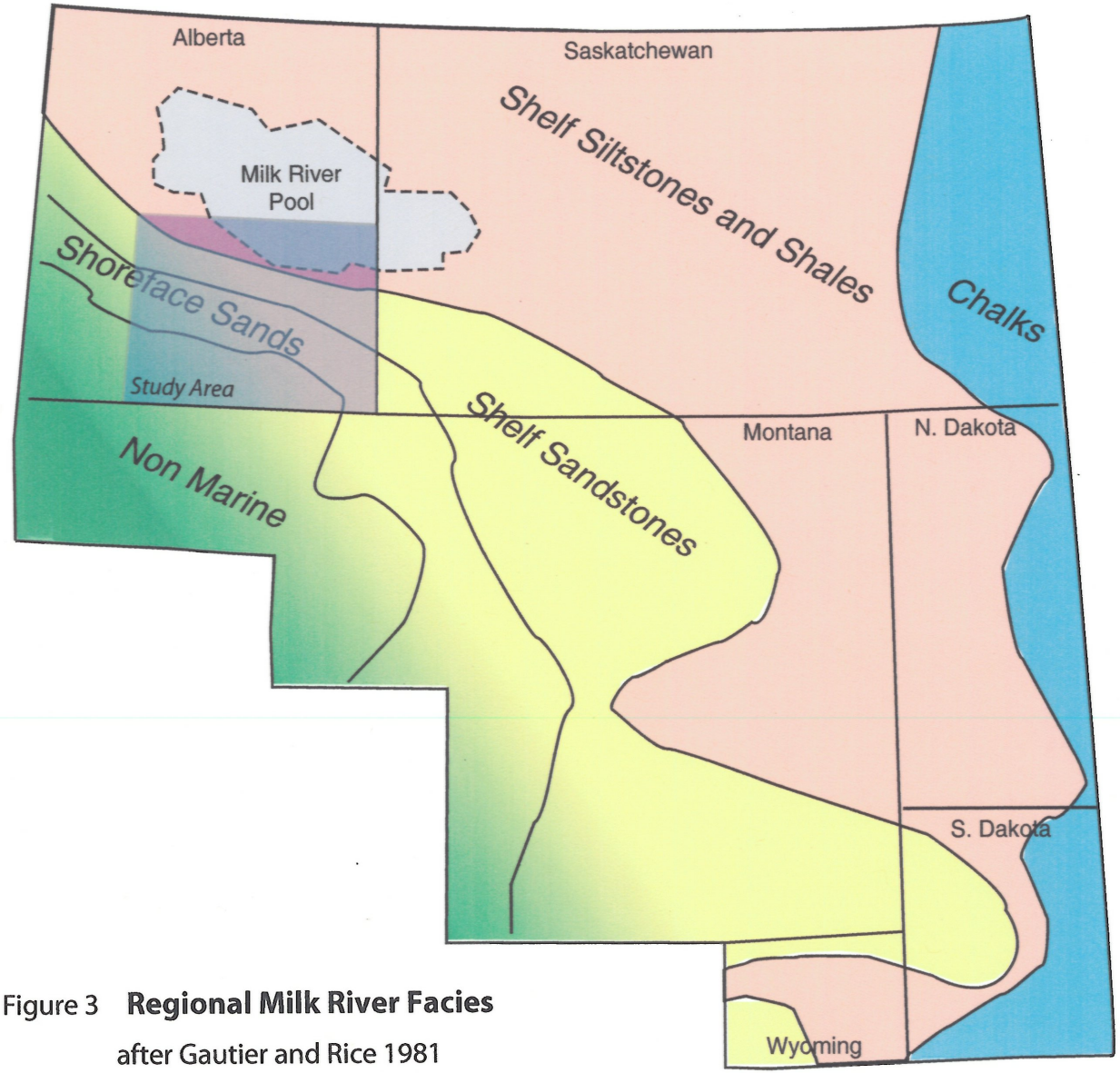
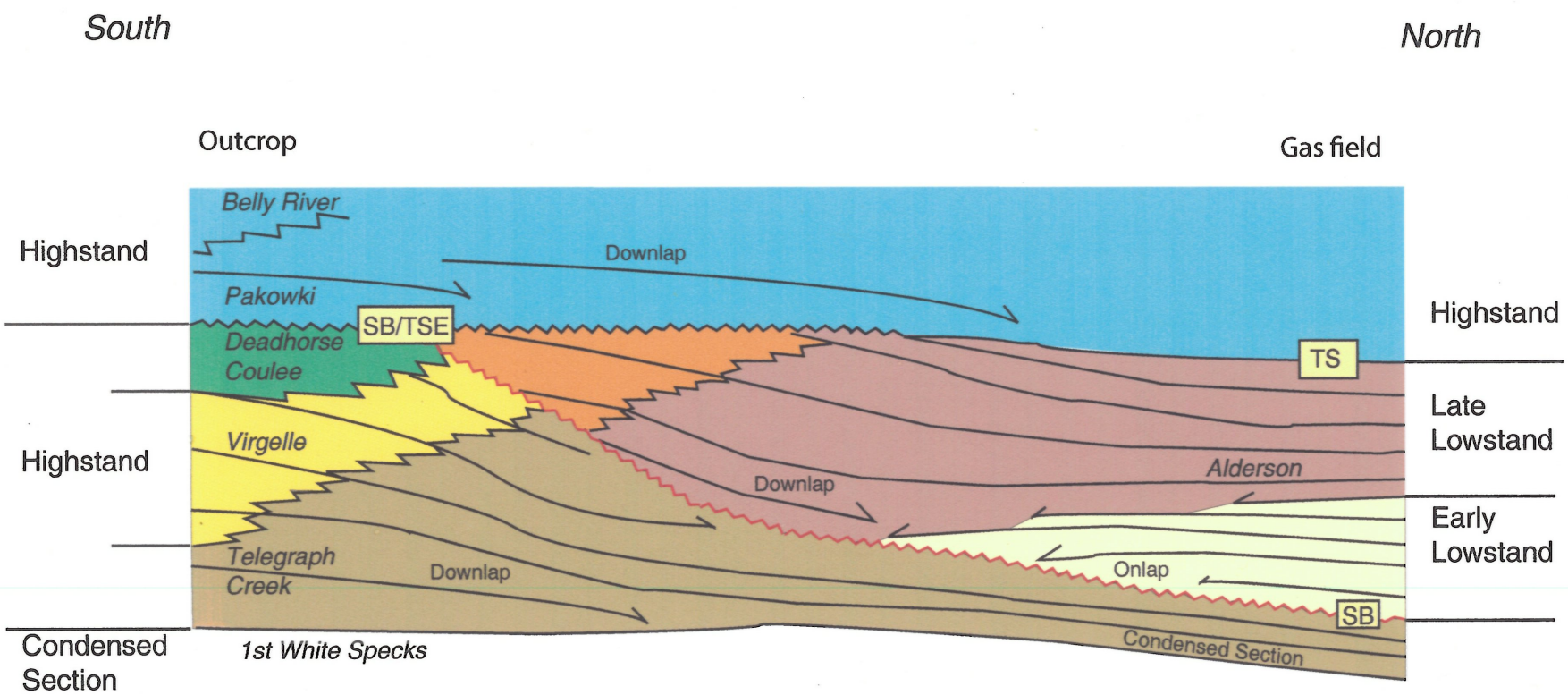


Figure 3 **Regional Milk River Facies**

after Gautier and Rice 1981



SB - Sequence Boundary
TS - Transgressive Surface
TSE - Transgressive Surface of erosion

Figure 4 Milk River / Alderson Stratigraphic Model

Upper Alderson, near the southern edge of the unit. Outcrop work from equivalent rocks in central Montana indicates that these are shallow marine to shoreline sands (O'Connell, 2011).

Lithological and Stratigraphic Units

The lithological and stratigraphic units mapped for this study are shown in the cross-sections summarized in figures 5, 6 and 7. These cross-sections are from the southeastern, central and northwestern part of the study area and each of them is oriented parallel to stratigraphic dip. The stratigraphic scheme is similar in each section. In the southwest the Telegraph Creek, Virgelle and Deadhorse Coulee members are present and these are truncated in a northeasterly direction. The Alderson Member is present in the northeast, and contains a sand body known as the Upper Alderson Sand at the southwestern edge of the Alderson Member.

There are ***3 key stratigraphic surfaces*** bounding the Milk River Formation and Alderson Member:

1. The Base of the Milk River Formation

This is a composite surface marking the contact between the condensed shales of the First White Specks Formation and the shales of the Telegraph Creek Member. In the northwest part of the study area the Telegraph Creek Member is absent and the shales of the Alderson Member directly overlie the First White Specks. In this area the contact at the base of the Milk River is the sequence boundary that underlies Alderson Member.

2. The Milk River - Alderson Sequence Boundary

This surface marks a basin-wide drop in sea level accompanied by a major erosional event. The time gap at this surface is estimated to be in the order of 2.5 million years. This surface truncates the Telegraph Creek, Virgelle and Deadhorse Coulee Members, and underlies the Alderson Member. In core the surface is often marked by a chert pebble

