Investigating Sequestration Potential of Carbonate Rocks during Tertiary Recovery from a Billion Barrel Oil Field, Weyburn, Saskatchewan: the Geoscience Framework (IEA Weyburn CO_2 Monitoring and Storage Project)

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Introduction

In Western Canada the application of CO_2 injection for enhanced, 'tertiary' oil recovery is a relatively recent addition to the arsenal available to reservoir engineers. The first successful application of CO_2 as a miscible fluid in Western Canada began in 1984 at Joffre Field, a Cretaceous marine siliciclastic reservoir in southern Alberta. A significant portion of the remaining proven conventional oil reserves in Western Canada, however, reside in large mature Paleozoic carbonate fields, such as the Mississippian Weyburn Field in SE Saskatchewan (Figure 1). In combination with economically dictated tertiary recovery schemes, these large fields could provide attractive geologic sites for future sequestration of greenhouse gases. An immediate challenge to geoscientists is to assess the ability of these geologic containers to store CO_2 for geologically significant lengths of time.

The CO_2 miscible flood recently initiated by PanCanadian Resources at the Weyburn Field provides an ideal natural laboratory to begin an investigation into this assessment process. To this end, the International Energy Agency (IEA) and a consortium of industry and government partners have designed a comprehensive suite of research and monitoring activities that focus on understanding the regional geologic context of the reservoir, assessing its CO_2 storage capabilities, providing baseline characterization of the rock-fluid reservoir medium, as well as monitoring the progress of the miscible front.

This paper summarizes the local reservoir geology of the Weyburn Field and outlines the specific initiatives underway through the IEA to provide one of the critical components of the Monitoring and Storage Project, the broader geoscience framework of the field.

Geology of the Weyburn Field

Production history

The Weyburn Field (Figure 2) covers an area of about 180 km^2 (70 square miles) and produces 29 API gravity crude oil from Mississippian shallow-water carbonates at a mean depth of 1450 m. Pay thickness ranges from 5 m to over 30 m with an average of about 10 m. Following its discovery in 1954, the Weyburn Field was produced by primary depletion for about 10 years. In an effort to arrest declining production an inverted nine-spot waterflood scheme was introduced in 1964 targeting the higher permeability lower limestone member of the Midale carbonate. After achieving maximum rates of more than 7000 m^3/day by 1966, pool production declined to less than 2000 m^3/day by 1985. An aggressive vertical infill drilling program (to 40-60 acre spacing) began in 1986; it successfully arrested production decline and returned production to almost 4000 m^3/day. Horizontal drilling was introduced at Weyburn in 1991 and became the preferred production strategy over the ensuing 10 years. Unlike the earlier vertical phase, horizontal drilling now targeted the largely unswept reserves in the low-permeability, high-porosity dolostones within the upper Midale. By the mid-1990s, planning for a CO_2 miscible flood was well underway and CO_2 injection began in the fall of 2000 in the 19 pattern, Phase 1A area (Figure 2). A variety of engineering, geochemical and seismic efforts are currently underway to monitor progress of the miscible front and optimize sweep efficiency.

Regional setting – the trap

The 1.4 billion barrel (0.2 billion m^3) Weyburn Field in southeast Saskatchewan is one of several large oil fields discovered along the Mississippian subcrop belt of northern Williston Basin (Figure 3). Reservoired hydrocarbons have accumulated in a series of combined stratigraphic, diagenetic and hydrodynamic traps. Progressive northeasterly incision of the Mississippian succession below the sub-Jurassic unconformity has created ideal trapping conditions where porous shallow-marine carbonates are regionally juxtaposed against relatively impermeable, fine-grained ‘red bed’ siliciclastics of the Triassic to Jurassic Watrous Formation (Figure 4). The efficiency of hydrocarbon trapping at the Mississippian subcrop is further enhanced by widespread occurrence of primary cycle-capping anhydrites within the Mississippian section, as well as widespread development of a sub-unconformity diagenetic “caprock” of anhydritized dolostone (Kendall, 1975; Kent, 1987, 1999). More locally, such as at Weyburn, a ‘hydrodynamic’ trapping component is also created by the presence of high irreducible water saturations in updip, very low-permeability cryptocrystalline dolostones underlying the unconformity. The development of such subtle hydrodynamic traps is documented in some detail by Coalson *et al*., 1994.

The presence of bottom seal across the Weyburn Field is more problematic. With the exception of northerly margins of the field where the Frobisher Anhydrite is present, Midale reservoir carbonates directly overlie dolostones of the Frobisher Marly. Furthermore, historical drill stem test results and log evaluations suggest that the original free-water level within the field extended well into the Frobisher beds (Weyburn Sub-Committee, 1962). In reality, however, significant communication with Frobisher reservoirs is tempered by widespread occurrence of metasomatic anhydrite replacement at the base of the Midale and by scarcity of reservoir-quality units within the upper Frobisher beds (Frobisher Marly beds under Weyburn are generally dominated by non-reservoir argillaceous, silty and anhydritic dolostones and marls). On the reservoir production time scale, therefore, communication with Frobisher reservoirs is probably local and limited.

Midale stratigraphy

At Weyburn Field, oil is trapped within Osagean-age Midale strata of the Madison Group (Figure 4). As is common throughout the upper Mississippian succession of the Williston Basin, alternating porous carbonates and impermeable anhydrites record fluctuating sea levels and episodic isolation and evaporation within a shallow water intracratonic basin. The reservoir is sandwiched between low permeability dolostones and anhydrites of the Frobisher and anhydrites of the Midale Evaporite. Though locally reduced in thickness to only a few metres by erosion on the sub-Jurassic unconformity, the Midale Evaporite forms a regional top seal across the field. Figure 5 illustrates Midale stratigraphy relative to a typical reservoir log response.

The Midale carbonate reservoir is subdivided into two informal lithostratigraphic units: a lower limestone-dominated unit called the "Vuggy", and an upper, mainly dolostone unit referred to as the "Marly" (Figure 5). Thicknesses vary from 10 to 22 m in the Vuggy and 1 to 11 m in the Marly. Recent core-based sequence stratigraphic interpretation by PanCanadian (Figure 6) indicates that the Vuggy can be further subdivided into two sequences separated by a mappable surface of subaerial exposure and erosion. A heterogeneous package of calcareous algal/coated-grain/pisolitic wackestones, packstones and grainstones, with visible "vuggy" and fenestral porosity, is characteristic of the lower Vuggy. Patchy cementation by calcite, anhydrite and dolomite add to the overall heterogeneity. Internal higher order cyclicity within the lower Vuggy permit further breakdown of this unit for purposes of reservoir modelling (V2-V6; Figure 6). Mapping of the lower Vuggy interval reveals a generally northeasterly trend of 'shoal' thicks and intervening 'intershoal' thins (Figure 7).

The overlying upper Vuggy sequence is distinguished in core by the general absence of coarse vuggy porosity and depositional fabrics dominated by abraded skeletal packstones and wackestones. Upper Vuggy thickness generally varies inversely with that of the lower Vuggy with thick upper Vuggy intervals associated with thin, 'off-shoal' areas of the lower Vuggy.

Mud-dominated fabrics of the high porosity, microsucrosic Marly dolostones abruptly overlie the upper Vuggy. Isopach mapping of the Marly interval illustrates a generally southwestward thickening wedge that, in cross-section, appears to onlap the upper Vuggy surface to the northeast. Two Marly layers (M1 and M3; Figure 6) are distinguished based on widespread development of a low porosity, calcareous marker bed (M2) within the Marly. Below the capping Midale Evaporite, a thin (1 - 3 m thick) transitional unit made up of laminated, silty and anhydritic dolostones is commonly referred to as the "Three Fingers" (due to its characteristic gamma response; see Figure 5). This unit is considered to be non-reservoir facies in most areas.