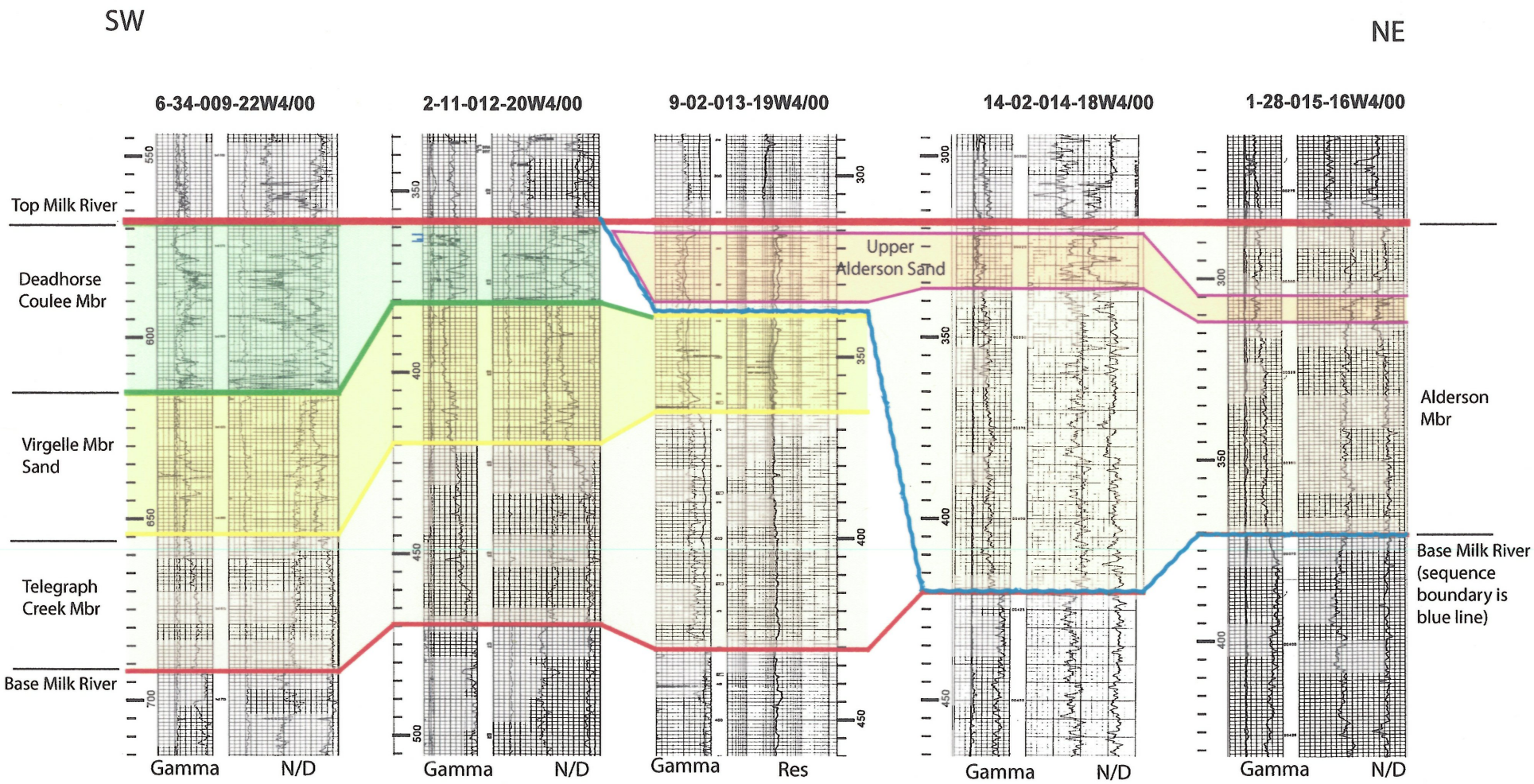


Figure 5 Stratigraphic Summary - Cross-Section 20

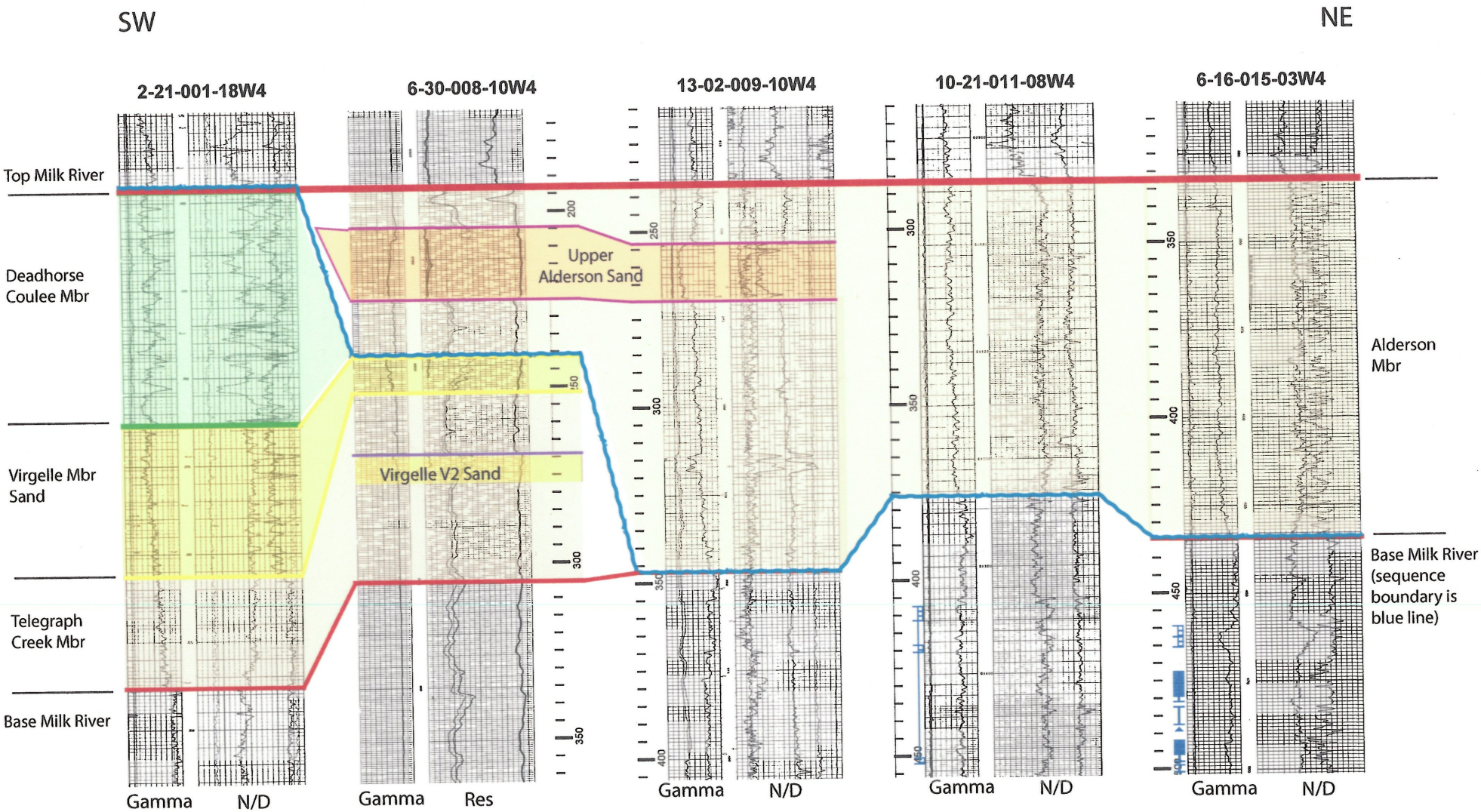


Figure 6 Stratigraphic Summary - Cross-Section 80

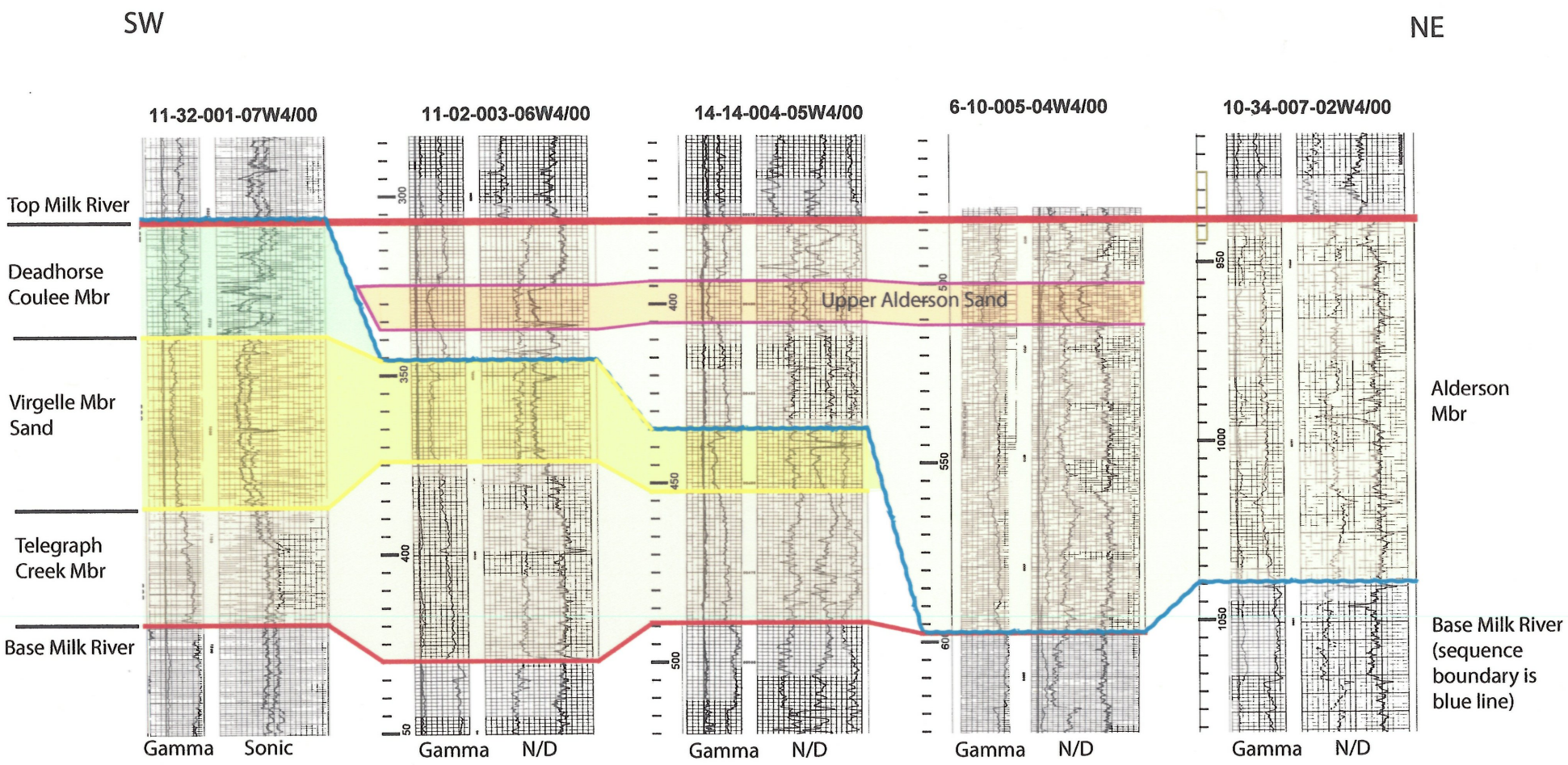


Figure 7 Stratigraphic Summary - Cross-Section 130

lag. Because the surface often separates underlying and overlying shales (ie. a shale-on-shale contact), it is not always possible to determine its precise location in the section.

3- The top of the Milk River

This surface is often referred to as 'The Milk River Shoulder' and is expressed as a resistivity signature that is one of the most distinctive well log markers in the Upper Cretaceous of this basin. This is a diachronous surface that becomes younger from south to north. A pebble lag is often present at the contact between the Milk River Formation and the overlying Pakowki Shale.

Lithological Units

1. The Virgelle Sandstone

This is a composite sand unit that consists of multiple shoreline sandstones that have amalgamated to form a thick, continuous, regional sand sheet. An example of this amalgamation is shown in figure 8 which consists of four wells from T9 R17w4. Here there are two distinctive coarsening-upward sand bodies each representing a single progradational shoreface sand cycle. The older unit, referred to as Shoreface Unit 1, thins from 25m of sand in the southwest to less than 5m of sand in the northeast. There is a corresponding northeasterly increase in the thickness of the younger unit, Shoreface Unit 2. These two units are separated by a local transgressive surface.