Depositional environments

Several authors including Kent (1984, 1999) and Lake (1998) have discussed regional aspects of Mississippian Madison Group deposition within the Williston Basin. These authors are in general agreement that the characteristic style of sedimentation was that of a periodically restricted, shallow epeiric sea. Typical features include extremely shallow depositional slopes coupled with predominance of shallow-water facies exhibiting abrupt vertical facies transitions on a regional scale. The carbonate reservoir at Weyburn represents an erosional remnant of a considerably more extensive marginal ramp on the northern flank of the Williston Basin. Recent sedimentological studies by PanCanadian on cores in the Phase 1A area suggest the presence of four distinct depositional settings that reflect responses of an intracratonic epeiric ramp to significant eustatic fluctuations. The inferred spatial relationships of these environments are summarized in Figure 8.

Initial lower Vuggy deposition occurred in response to the early phases of a major transgression over the Frobisher surface. Stacked strongly progradational cycles with evidence of repeated subaerial exposure record deposition within a marginal marine, peritidal island/lagoon complex. This style of sedimentation ceased abruptly in response to major sea level fall and further subaerial exposure. Up to 8m of relief on the lower Vuggy surface developed due to a combination of depositional topography and erosional incision. Considerable porosity enhancement probably also occurred at this stage.

Significant sea level rise over the eroded lower Vuggy resulted in major inundation of the shelf and change in depositional setting to a dominantly subtidal, open-marine mid-ramp influenced by storm- and wave-reworking. Blanket-like deposition of the distinctive non-vuggy, skeletal-rich beds of the upper Vuggy largely obliterated pre-existing lower Vuggy topography.

A hiatal surface, represented by a widespread *Thalassinoides*-burrowed layer, marks the onset of a third major shift in depositional style within the Midale beds. Grain-dominated textures characteristic of the upper Vuggy sequence abruptly give way to extensively bioturbated, mud-dominated textures in the overlying Marly sequence. The predominance of skeletal and non-skeletal algal remains, ostracods and the introduction of terrestrial silt and clay suggest basinal shift of facies to a more proximal, quiet-water subtidal setting. The apparent regional extent of these environments seaward of an evaporitic coastal plain, represented by the overlying upper Marly and Midale Evaporite, argues for deposition within an extensive epeiric lagoon that may have developed in response to regional isolation of the Williston Basin. Depositional environments may have included both relatively deep, outer ramp equivalents in distal areas and very shallow restricted euryhaline bays in more proximal areas. Within the Marly an overall brining-upward and shallowing-upward succession is suggested by the upward change from a diverse Cruziana ichnofacies to a *Planolites/Chondrites*-dominated ichnofacies with preserved algal lamination (see Keswani and Pemberton,1993). Marly deposition culminated in silty, anhydritic tidal flat and sabkha dolo-laminites of the upper Marly “Three Fingers” zone. Subsequent deposition of the Midale Evaporite records the final shift to a fully coastal marine to continental evaporitic setting comprising extensive salina and playa deposits.

Reservoir characteristics

Table 1 summarizes the key reservoir attributes of the Midale beds in the Weyburn Field. Markedly different flow characteristics between the lower Vuggy, upper Vuggy and Marly reflect the combination of a) different primary depositional settings and textures, b) markedly different secondary diagenetic overprints, and c) varying rheological responses to imposed stress. Lower Vuggy reservoir characteristics (extreme heterogeneity, low to moderate porosity, low to high permeabilities) are predictable products of texturally diverse peritidal deposits overprinted by a complex history of near-surface and burial dissolution and cementation. On the other hand, the relatively homogeneous reservoir characteristics of the upper Vuggy (low to moderate porosity, low permeability) directly reflect more uniform, finer grained depositional textures and absence of strong diagenetic overprints.

Reservoir characteristics of the Marly (relatively homogeneous, high porosity, low permeability) are, foremost, a function of early dolomitization of ‘bio-homogenized’, mud-dominated fabrics. Variations in reservoir quality within the Marly occur mainly in response to variations in degree of dolomitization, and a general upward trend to finer crystalline, lower permeability fabrics. Severely reduced reservoir quality is commonly associated with partial dolomitization within either thin skeletal-rich packstones or organic-rich, microstylolitic beds; both of these are widespread at the top of the M3 zone and combine to form a correlatable low-permeability zone separating M1 and M3 layers.

Fractures

One of the more prominent features of the Weyburn Midale reservoir is the presence of sub-vertical natural fractures, both open and cemented. Not only are these obvious in numerous well cores, but are also clearly imaged on borehole image logs. Analysis of these image logs indicate that the dominant fracture orientation is parallel to the current SW–NE orientation of maximum horizontal stress (Bell and Babcock, 1986; Adams and Bell, 1991). Secondary fracture trends in more SE–NW orientations have also been defined (Bunge, 2000). Previous core studies at Weyburn (Churcher and Edmunds, 1994) have estimated fracture spacing at between 0.3 and 10 m with highest densities in the upper Vuggy and lowest in the Marly. The low fracture density in the Marly at first appears to be inconsistent with the normally more brittle response of crystalline dolostones. However, the very high porosities and sucrosic textures typical of the Marly dolostones appear to have induced a more ductile response to stress.

Whereas the presence of significant fracturing at Weyburn is indisputable, the degree to which these fractures affect directional reservoir permeability, flow characteristics and producibility is more difficult to determine. Perhaps the strongest evidence for influence of fractures is the pronounced preferred “on-trend” water breakthrough response during waterflood. However, much of this effect is possibly a by-product of northeasterly propagation of fractures under high injection pressures, combined with the preferred northeasterly orientation of the high-permeability lower Vuggy shoals. Furthermore, history matching of the breakthrough response does not require permeabilities significantly higher than average, core based matrix permeabilities. PanCanadian’s analysis of scattered pressure transient data also does not easily support strong dual porosity reservoir behaviour. The classic dual porosity response may, however, be partly masked by either the interaction of the markedly different Marly and Vuggy flow systems, or the homogenizing effect of microfracturing, which is widely observed in thin sections of the lower Vuggy.

These ambiguities have made it difficult to develop a satisfactory, comprehensive fracture model for the Weyburn reservoir. The extent to which fractures will influence CO_2 flood performance remains a key issue to be addressed by the IEA Weyburn CO_2 Monitoring and Storage Project. One of the avenues PanCanadian and the IEA are pursuing is the acquisition of multicomponent 3-D seismic data to assist in spatial characterization of the fracture system.

Flood monitoring

A critical element of successful, efficient tertiary recovery schemes involves diligent monitoring of flood conformance as well as the overall progress of the flood front. PanCanadian is addressing this process through monitoring of production fluid composition and volumes, chemical tracer studies and muticomponent 4D seismic.

Production testing on individual wells will be done at regular intervals in five newly constructed satellite stations. Each satellite is equipped with a three-phase test separator for measuring oil, water and gas flow rates. Produced gas is monitored for CO_2 using infra-red analyzers and dragar tube sampling. Samples of produced oil, water and gas will be periodically collected for more detailed compositional analysis. A tracer study will be implemented in March 2001 using perflourocarbons to trace CO_2 injection gas at seven injection wells. The study will determine CO_2 conformance in three flood patterns and assist in designing flood operations. A screening study has also been initiated at University of Regina to evaluate commercially available CO_2 surfactants and diverting agents for CO_2 mobility control.

Together with Colorado School of Mines, PanCanadian will be acquiring four multicomponent 3-D seismic surveys within the initial Phase 1A area over a period of about three years; the key baseline survey was acquired in 1999. The seismic surveys use the latest acquisition techniques to acquire both P and S wave data in an attempt both to monitor the progress of the flood front and to assist in improving spatial resolution of reservoir properties (porosity-thickness and fracture-permeability). Interpretation of the seismic data is being enhanced by the co-ordinated acquisition of two multicomponent 3-D vertical seismic profiles (VSPs) as well as single-well and cross-well (horizontal to horizontal) seismic tomography.