Similar high-frequency shoreface sands of local extent are common within the Virgelle Member. The two units in figure 8 are in lithological contact and form a continuous sand body with no significant internal lithological barriers. For this reason the sands are mapped as one lithological unit referred to here as the ***V1 Sand.***

There are locations where the underlying Virgelle sand becomes lithologically separate from the overlying V1 sand. In this case a lithological barrier is present, usually consisting of a 5m shale interval, or greater. These sands are mapped separately and

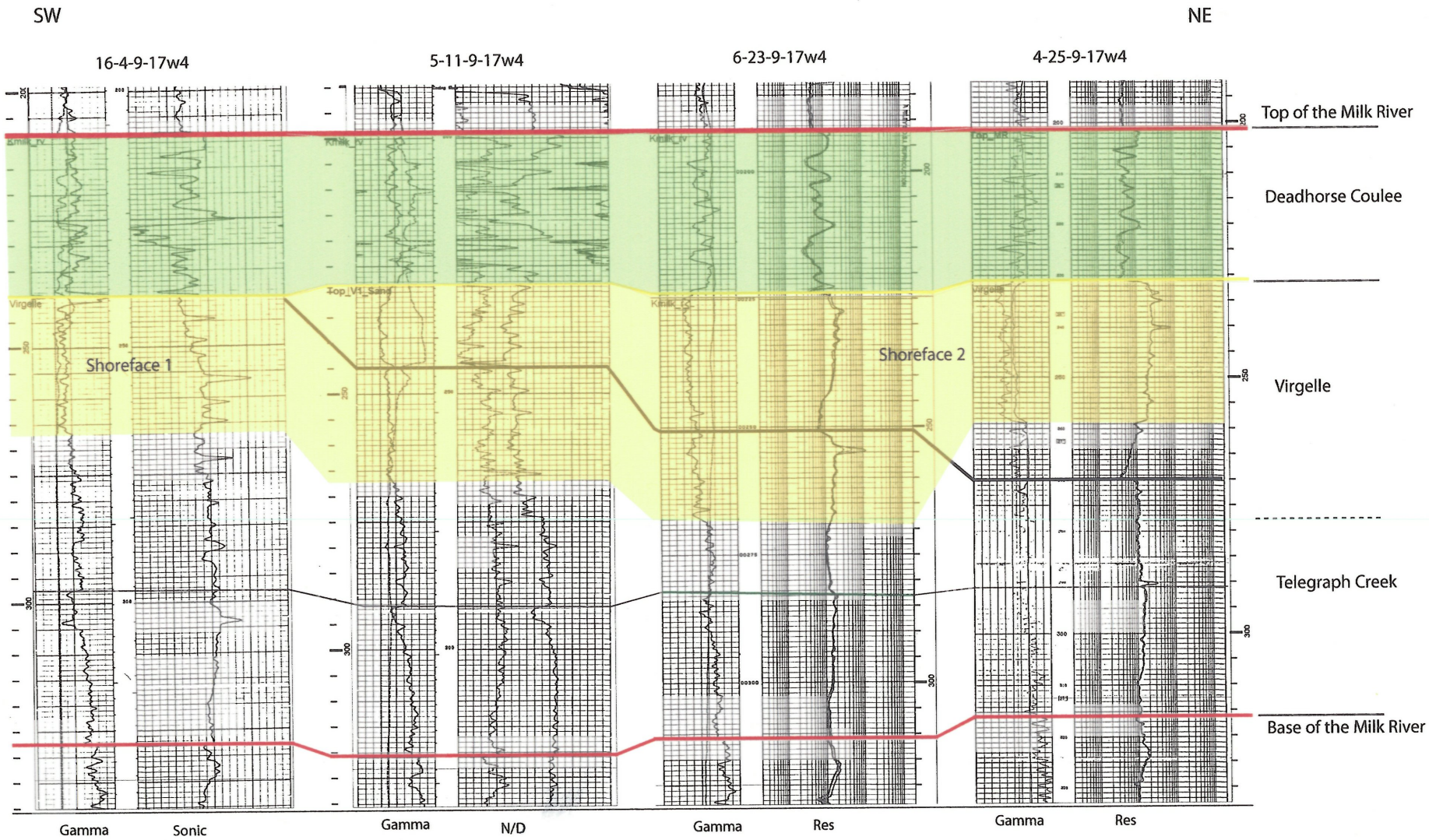


Figure 8 Virgelle Shoreface Sands

referred to here as the ***V2 Sand.*** Many examples of these are present on the detailed cross-sections, and one example is present in cross-section 80 (figure 6).

There are also internal sand quality variations within the V1 sandstone. An example of this is shown in figure 9. Here the composite V1 sand is 45m thick. The upper 27m, however, has a significantly higher sand quality than the lower 18m. The upper sand has a sharp-base, a blocky log signature, a cleaner gamma log and a higher porosity. The underlying sand has a serrated gamma log signature indicating a lesser quality sand, with a lower porosity. This sand quality difference is probably due to facies variation, with the lower sand being of shoreface origin, while the upper sand is a fluvial or estuarine channel incised into the top of the shoreface. These high frequency facies variations, and their local extent, mean that it is impractical to map them individually on a regional scale, so they are mapped as a single sand body.

2. The Deadhorse Coulee

This is a non-marine unit deposited in the coastal plain environments landward of the Virgelle shorefaces. The unit consists predominantly of shale, organic shale, coal, and fluvial sands. The fluvial sand consists of fining-upward sand-filled channels, usually 5m or less in thickness. These sand channels have little continuity and cannot usually be correlated between wells. The Deadhorse Coulee forms a thick, low-permeability barrier at the top of the Virgelle sand aquifer.

3. The Alderson Member

The Alderson Member is entirely marine and was deposited in proximal to distal offshore marine environments. Alderson Member lithologies consists of very fine-grained sand, silt and mud. Individual layers of sand or silt are rarely more than a few centimeters thick. Typically the sediment was reworked by moderate to intense bioturbation, resulting in a range of mixed lithologies from silty and muddy sand, to sandy and muddy silt, and silty and sandy mud, with many gradations in between. A significant proportion of mud is always present and usually form 50% or more of the lithology. A large proportion of the mud consists of smectitic 'swelling clays' that are highly reactive to water. Sand is

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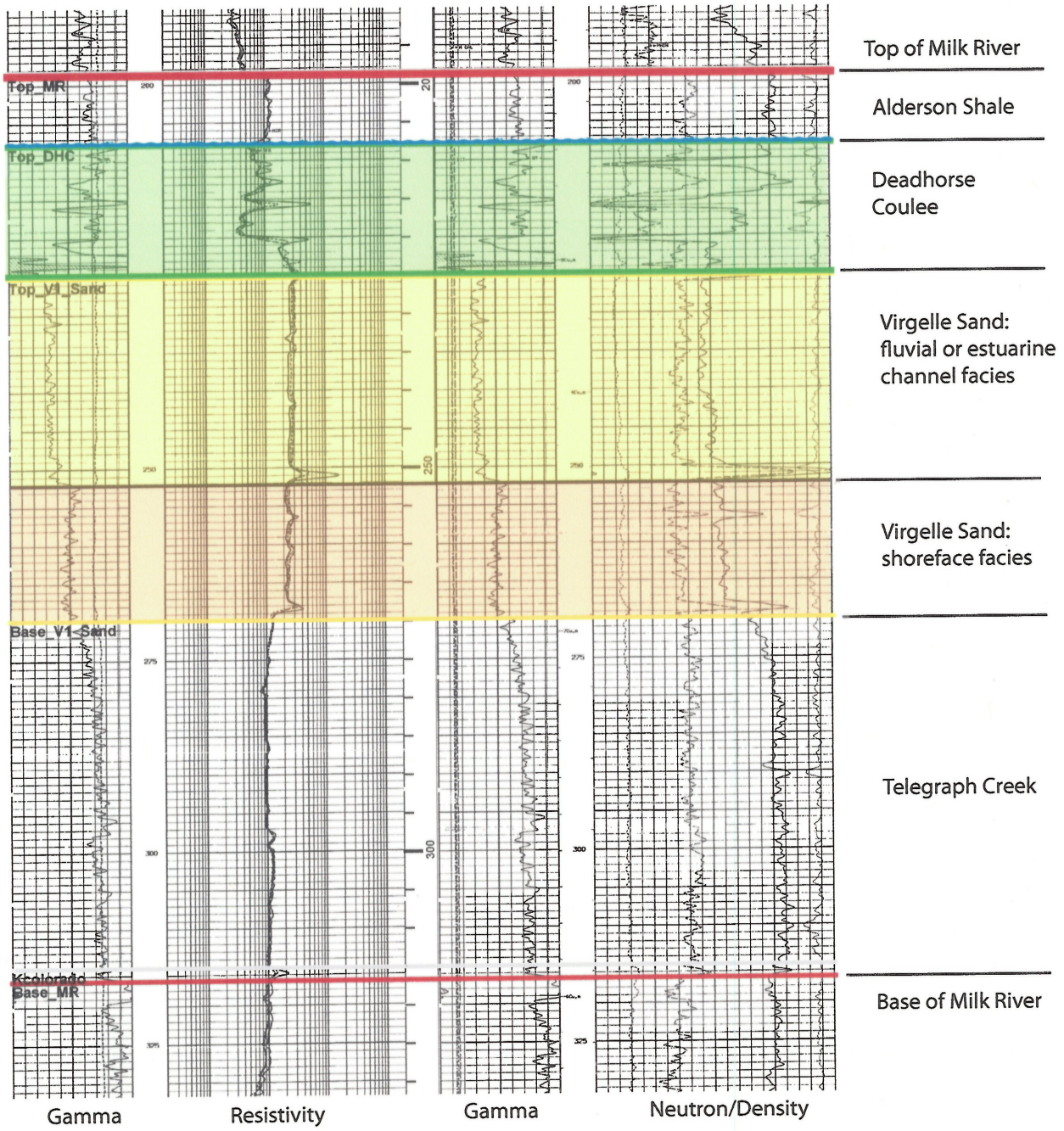


Figure 9 - Virgelle Sand Facies

typically 25% or less of the total lithology. Gas reservoirs are hosted within laminated muddy, low-permeability sands and silts, but most of the Alderson Member consists of homogenous sediments that have little reservoir potential because the lithology is not capable of transporting gas or water at significant rates.

Correlation and mapping of individual sandy Alderson cycles in Alberta and Saskatchewan shows that they form large lobate sand bodies that can be several townships in size. These lobes often have a uniform or blocky vertical sand content, or they may form very gradual coarsening-upward units which become sandier upwards. Typically these lobes have an overall progradational depositional pattern but along depositional strike they appear to occur randomly.

4. The Upper Alderson Sand

The Upper Alderson Sand is present within the upper part of the Alderson Member. The cross-sections show that the sand is thickest near the southwestern edge of the Alderson Member, and thins towards the northeast. At the southwest edge of the sand unit the Alderson Sand is typically in erosional contact with the Deadhorse Coulee Member. Usually it is separated from the underlying V1 Sand by Alderson shales. However, there are many locations where the Upper Alderson Sand and the V1 Sand are in contact. An example of this is shown in cross-section 20 (figure 5) where the Upper Alderson and Virgelle Member Sand are in contact and cross-formational water flow is likely.