IEA Monitoring and Storage Project – Investigating the Broader Geoscience Framework

Background

The prime long-term objective of the IEA Weyburn CO_2 Monitoring and Storage Project is to assess the capacity of an oil reservoir to store CO_2 over time. A multinational, multidisciplinary approach is being used, with six main task areas initially involved: 1) collecting field data and samples; 2) investigating the broader geoscience framework; 3) geochemical sampling, monitoring and prediction; 4) monitoring CO_2 movement; 5) evaluating CO_2 storage performance; and 6) calculating the economics of CO_2 storage. The results of the project, which are likely to have worldwide significance for sequestration of anthropogenic greenhouse gases, are expected to be publicly available in 2004 or 2005. The overall budget is estimated at over $14 million (Canadian). Whilst a substantial proportion of the required funding is now in place, efforts to obtain the balance continue.

Task objectives

To help the project to meet its objective, the main problems to be investigated in the geoscience framework task area include: i) the distribution of porosity and permeability within the Weyburn reservoir, in laterally equivalent strata and in underlying and overlying rocks, ii) the distribution and role of fractures within the Weyburn reservoir, in laterally equivalent strata and in underlying and overlying rocks, iii) the distribution of fluids within the Weyburn reservoir, in laterally equivalent strata and in underlying and overlying rocks, iv) factors controlling the distribution of porosity, permeability, fractures and, ultimately, fluid flow; v) migration pathways of the injected CO_2 ; and vi) CO_2 trapping mechanisms in the reservoir. Resolving such problems requires understanding of the relationships between sedimentation, diagenesis, salt dissolution, tectonics, and fluid flow pathways and barriers within the entire sedimentary section. The geoscience framework studies will investigate these relationships from the contact of Precambrian crystalline basement with Cambrian sediments to the present-day surface for a distance of up to 100 km from the Weyburn Field (Figure 9).

Approach

The geoscience framework task area has been subdivided into six main components: 1) pre-Mississippian geology; 2) Mississippian and post-Mississippian geology; 3) hydrogeology; 4) reflection seismic studies; 5) geoscience synthesis and 6) incorporation of detailed Weyburn Field geological information. In order to produce valid and valuable results, the need to assemble a team with expertise in different geoscience disciplines was recognized from the project's early beginnings in 1999. Saskatchewan Energy and Mines took a lead role in inviting experts from the earth sciences departments of several western Canadian universities to participate (Figure 2). Also recognized was the need for a contract research scientist who, based with Saskatchewan Energy and Mines, will co-ordinate the various tasks and have overall responsibility for synthesizing and interpreting the various datasets to build a comprehensive geoscience framework of the study area.

Saskatchewan Energy and Mines, under the leadership of Chris Gilboy, is responsible for pre-Mississippian geology (component 1) and for co-ordinating the task area and synthesizing resultant geoscience information (component 5). Research into the geology of Devonian strata, with emphasis on evaporite distribution in the study area, will be led by Kim Kreis. Fran Haidl will co-ordinate studies of the influence of the geological evolution of pre-Mississippian strata on the sedimentology, diagenesis, and distribution of porosity and permeability in Mississippian reservoirs.

The University of Regina, under the leadership of Dr. Hairuo Qing, is to study the geology of Mississippian and post-Mississippian strata (component 2) with emphasis on stratigraphic, sedimentological, diagenetic and fracture-trend analyses. Dr. Katherine Bergman is a co-researcher with responsibility primarily for studies of the clastic strata overlying Mississippian rocks.

The University of Alberta, under the leadership of Dr. Ben Rostron, is responsible for quantifying the 3-D fluid-flow rates and directions with a primary objective of identifying potential CO_2 leakage pathways (component 3).

The University of Saskatchewan, under the leadership of Dr. Zoli Hajnal, is initially to reprocess existing seismic reflection and wireline information, then, in collaboration with the co-ordinating geoscientist, to integrate the resulting data with geological information supplied by other team members to build a three-dimensional stratigraphic model of the study area (component 4).

PanCanadian Resources, through its Voyageur Business Unit, will provide geological expertise and information that is helpful towards clarifying understanding of geological relationships in and immediately around the Weyburn Field (component 6).

Summary of current status

In mid-February, 2001, first-phase (2001) budgets were allocated to team partners in the following amounts:

University of Alberta – $50,000

University of Saskatchewan – \$148,000
University of Regina – \$50,000
Saskatchewan Energy and Mines – \$110,000.
Total: \$358,000.
At the time of writing, various agreements have to be signed and other minor logistical obstacles overcome before research into the geoscience framework of the wider Weyburn area begins in earnest.

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Figure Captions

Figure 1. Location of the Weyburn Field, Williston Basin.

Figure 2. Summary of Weyburn reservoir data showing outline of field and initial Phase 1A area of the CO_2 flood.

Figure 3. Mississippian subcrop trends and oilfields, Williston Basin (from Kent ,1985).

Figure 4. Mississippian stratigraphy, SE Saskatchewan.

Figure 5. Typical log response and major reservoir zones within the Midale reservoir.

Figure 6. Midale geological model illustrating depositional sequences and reservoir flow units.

Figure 7. Generalized distribution of Midale Vuggy shoal and intershoal areas, Weyburn Field (from Churcher and Edmunds, 1994).

Figure 8. Diagrammatic representation of Midale depositional environments.

Figure 9. Location of the IEA CO_2 Monitoring and Storage Project's Geoscience Framework study area.

Figure 10. Information-flow diagram for participants in the Geoscience Framework synthesis (not shown are the direct links between 1 and 4, and 2 and 3).

Table 1. Summary of Midale reservoir characteristics, Weyburn Field.