The Upper Alderson Sand is a blocky, sharp-based unit that was deposited in a sandy shoreline setting. These shoreline sands grade laterally towards the northeast into sandy shales. The detailed cross-sections show that it often divides into thinner sand units separated by shales. These thinner shaly sand units are mapped as a single sand unit where it is reasonable to assume that the sands are in lithological contact. In locations where there is a significant shale break, usually 5m or greater in thickness, then an underlying Alderson sand, the ***Upper Alderson1 Sand***, is correlated and mapped.

Maps

1- Milk River Formation Isopach *(figure 10)*

This is a combined isopach of all Milk River Members and shows that they share a common stratigraphic strike. The Milk River thins from a maximum of 150m in the southwest corner of the area to 100m in the northeast corner.

2. Isopach of the Combined Telegraph Creek, Virgelle and Deadhorse Coulee Members *(figure 11)*

This is a map of the three older Milk River Members, and excludes the Alderson Member. This has a maximum thickness of 150m in the southwest corner of the area thinning to the northeast, where it is approximately 90m thick, just to the west of the zero edge. The erosional zero edge extends northwestwards from T1 R2w4 to T14 R18w4 where it has an E-W orientation. Note that in the south-central part of the study area there is a region of approximately 14 townships where the Milk River Formation is absent or incomplete.

3. Deadhorse Coulee Member Isopach *(figure 12)*

The Deadhorse Coulee has a maximum thickness of 60m in the southwest corner of the study area, thinning towards the northeast to approximately 10m east of the zero edge. The zero edge extends northwards from T1 R5w4 to T13 R22w4.

4. Virgelle Sand Member (V1) Isopach *(figure 13)*

The Virgelle sand is highly variable sand sheet that covers an area of approximately 175 townships. It has a maximum thickness of 69m and a minimum non-erosional thickness of 20m. As previously described, this is a lithostratigraphic map that incorporates many shoreline sandstones and local incised sands. The sands have a distinctive NW-SE trend, paralleling the linear trend of the Virgelle shorelines. There are at least three of these

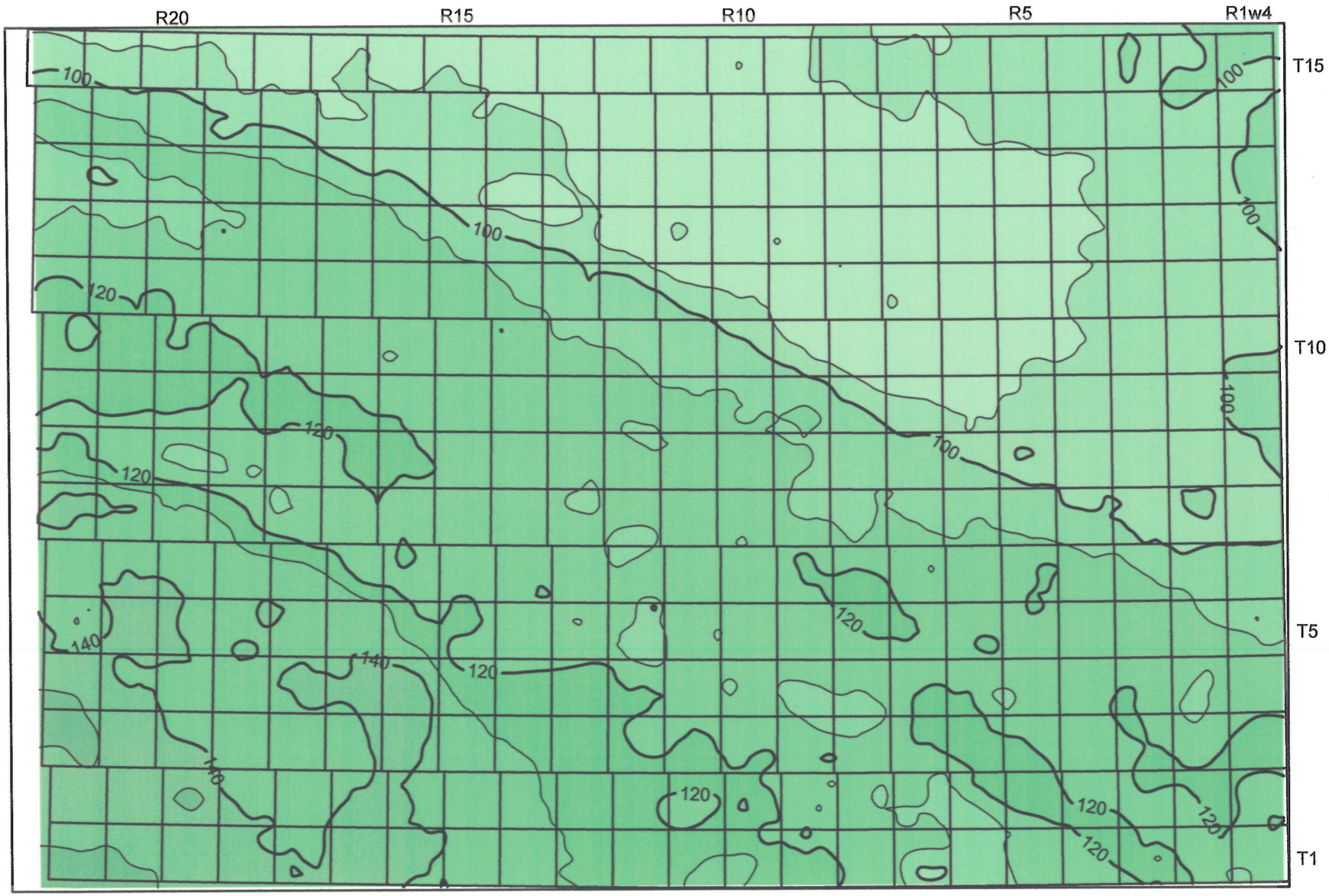


Figure 10 Milk River Isopach

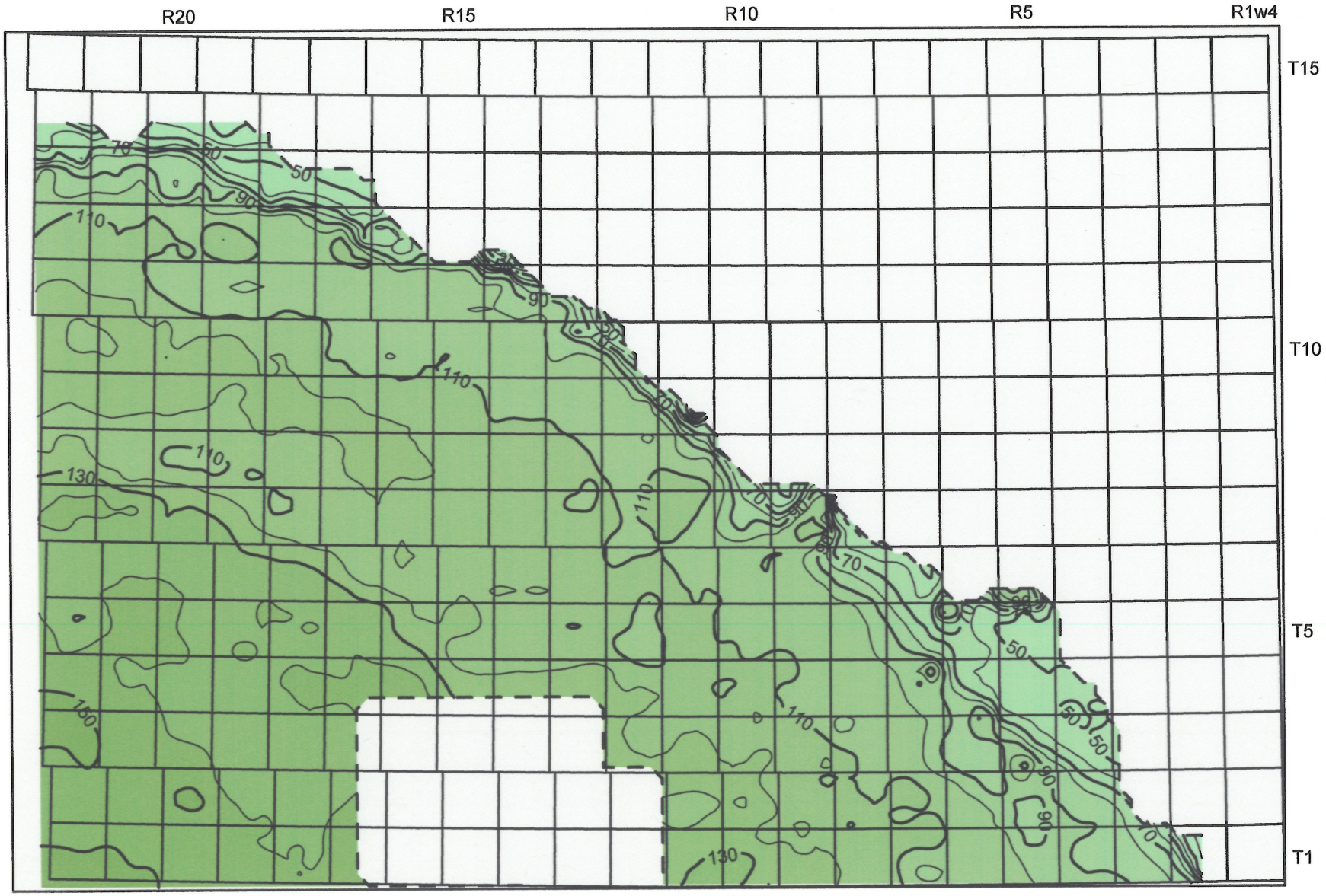


Figure 11 Isopach of the Telegraph Creek, Virgelle and Deadhorse Coulee Members

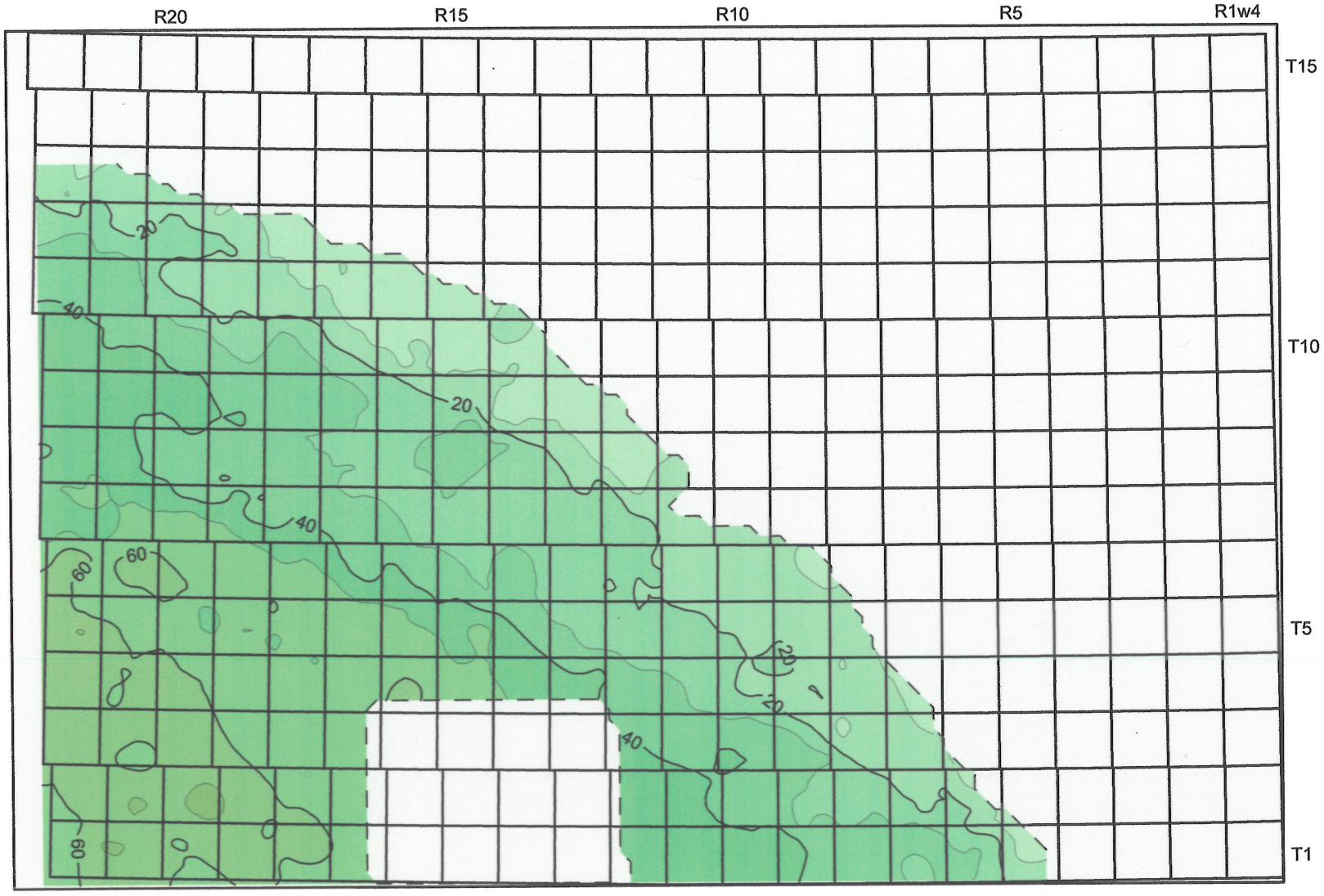


Figure 12 Deadhorse Coulee Member Isopach

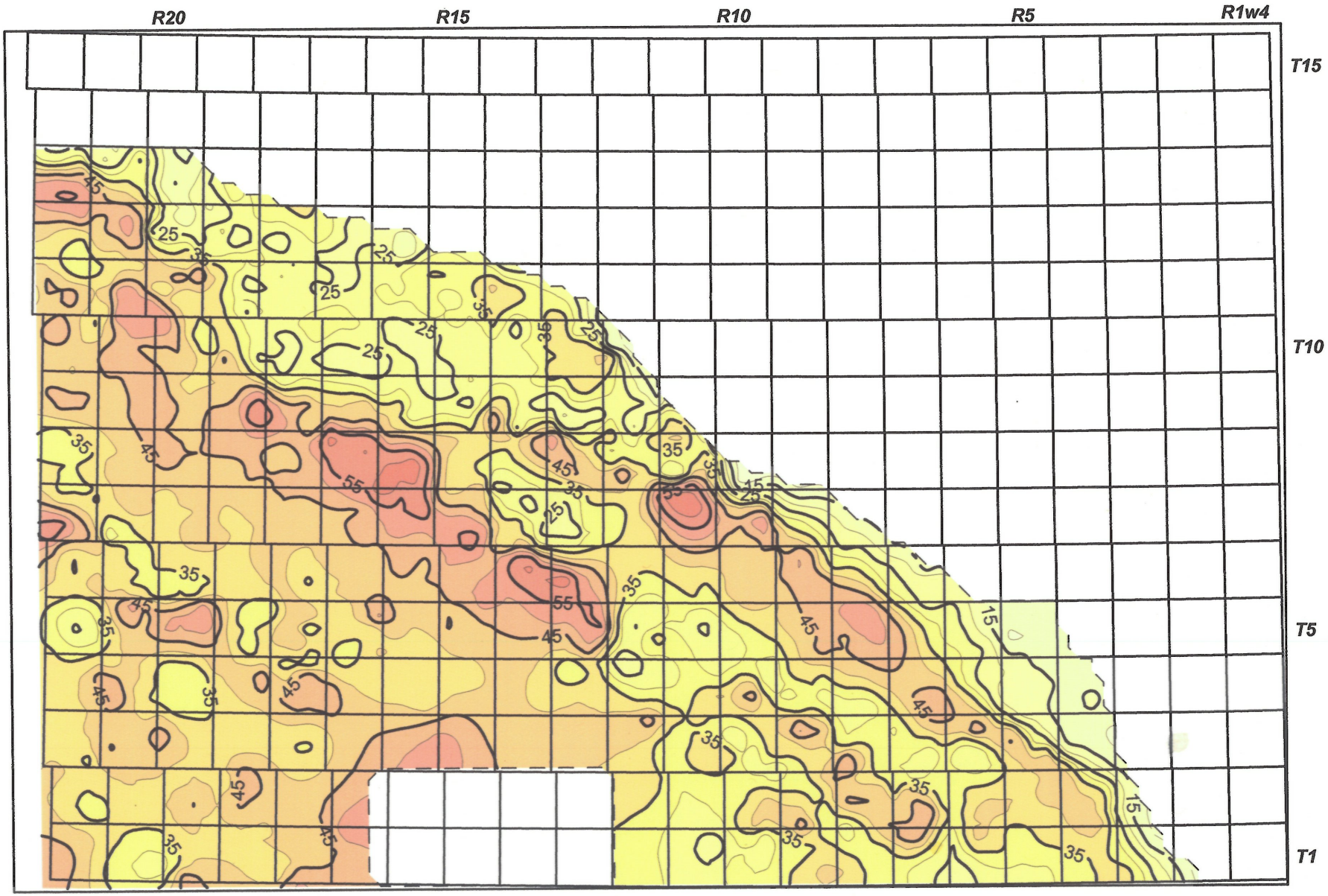


Figure 13 Virgelle Sand Isopach

linear NW-SE trends, one in the southwest, one in the central part of the area, and one paralleling the zero edge. The zero edge extends from T1 R2w4 to T13 R20w4 where it has and E-W orientation.

5. The Virgelle V2 Sand *(figure 14)*

This sand is between 5m and 20m thick. They form lobate sand bodies with a general NW-SE trend. The rationale for picking these sand separately from the V1 sand has previously been described on page 4. They are largely an artifact of the lithological mapping process, and can be included with the main Virgelle sand body.

6. Alderson Member Isopach (figure 15)

This is the reciprocal of map 2 and consists of the Alderson Member, which is present between the Milk River sequence boundary and the top of the Milk River. The zero edge extends from T1 R5w4 to T13 R22w4. Immediately to the east of the zero edge the Alderson consists of a thin muddy unit up to 15m thick. The Alderson rapidly thickens to the northeast over a 1 to 2 township area, where it is in excess of 100m thick. This is due to the presence of the sandy Upper Alderson shoreface units in this area. In the northern and northeastern part of the area the Alderson is highly muddy and averages between 90m and 100m in thickness.

7. Upper Alderson Sandstone Isopach *(figure 16)*

The Upper Alderson shorefaces are present to the east of the erosional edge where the Milk River sequence boundary truncates the Deadhorse Coulee and Virgelle Members. This has resulted in a series of linear sand bodies paralleling the erosional edge. There are two distinct sand bodies. The southern sand covers an area of 44 townships and is between 5m and 22m thick with a NW-SE trend. The northern sand body covers an area of 30 townships, is between 5m and 38m thick, and has a WNW-ESE trend.

There is a 0.5 to 1 township gap between the two sand bodies, and the sands thin towards this gap. The gap between the sands and the different orientation of the sand bodies indicates that there were two separate shorelines present during the Upper Alderson, and