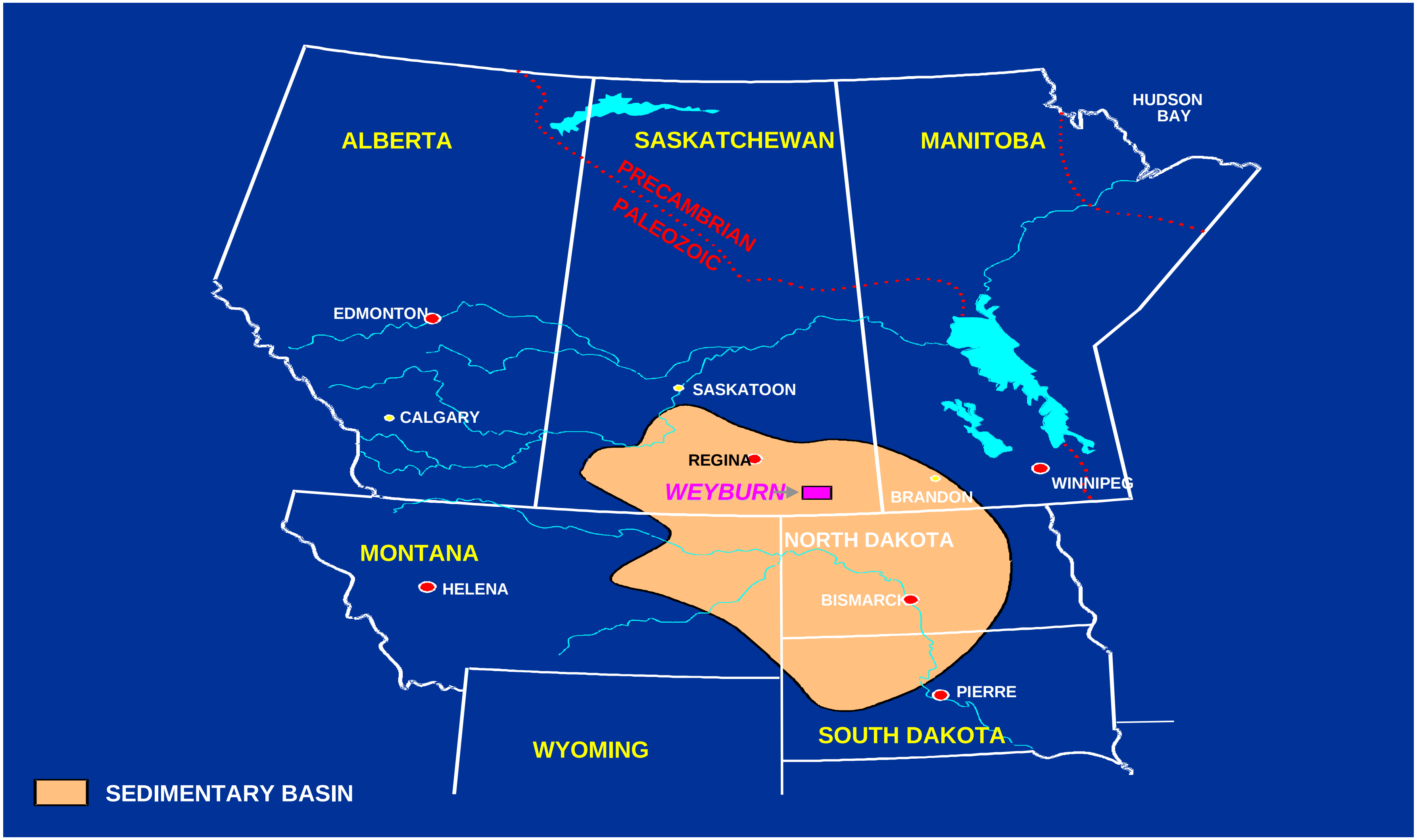

HUDSON BAY
ALBERTA
SASKATCHEWAN
MANITOBA
PRECAMBRIAN
PALEOZOIC
EDMONTON
SASKATOON
CALGARY
REGINA
WEYBURN
BRANDON
WINNIPEG
MONTANA
NORTH DAKOTA
HELENA
BISMARCK
PIERRE
SOUTH DAKOTA
WYOMING
SEDIMENTARY BASIN

Fig. 1

Discovered:	1954
Area:	70 sq. miles
Current oil rate:	18,000 BOPD
Number of wells:	1016 total 660 vert. oil 158 hz. oil 197 inj.
Sour crude:	25-34 API
Depth:	1450m (4760 ft)
OOIP:	1,400 MMbbls
Cum. Prod. (12/98):	351 MMbbls
Total recovery to date:	25%

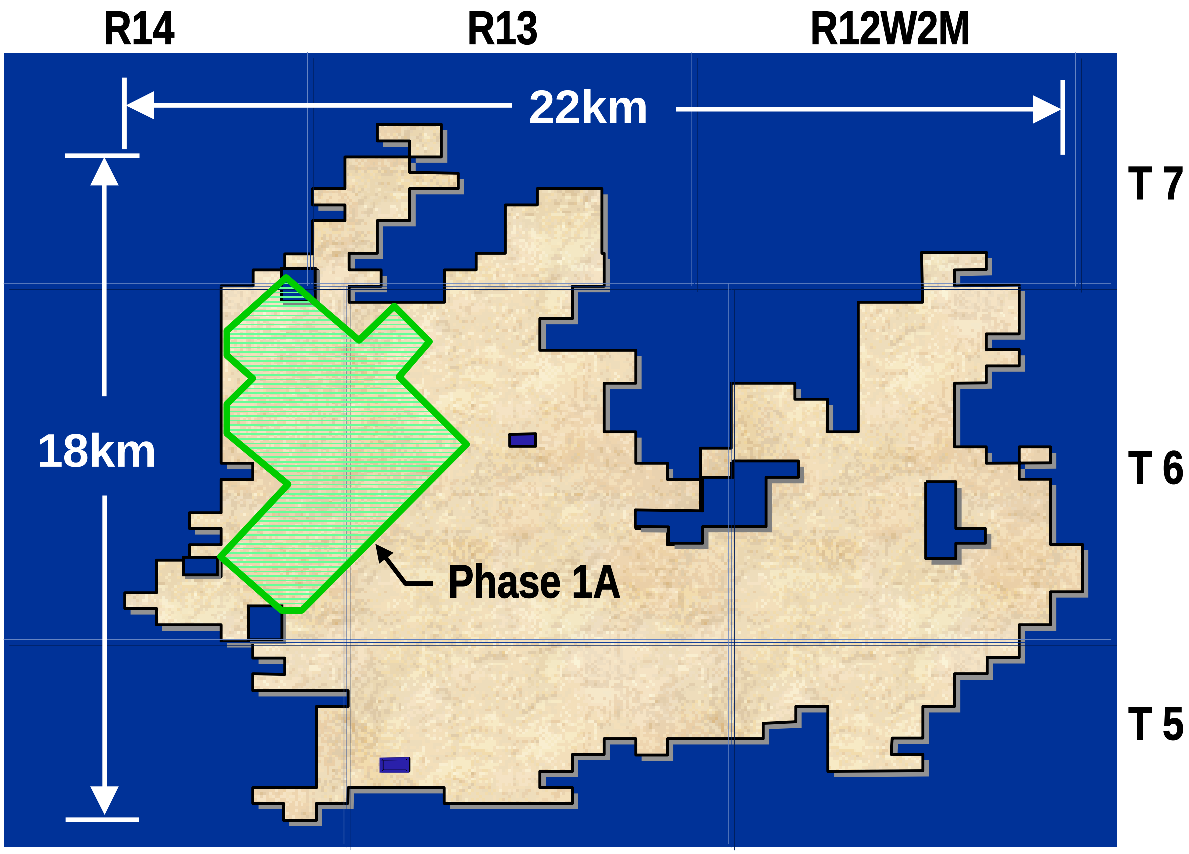
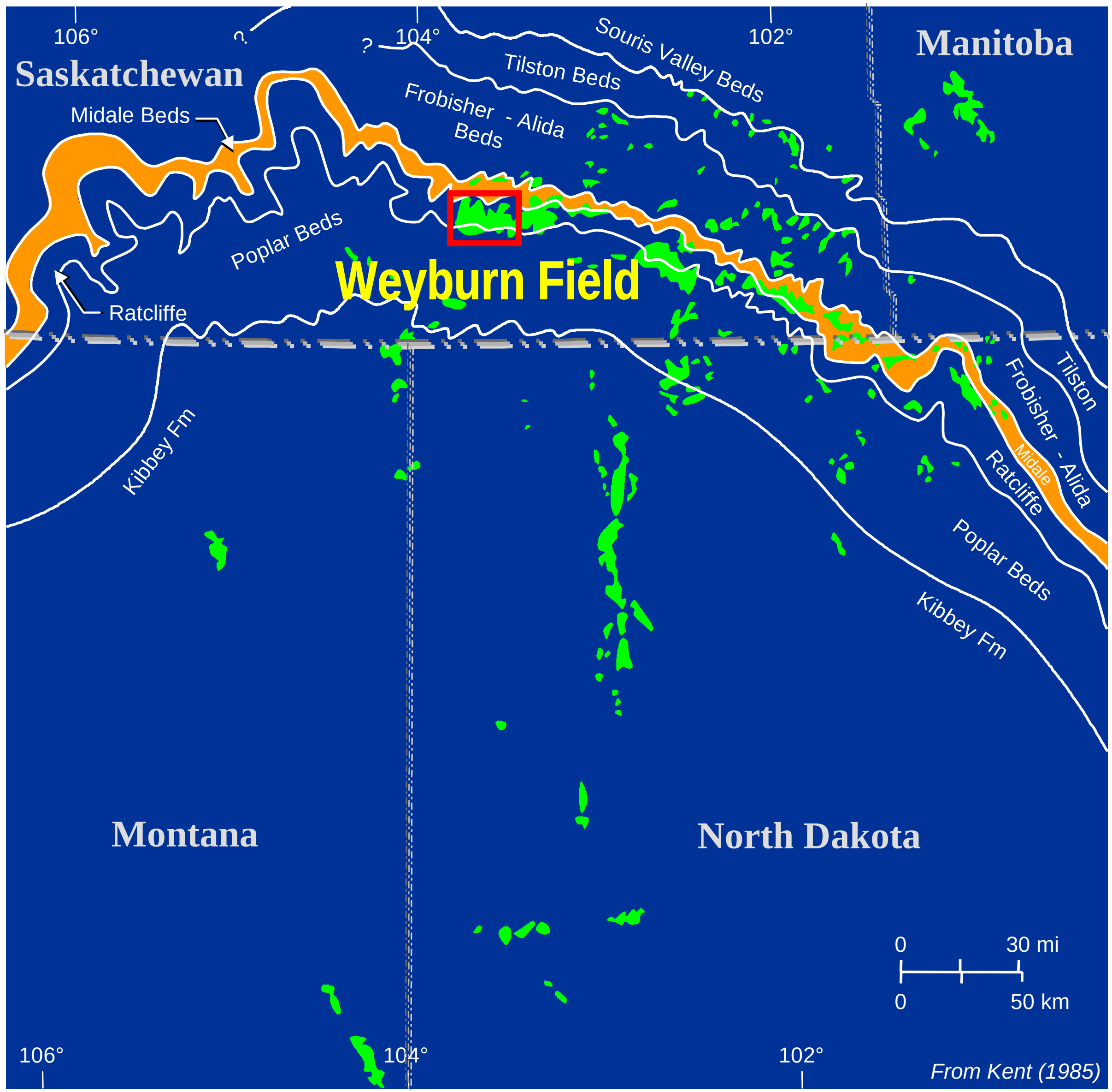