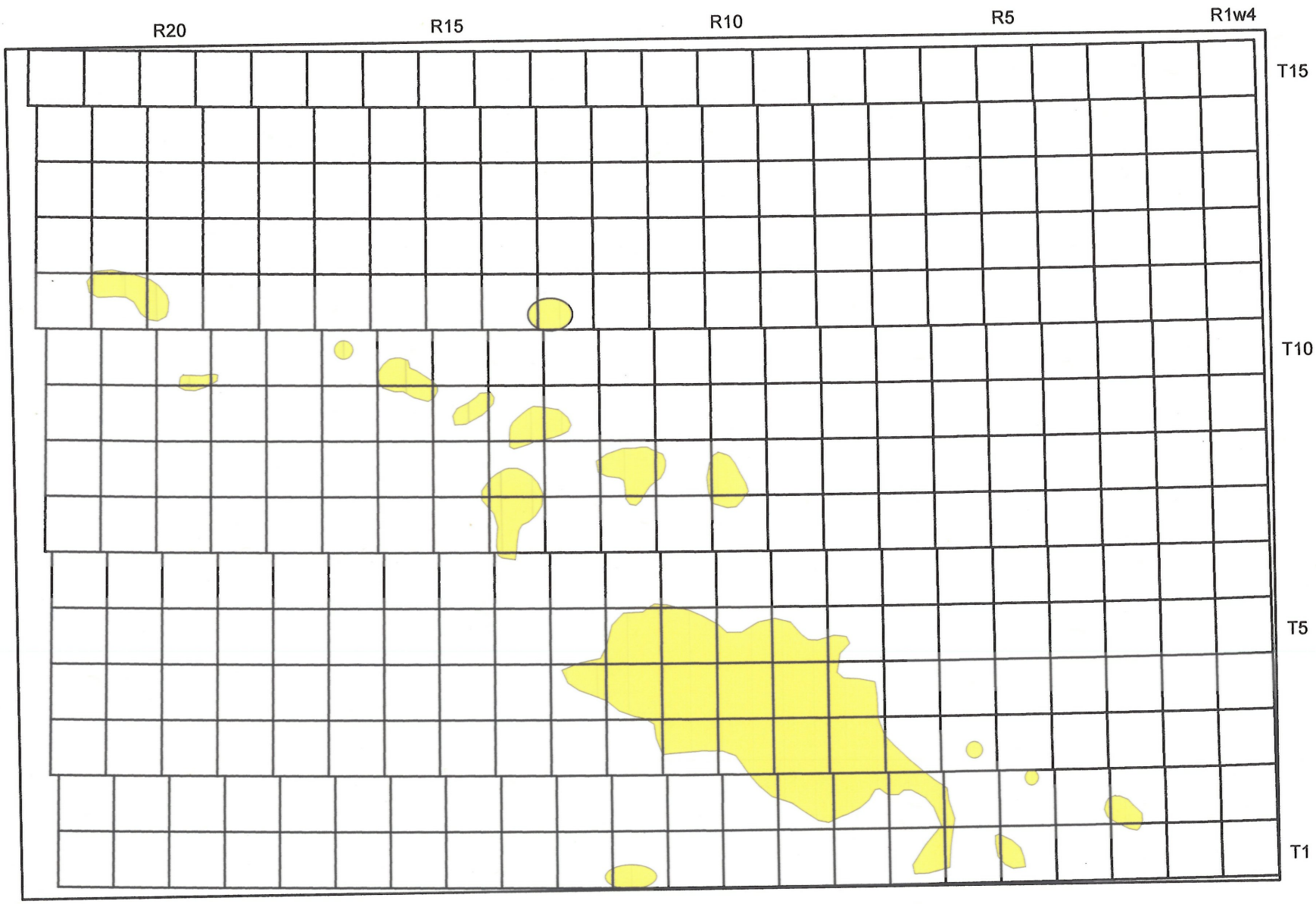


Figure 14 Virgelle V2 Sand Distribution

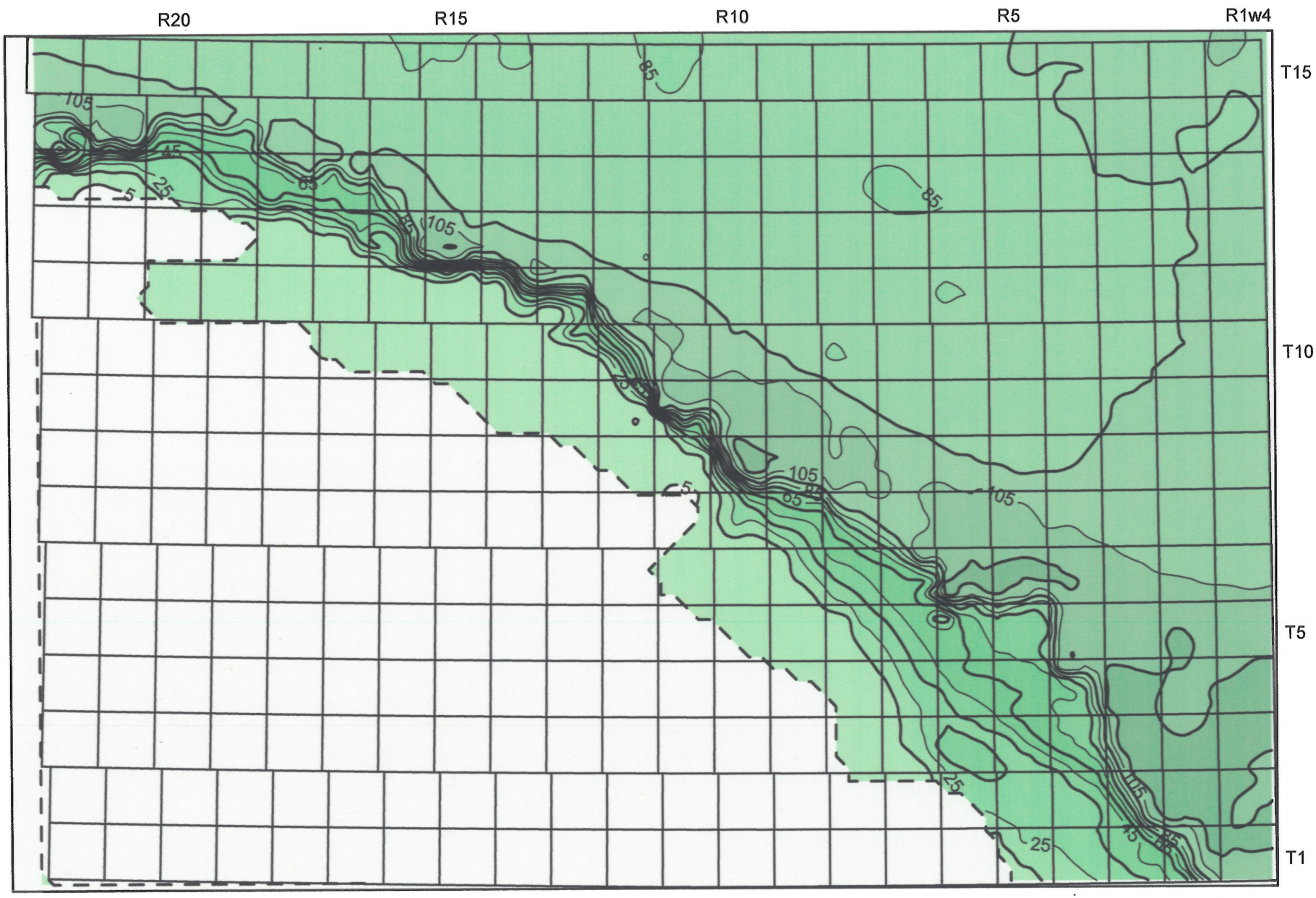


Figure 15 Alderson Isopach

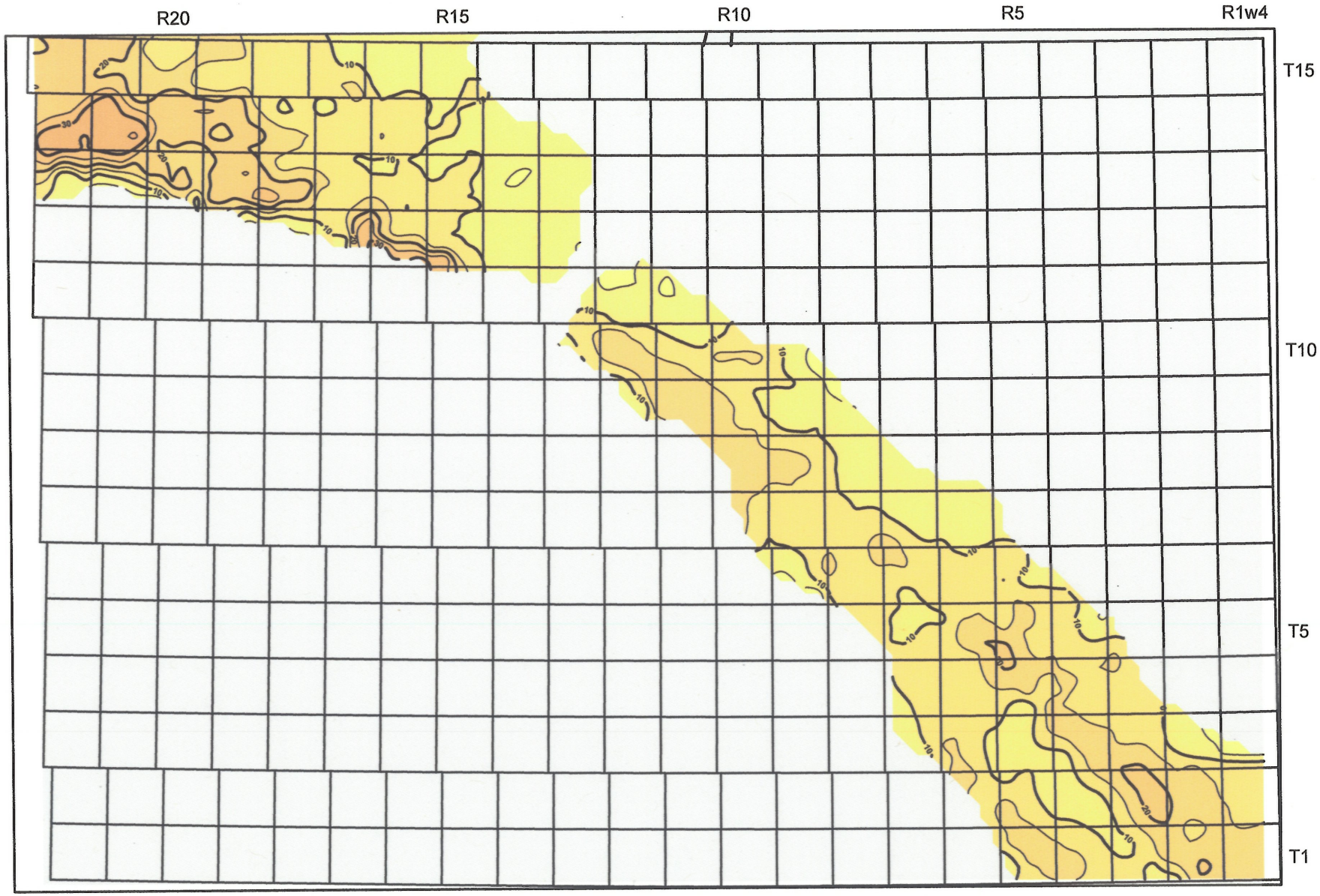


Figure 16 Upper Alderson Sand Isopach

that there was a significant reorientation of the regional Milk River shoreline in the northern part of the study area.

8. Upper Alderson 1 Sandstone *(figure 17)*

This sand is between 3m and 11m thick. It forms small lobate sand bodies with a general NW-SE trend. These sands occur as separate sand bodies below the main Upper Alderson Sand. Similar to the V2 Sand they are largely an artifact of the lithological mapping process, and can be included with the main Upper Alderson sand body.

9. Structure at the Milk River Top *(figure 18)*

The structure at the top of the Milk River illustrates the uplift the Laramide Sweetgrass Arch in this region. The Arch is a northward plunging compound antiform (Kent and Christopher, 1994). There is a relief of 800m from the northwest corner of the study area (250m) to the crest of the Arch at T1 R17w4 (1,080m). The contours show a radial pattern which dips gradually towards the east and northeast, but sharply drops away to the west in Ranges 21 and 22 where the Arch approaches the steeply dipping Rocky Mountain geosyncline. A broad 50m contour interval is shown here, but there are many contour deflections that indicate large fault zones associated with the Arch.

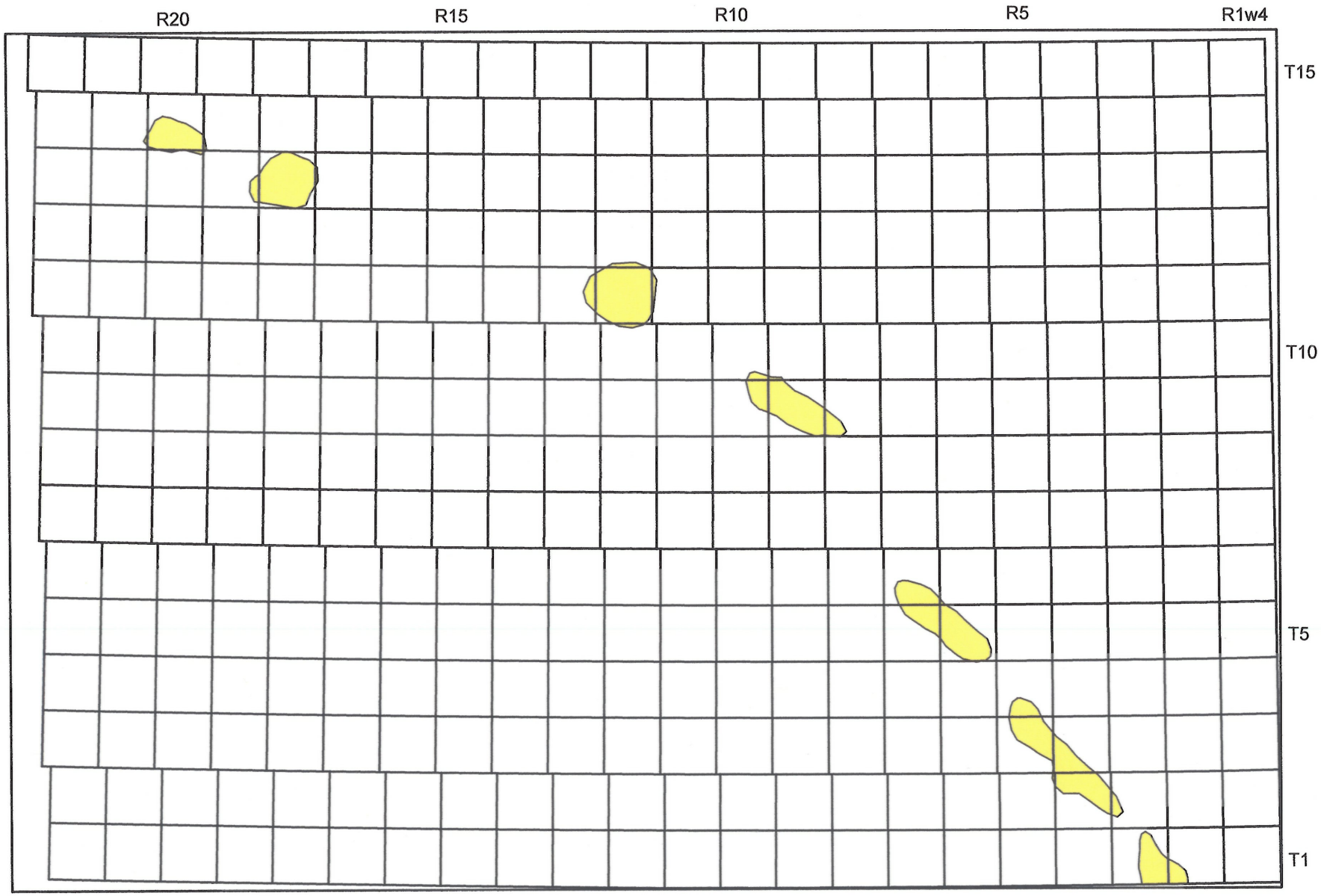


Figure 17 Upper Alderson 1 Sand Distribution
- values range from 3m to 11m

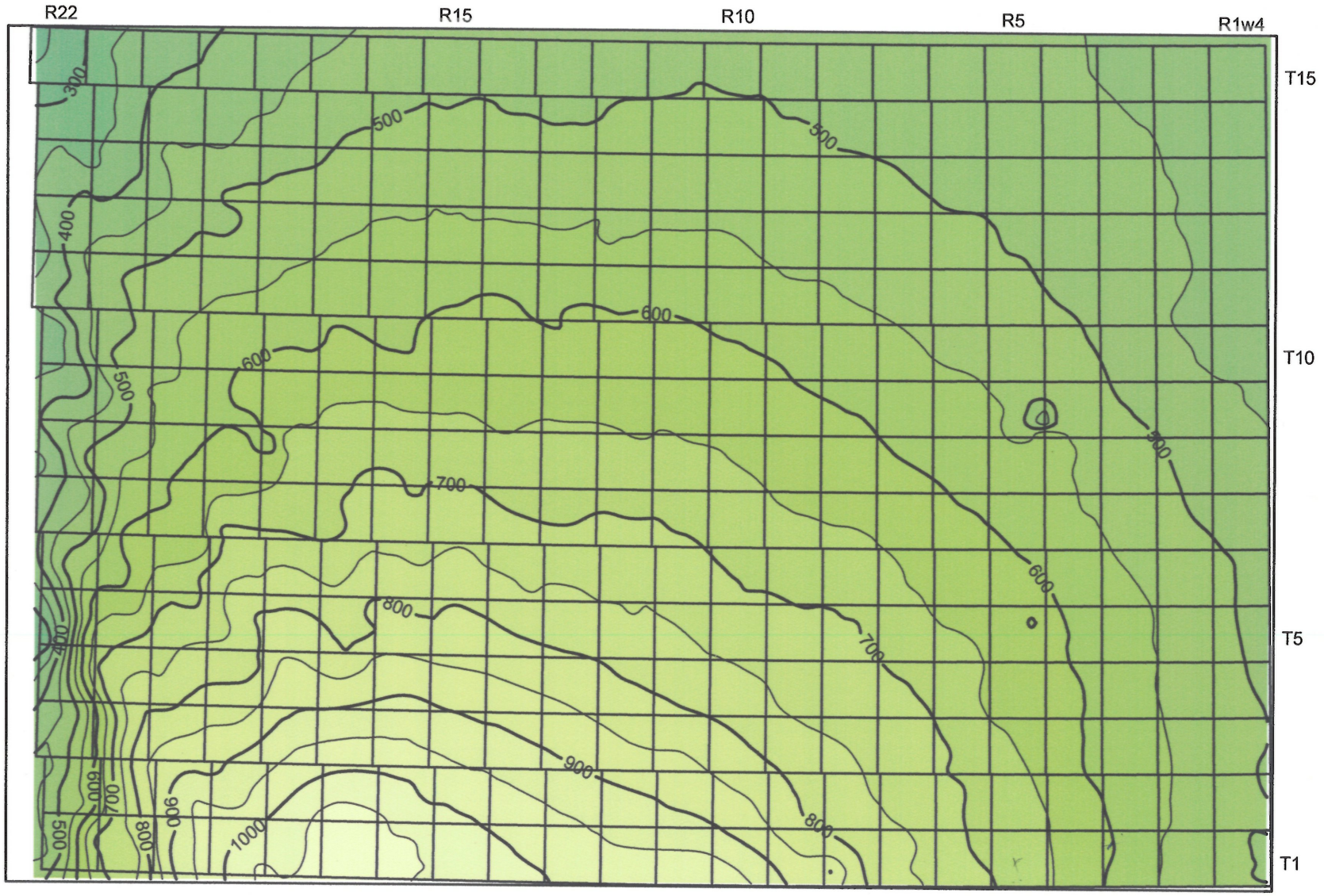


Figure 18 Structure at the top of the Milk River

Milk River Hydrogeology

Analyses of Milk River hydrology have been published by Meyboom (1961) Berkenpas (1991). These publications describe how Virgelle Member sandstones are exposed in outcrops along the Milk River at the crest of the Sweetgrass Arch in southern Alberta and northern Montana. This is an area of recharge; water enters the Virgelle sand in this area and flows downdip into the subsurface. It has been generally assumed that this meteoric water flow continues through the Milk River Formation to the southern edge of the Milk River Gas field, following the stratigraphic scheme of Meijer Drees and Mhyr (1981). A hydrodynamic trapping mechanism was proposed, and this is summarized in figure 18, from Berkenpas (1991).

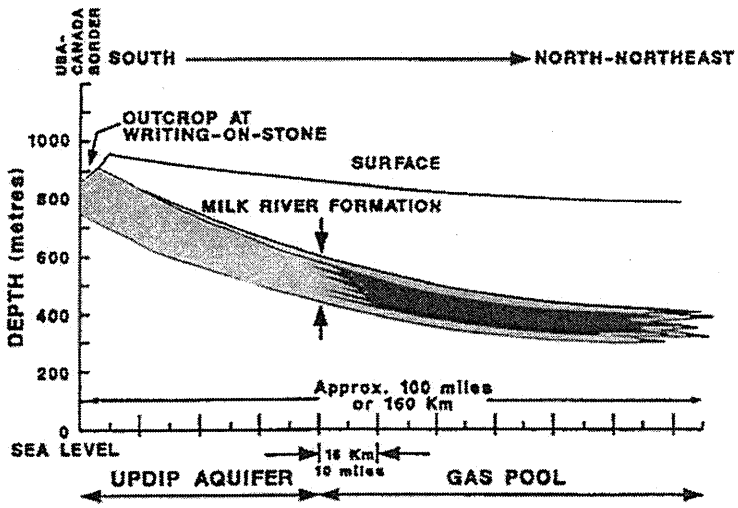
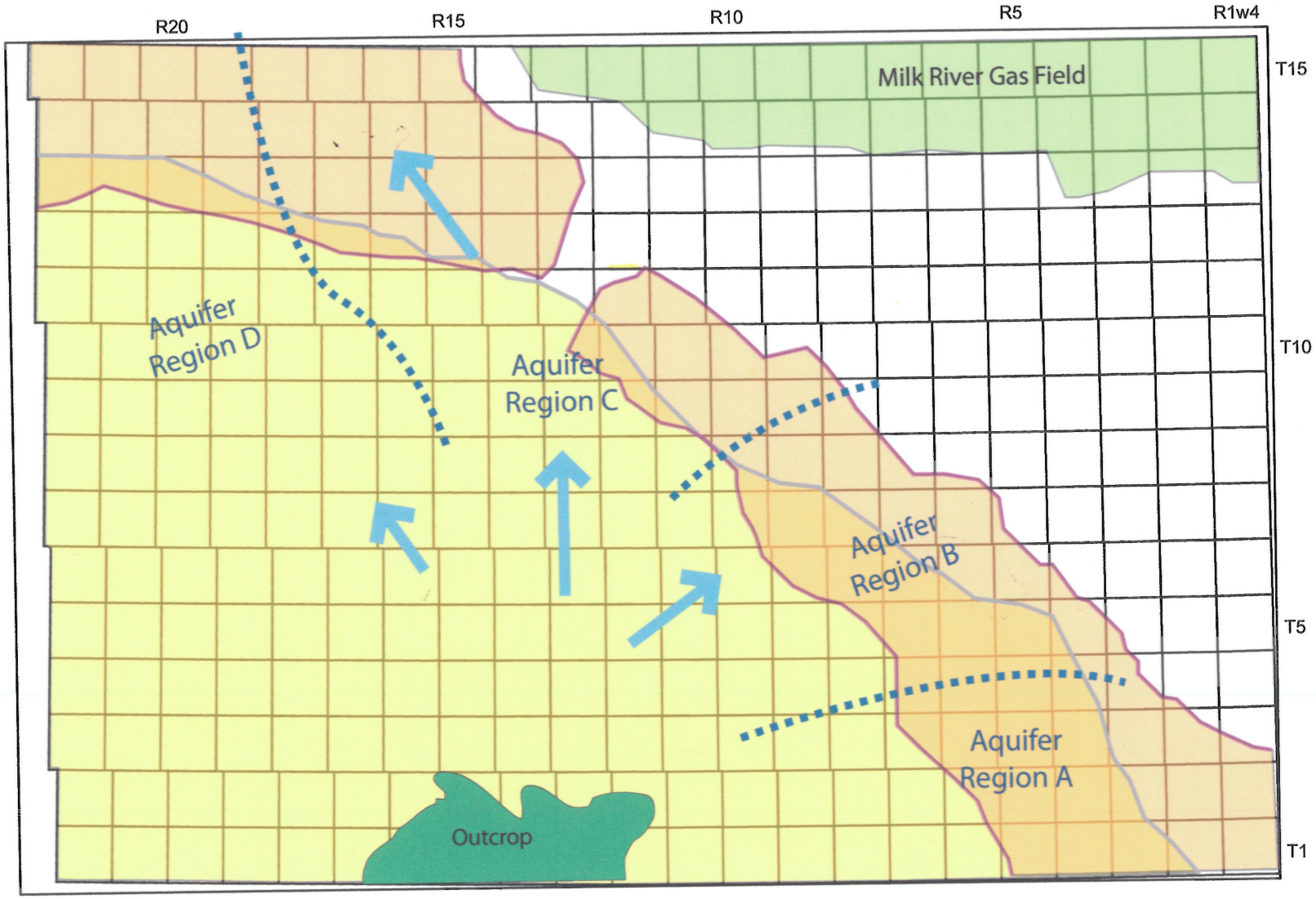