Fig. 2



From Kent (1985)

Fig. 3

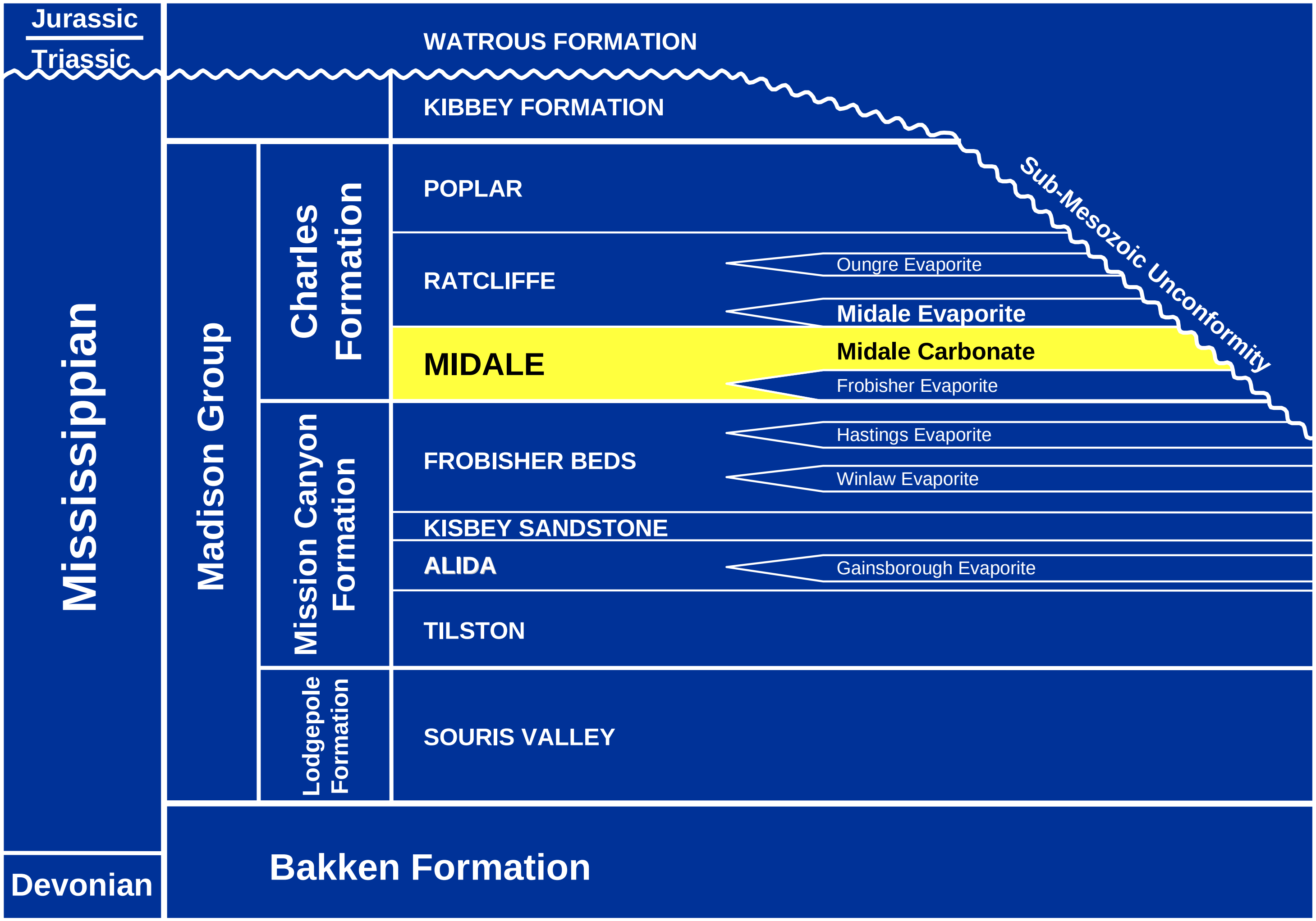

Jurassic
Triassic
WATROUS FORMATION
KIBBEY FORMATION
Mississippian
Madison Group
Charles Formation
POPLAR
RATCLIFFE
Oungre Evaporite
Midale Evaporite
MIDALE
Midale Carbonate
Frobisher Evaporite
Sub-Mesozoic Unconformity
Mission Canyon Formation
FROBISHER BEDS
Hastings Evaporite
Winlaw Evaporite
KISBEY SANDSTONE
ALIDA
Gainsborough Evaporite
TILSTON
Lodgepole Formation
SOURIS VALLEY
Devonian
Bakken Formation

Fig. 4

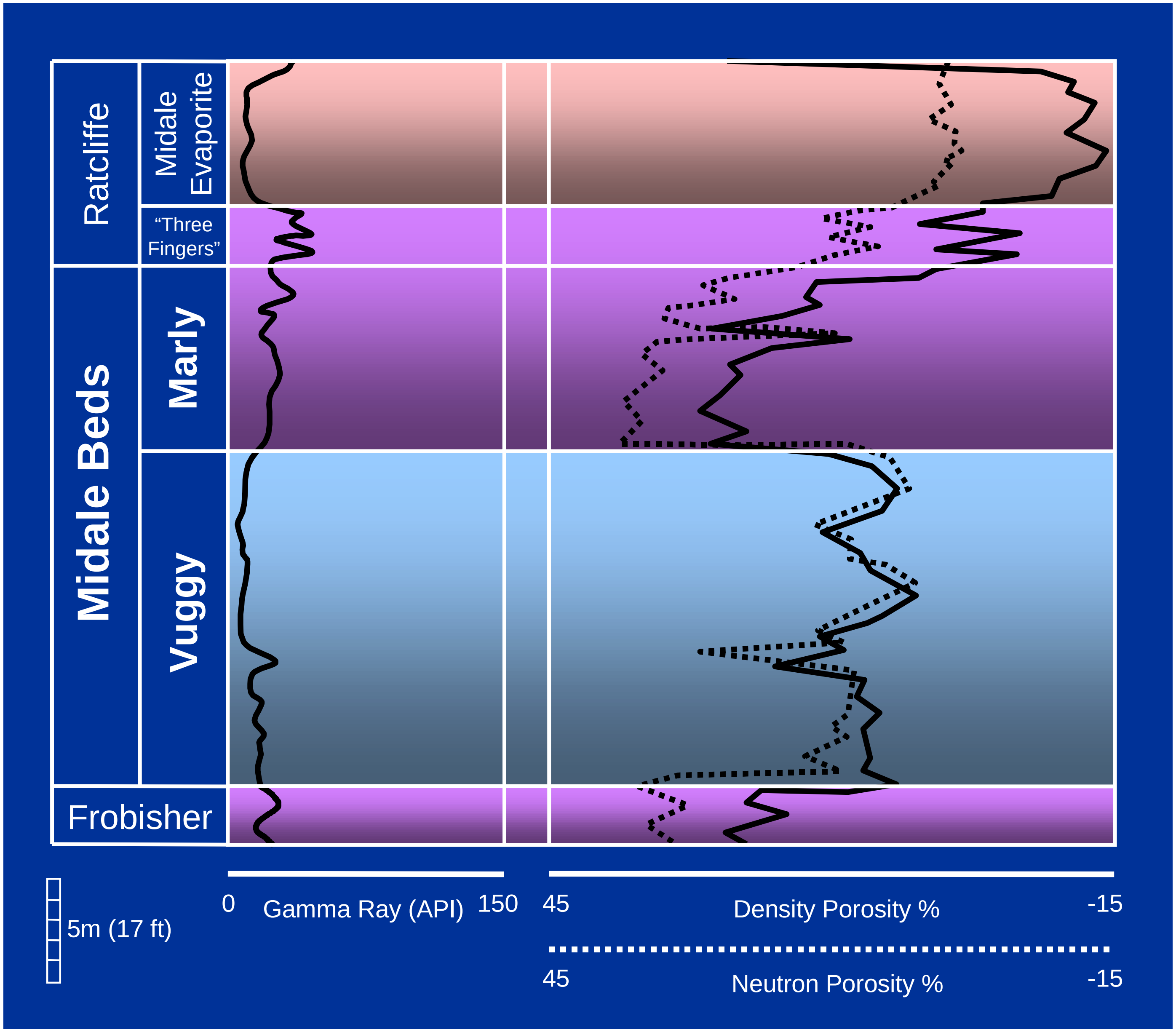

Ratcliffe
Midale Evaporite
"Three Fingers"
Midale Beds
Marly
Vuggy
Frobisher
5m (17 ft)
0
Gamma Ray (API)
150
45
Density Porosity %
-15
45
Neutron Porosity %
-15

Fig. 5

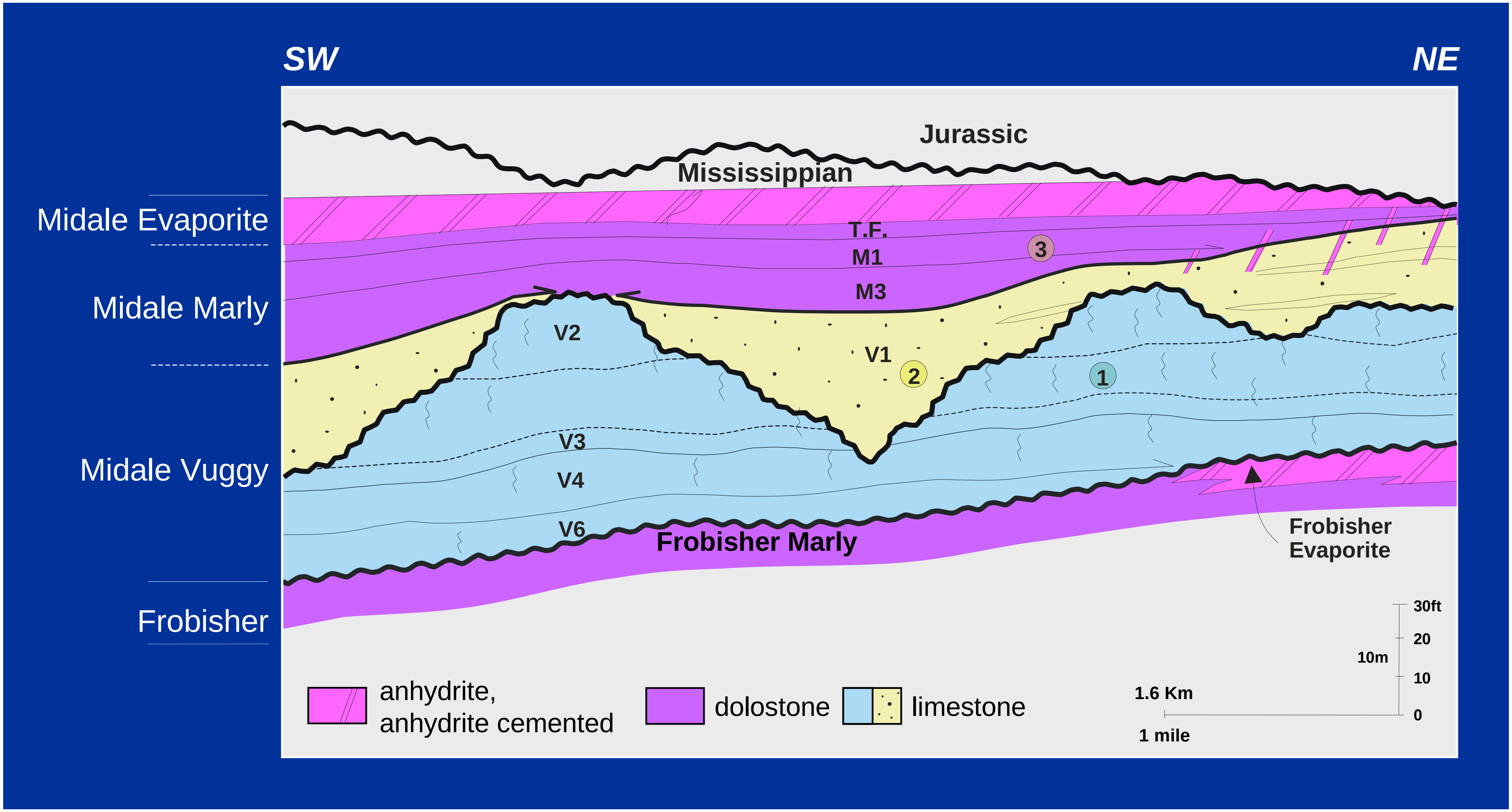

SW
NE
Jurassic
Mississippian
Midale Evaporite
Midale Marly
Midale Vuggy
Frobisher
T.F.
M1
M3
3
V2
V1
2
1
V3
V4
V6
Frobisher Marly
Frobisher
Evaporite
30ft
20
10m
10
0
1.6 Km
1 mile
anhydrite,
anhydrite cemented
dolostone
limestone