Figure 18 Relationship between the Milk River Aquifer and gas pool from Berkenpas (1991)

Berkenpas (1991) also constructed a series of pressure/depth plots to determine the flow relationships in the Milk River, and from these he mapped four regions of similar pressure trends in the aquifer. He shows the directions of water flow in the aquifer radiating outwards from the region of the outcrop. Figure 19 shows the Virgelle and Upper Alderson aquifer sandstones mapped in this study, and the southern edge of Milk



Northern edge of Virgelle Sand

Edges of the U. Alderson Sand

Milk River Production

Virgelle Aquifer Sand

Upper Alderson Aquifer Sand

Direction of water flow in the Aquifer (from Berkenpas, 1991)

Division between Aquifer Pressure Trend Regions (from Berkenpas, 1991)

Figure 19 - Location of Milk River Aquifer Sands, Milk River Production and Aquifer Pressure Trend Regions

river gas production. These are overlain by the pressure trend regions and the direction of water flow in the aquifer, as determined by Berkenpas (1991).

Several conclusions can be drawn from this summary diagram:

1. The main radial water flow to the north of the Milk River outcrop is contained within the Virgelle sand sheet.
2. There is northwesterly trending water flow within the northern Upper Alderson sand. This flow-trend is parallel to the southern edge of the Milk River gas field and appears to direct water flow away from the field area
3. The northern and eastern erosional edge of the Virgelle sand are between 4 and 12 townships to the south of the Milk River gas field.
4. The northern and eastern edges of the Upper Alderson sands are between 1 and 10 townships to the south of the Milk River gas field. Note that the cross-sections in this report show that the Upper Alderson sand is very thin at its northern and eastern edges and the sand is equivalent only to a small portion of the upper part of the Alderson section in the Milk River gas field.
5. The aquifer sands have no direct lithological connection to the Milk River gas field.
6. Meteoric, fresh water flow from the Virgelle and Upper Alderson sands have to flow through the Alderson Member in order to reach the southern edge of the Milk River gas field. The Alderson Member is predominantly mud with thin, discontinuous, low-permeability, very fine-grained muddy sands and silts.

In view of these lithological parameters and sandstone geometries it seems unlikely that hydrodynamic trapping is in effect at the southern edge of the Milk River gas field. It is also unlikely that water production from the Virgelle or Upper Alderson aquifer sands will affect Milk River gas production in any way.

The Whisky Creek Aquifer

This information about the Whisky Creek Aquifer is extracted from an online report by Baxter and Brown (2009) located at

http://www.esaa-events.com/watertech/2009/pdf/Presentation27.pdf

The Whisky Valley aquifer is a buried channel aquifer that underlies the Milk River in Warner County in southern Alberta, in T1 and T2, R15, 16 and 17w4, immediately south of the town of Milk River. The aquifer has an east-west trend and is 19km in length and between 1.5km and 6.5km wide. The aquifer averages between 5m and 10m in thickness, with a maximum thickness of 22m. A cross section indicates that the aquifer is underlain by till and 'shale bedrock' and that it does not incise into the Milk River Formation. However, the Milk River Formation lies very close to surface in this area and some contact between the Whisky Creek aquifer and the Milk River Formation seems likely.

Whisky Creek Hydrological inputs are:

Downward seepage – 42%

Lateral seepage – 3%

Upward seepage – 40%

From the Milk River – 15%

Whisky Creek Hydrological outputs are:

Upward seepage – 12%

Lateral seepage - < 1%

Downward seepage – 7%

To Milk River 74%

To water wells – 7%

Milk River Fracture Analysis

Little information has been published regarding Milk River fracture analysis. Fracture studies have been carried out by the oil and gas industry in order to optimize well placement, spacing, and to evaluate the occurrence of horizontal and vertical fracturing and their impact upon fracture treatments.

Surface tilt fracture mapping is used to obtain fracture azimuth and dip, while downhole tilt mapping is used to measure fracture length and height. Fracture mapping has shown that the average fracture azimuth in the southern part of the Milk River gas field are oriented to the NE. The median azimuth is about N65°E, with variations in the 20° to 40° range.

Horizontal fracturing does occur within the Milk River field area, but these are related to reservoir pressures. Horizontal fractures generally occurs in areas of higher pressures, and pressure depletion reduces the amount of horizontal fractures. A map of Milk River pressure distribution is shown in figure 20. This shows a large area of pressure depletion between T15 and T24 corresponding to long-term production in the mature Milk River field area. In the field areas fracture lengths become shorter from east to west, while vertical heights become larger. Pressures are typically low in the region of the Virgelle and Upper Alderson aquifers, but increase substantially to the west, approaching the thrust belt.

Large-scale structural analyses of the Sweetgrass Arch have been published by Herbaly (1974) and Kent and Christopher (1994). Generalised statements indicate that orthogonal fracture patterns in the region of the Sweetgrass Arch are related to the reactivation of basement fault zones.

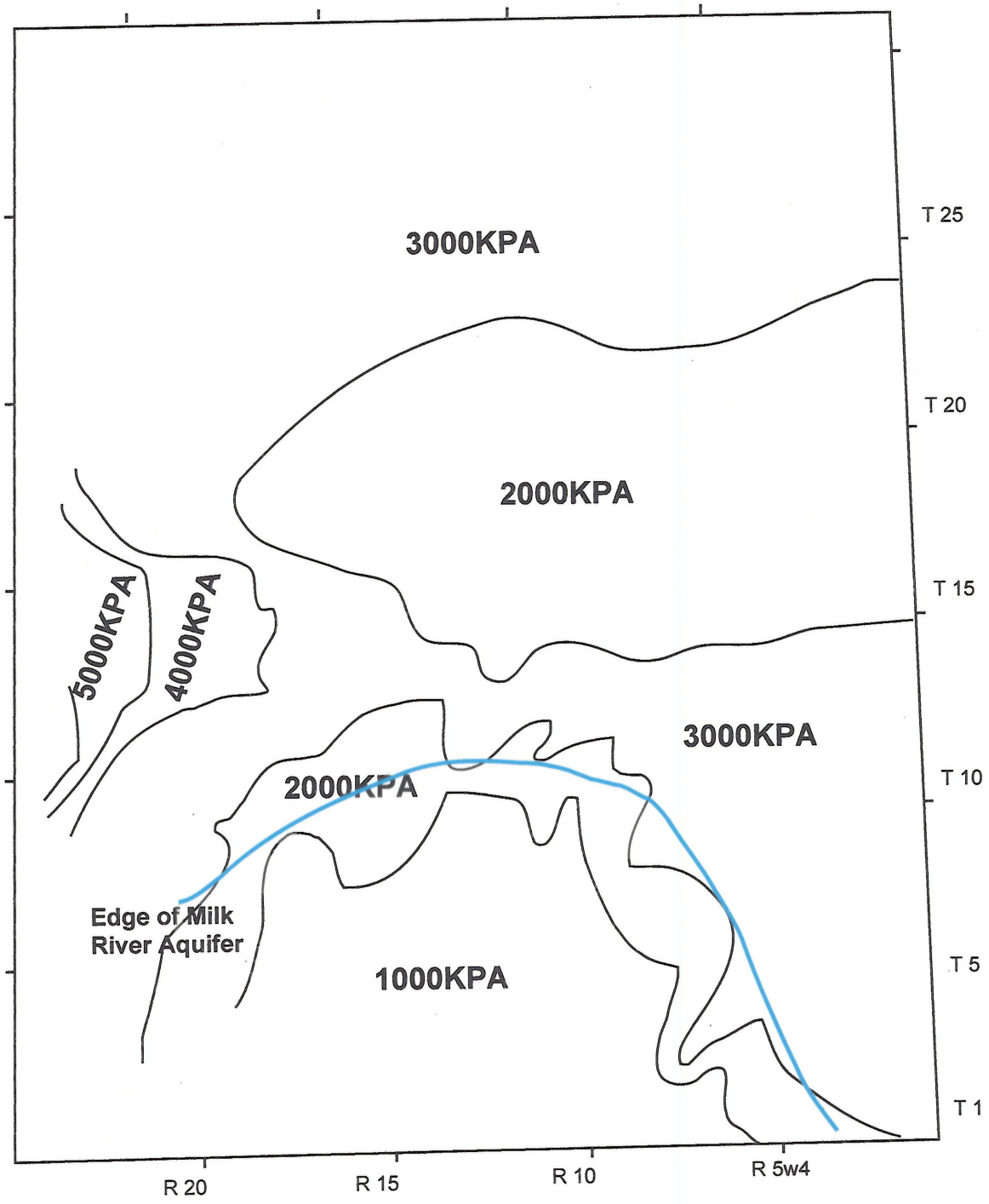


Figure 20 Milk River Pressure Map

Shaun O'Connell (unpublished;1996)

Conclusions

1. The Milk River aquifer consists of two regional sand units within the Milk River Formation. These are (i) the Virgelle Sand and (ii) the Upper Alderson Sand.

2. The Virgelle Sand is the largest aquifer sand. It is a continuous sand sheet up to 69m thick, covering an area of 175 townships. It is a composite sand consisting of many individual shoreline sand units and locally developed fluvial and estuarine channel sands. The Virgelle sand terminates in a northeasterly direction at a large, regional NW-SE trending erosion surface. Meteoric recharge in the area of the Sweetgrass Arch Milk River outcrop enters the Virgelle aquifer and flows into the subsurface.

3. The Upper Alderson Sand aquifer covers a total of 44 townships and is up to 38m thick. There are two separate Upper Alderson sand bodies, the southern sand has a NW-SE orientation, while the northern sand body has a WNW-ESE orientation..

4. The two aquifer sands are mostly separated by muddy sediments of the Deadhorse Coulee and Alderson Members, but they are in contact at the Virgelle erosional surface, and cross-formational flow is likely.

5. Both the Virgelle and Upper Alderson aquifer sands terminate well to the south of the Milk River gas field and are separated from it by muddy sediments of the Alderson formation, which acts as a barrier to water flow.

6. Because of the lithologies and sand geometries described here, it is unlikely that hydrodynamic trapping is in effect at the southern edge of the Milk River Gas field.

7. It is unlikely that water production from the Virgelle and Upper Alderson aquifer sands will affect operations or recovery in the Milk River gas field in any way.

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