Fig. 6

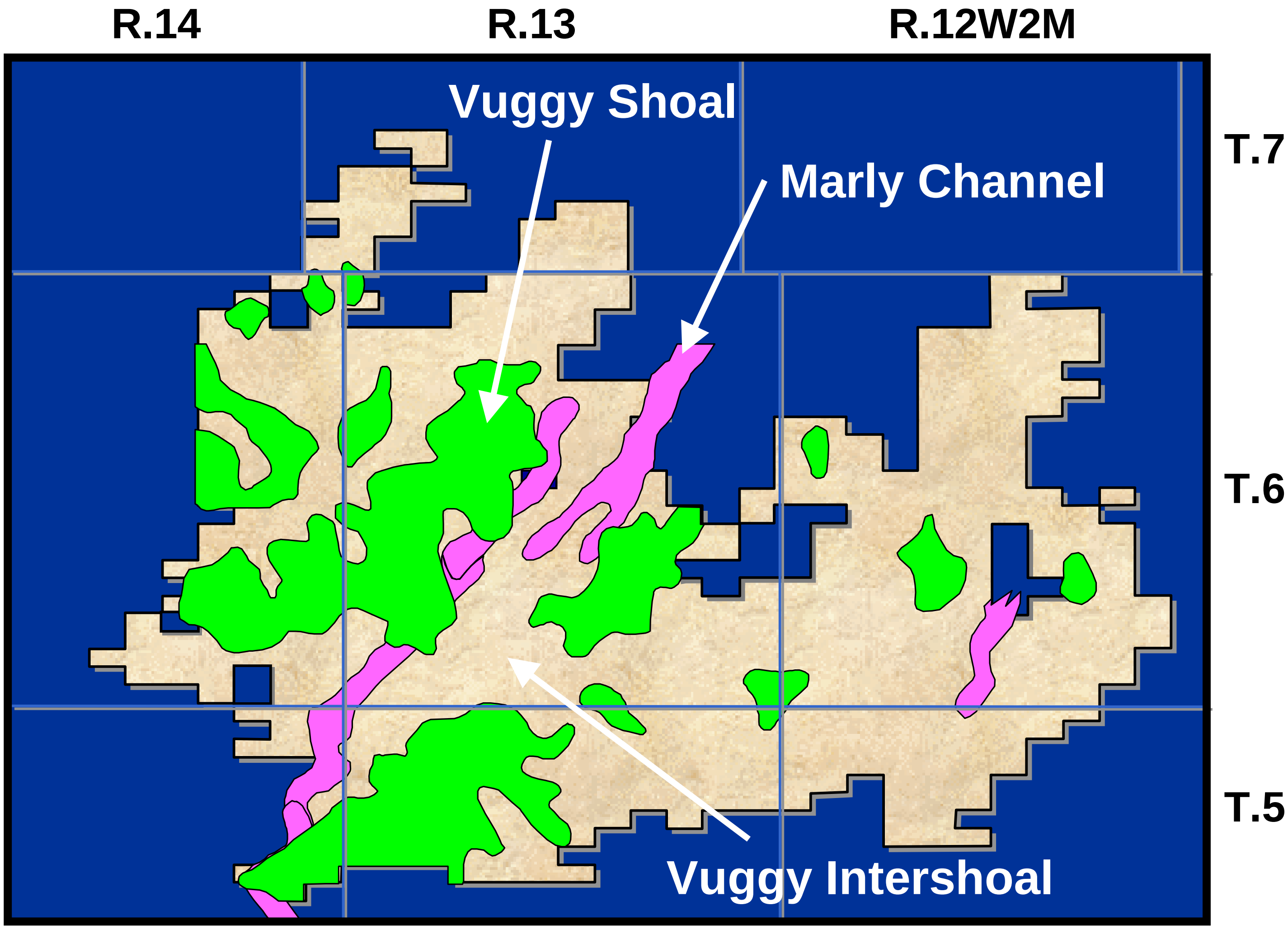
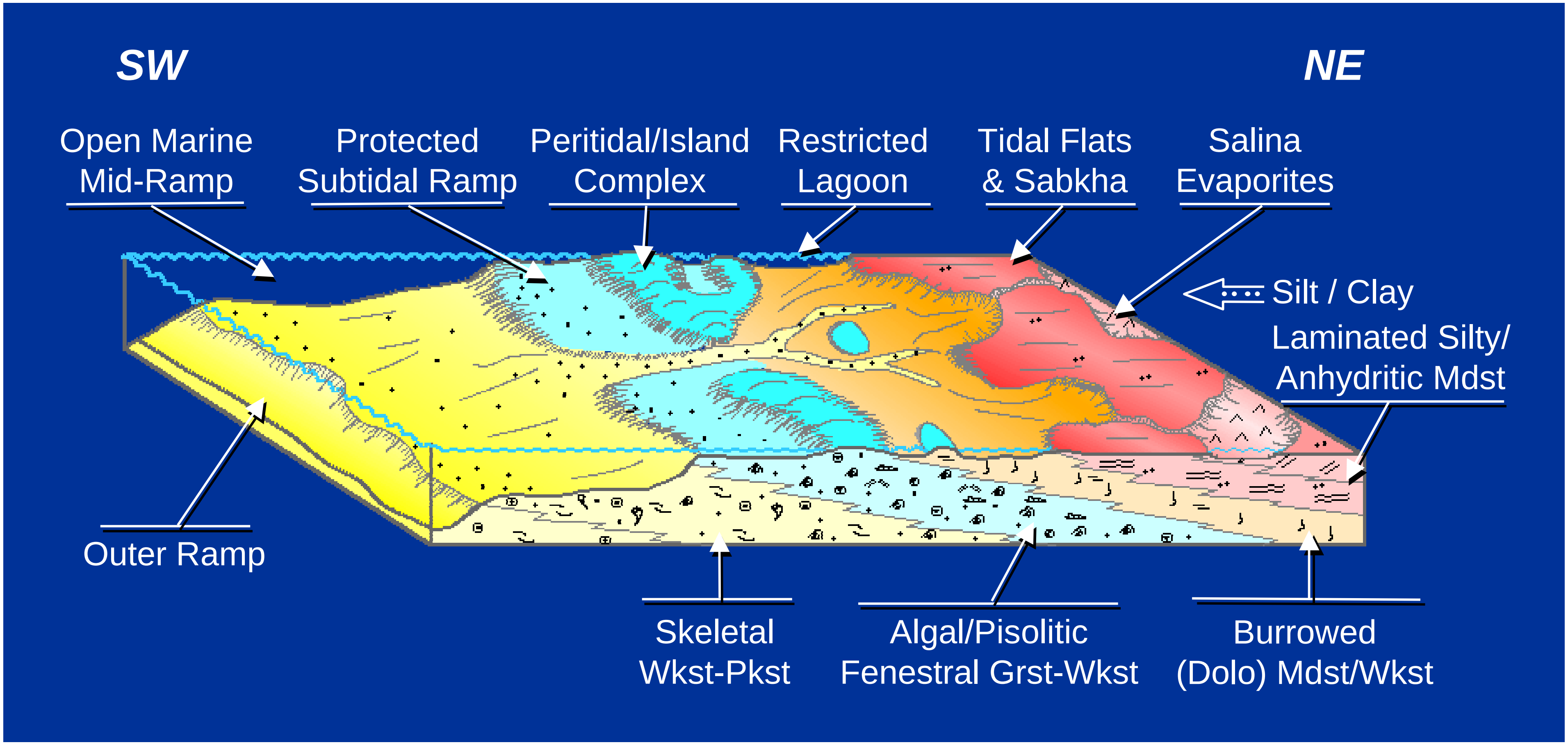

R.14
R.13
R.12W2M
T.7
T.6
T.5
Vuggy Shoal
Marly Channel
Vuggy Intershoal

Fig. 7



SW

NE

Open Marine Mid-Ramp

Protected Subtidal Ramp

Peritidal/Island Complex

Restricted Lagoon

Tidal Flats & Sabkha

Salina Evaporites

Silt / Clay

Laminated Silty/ Anhydritic Mdst

Outer Ramp

Skeletal Wkst-Pkst

Algal/Pisolitic Fenestral Grst-Wkst

Burrowed (Dolo) Mdst/Wkst

Fig. 8

Reservoir Zone	**Lithology & *Textures***	**Porosity** **(avg.% , *Type*)**	**Matrix Permeability** ***(avg.,md)***	**Heterogeneity**	**Fracture Density**
Marly *(M1, M3)*	**Dolostone** *mudstone, wackestone*	**20-37** (26) *intercrystalline* *moldic*	**<0.1 - 100** *(10)*	**Low** *bioturbation* *dolomitization*	**Low - Moderate** *(2-4m spacing)* *>25% Ø~unfract.*
Upper Vuggy *(V1)*	**Limestone** *packstone, wackestone*	**2-15** (10) *interparticle* *intraparticle*	**<0.01 - 20** *(1)*	**Medium** *thick bedded, bioturbation*	**High** *(<1m spacing)*
Lower Vuggy *(V2-V6)*	**Limestone** *mudstone to grainstone*	**5-20** (15) *fenestral vuggy*	**<1 - 500** *(50)*	**High** *well bedded, high order cyclicity, complex diagenesis*	**Moderate - High** *(<1-2m spacing)* *microfractured*

Table 1

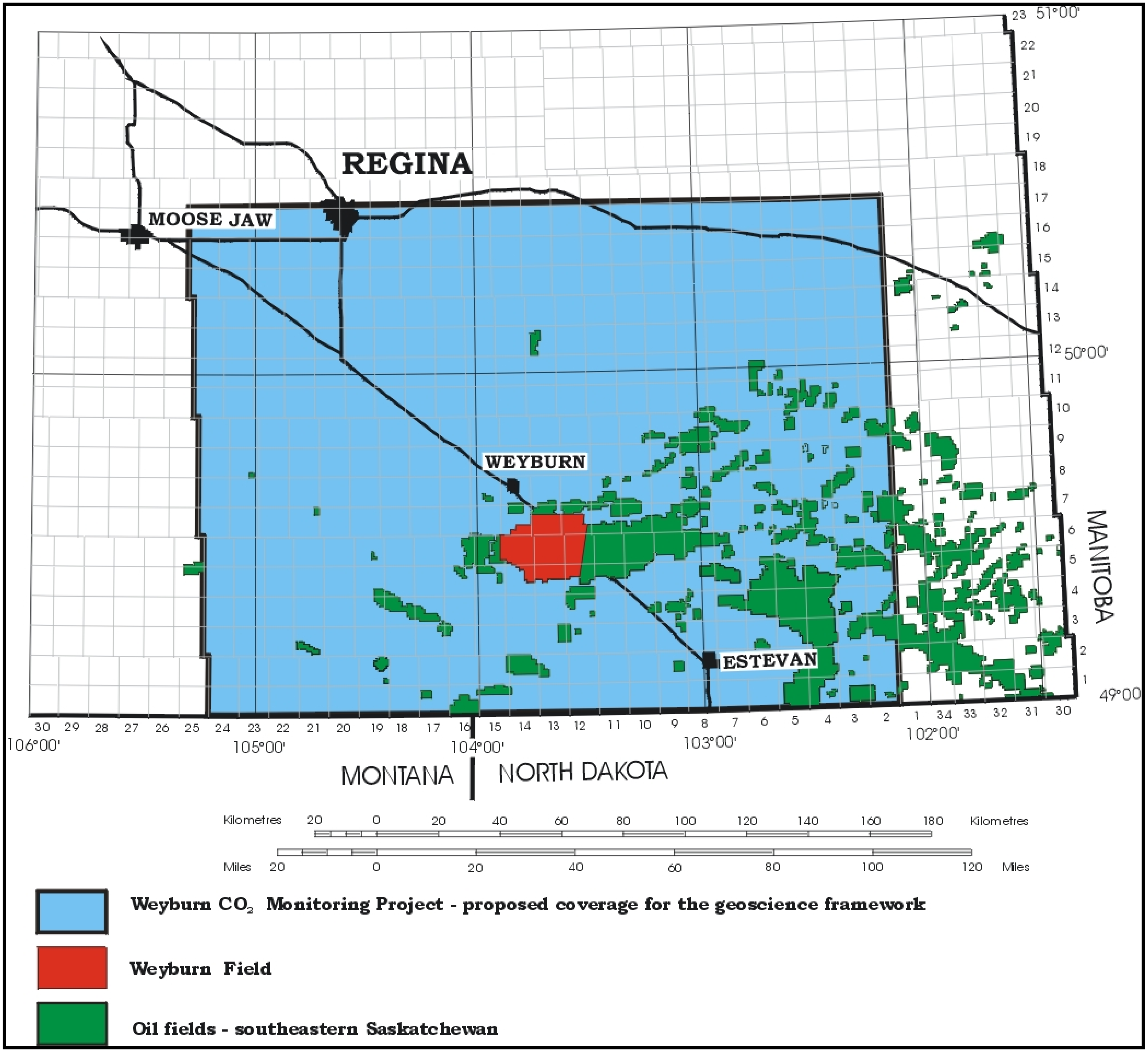

REGINA
MOOSE JAW
WEYBURN
ESTEVAN
MANITOBA
MONTANA
NORTH DAKOTA
51°00'
50°00'
49°00'
106°00'
105°00'
104°00'
103°00'
102°00'
23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 34 33 32 31 30
Kilometres 20 0 20 40 60 80 100 120 140 160 180 Kilometres
Miles 20 0 20 40 60 80 100 120 Miles
Weyburn CO₂ Monitoring Project - proposed coverage for the geoscience framework
Weyburn Field
Oil fields - southeastern Saskatchewan

Fig. 9

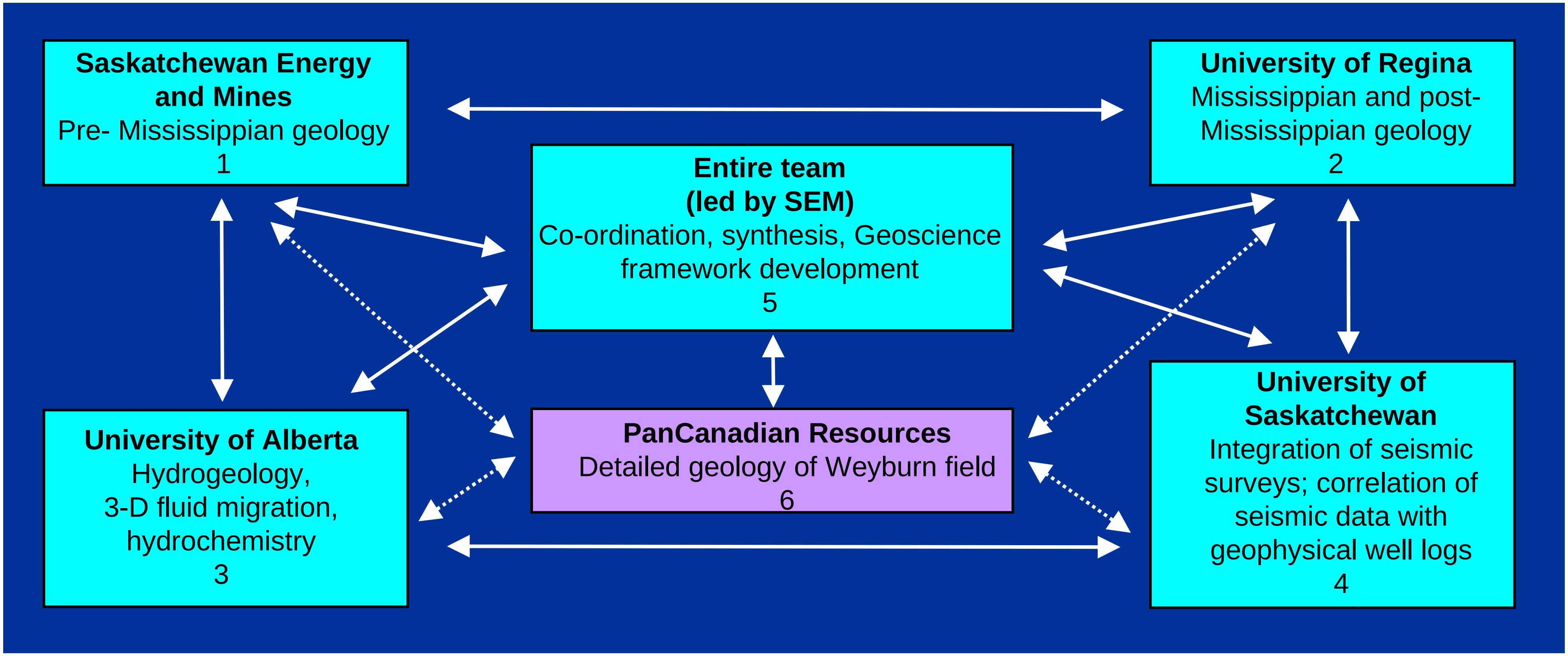

Saskatchewan Energy and Mines
Pre- Mississippian geology
1
University of Regina
Mississippian and post-Mississippian geology
2
Entire team
(led by SEM)
Co-ordination, synthesis, Geoscience framework development
5
University of Alberta
Hydrogeology,
3-D fluid migration,
hydrochemistry
3
PanCanadian Resources
Detailed geology of Weyburn field
6
University of Saskatchewan
Integration of seismic surveys; correlation of seismic data with geophysical well logs
4

Fig. 10