The Devonian Three Forks Formation: Manitoba's Newest Oil Play

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Introduction

The study area consists of the entire depositional area of the Three Forks Formation in southwest Manitoba (Figure 1).

The Sinclair Field is the newest oil field discovery in Manitoba and has greatly expanded in size and production since its discovery in 2004. The Sinclair Field has cumulatively produced approximately 197,000 m^3 oil (over 1 million barrels), and in 2005, approximately 20% of Manitoba's total oil production. Proven and probable reserves are estimated at 6.8 million m^3.

The productive interval of the Sinclair Field is dominantly the Devonian Three Forks Formation, Qu'Appelle Group, with minor production from the overlying Middle Member of the Mississippian Bakken Formation (Figure 2).

The Three Forks Formation was influenced by transgressive and regressive cycles, periods of exposure, gravity flows (Karasinski, 2006), and basin tectonics.

Stratigraphy and Deposition

The Three Forks Formation is subdivided into four units, similar to those recognized in southeastern Saskatchewan by Christopher (1961). In this study, units 2 and 4 are further subdivided into subunits. Figure 3 shows a reference log for the Three Forks and correlating core photos of each subunit.

Unit 1 is the lowermost unit and the most widespread, and is the most oxidized of the units; original fabric may have been a brecciated argillaceous dolomite with grey-green silty shale matrix. Unit 1 is productive is a small isolated pool in Sinclair Field. Unit 2 is an interbedded siltstone and shale, massive shale and occasionally brecciated, and is productive as a secondary reservoir at the Sinclair Field, Daly Field and Kirkella Field (Townships 9 to 12, Ranges 27 to 29W1). Unit 2 is subdivided into four subunits; from bottom to top they are named subunits 2a, 2b, 2c and 2d. Unit 3 is a red-brown highly oxidized silty dolomitic shale. Unit 4, the uppermost unit represented in Manitoba, is an interbedded siltstone, argillaceous dolomites and silty dolomitic shale with thick subunits of highly distorted and brecciated dolomitic siltstone beds. Unit 4 is subdivided into three subunits; from bottom to top they are named subunits 4a, 4b and 4c. Unit 4 is the primary and most productive reservoir at Sinclair Field and is a small isolated pool in Township 4, Range 29W1; production is coming from subunits 4b and 4c (Figure 4).

The Three Forks Formation is a cyclical transgressive-regressive sequence of argillaceous dolomites, brecciated, interbedded and interlaminated with silty dolomitic shales and claystones. The Three Forks was "deposited along a temperate, carbonate tidal flat that grades basinward towards and unrimmed carbonate platform" (Figure 5; Karasinski, 2006). This formation was influenced by transgressive and regressive cycles, periods of exposure, gravity flows (Karasinski, 2006), and basin tectonics.

Isopach and Structure

The regional isopach of the Three Forks generally thickens east to west, with its greatest thickness observed from Township 8 Range 29W1 south to the international United States boundary (Figure 6). The formation thins eastward with a rapid successive truncation of the units of the Three Forks towards the east (Figure 7). The units are truncated at the pre-Mississippian erosional surface. Units 3 and 4 are sharply truncated along a north-south trend between Ranges 28W1 and 29W1. East of this truncation, the isopach gradually thins eastward towards the subcrop edge, east of Range 25W1. Anomalously thick sections occur in a few wells far to the east, in Ranges 24W1 and 25W1 where Units 3 and 4 are preserved. Anomalous thicknesses of the Three Forks Formation are also noted in wells located at Virden Field.

The structure of the Three Forks shows a general northwest-southeast trend, with synclinal flextures at Sinclair, Daly and Virden Fields (Figure 8). Pronounced structural highs occur in the Daly Field, mimicking those seen in the Mississippian (Klassen, 1996). A prominent synclinal flexture of the contours is seen in the western half of Township 8, Range 28 W1.

Diagenesis

Karasinski (2006) conducted detailed thin section evaluations, in addition to scanning electron microscopy (SEM), X-ray diffraction (XRD), and stable isotope techniques. Karasinski (2006) developed a detailed description of the diagenetic evolution of the Three Forks and Middle Bakken Formations (Figure 9). Several stages of diagenesis occurred. Dolomitization of the entire sequence occurred at early and middle stages of diagenesis. Porosity development and occlusion occurred were early and late stage diagenetic alterations. A complex mineralization/cementation of various minerals occurred throughout its evolution. Minerals identified as key components include, in approximate order from early to late stage diagenesis: dolomite, phosphate minerals, pyrite, halite, ferric minerals (hematite and Fe-sulphates), authigenic silicates, and anhydrite.

Tectonics

The sub-Paleozoic extension of the Precambrian Superior Boundary Zone (SBZ) runs north-south in this area. The Birdtail-Waskada Axis (BWA; McCabe, 1967; Dietrich et al., 1998) runs roughly through the middle of the southern extent of the SBZ (Figure 10). Isopach and structural evidence suggest the presence of faults running parallel to the SBZ eastern and western margins; these faults were active at the end of the Devonian. These faults are herein referred to as the Sinclair fault and Sinclair fault offset, the latter being an en echelon extention of the former (Figure 10). Movements along these faults caused the preservation of the primary reservoir (Unit 4) of the Three Forks Formation east and west of the SBZ margins, while secondary reservoir unit (Unit 2) was exposed as a plateau on the BWA. The preservation of Unit 4 in some wells east of the SBZ margin opens up the possibility that, under the right trapping conditions, there may be another Sinclair-type play yet to be discovered east of Range 24W1.

To support this faulting theory, Dietrich *et al.* (1998) identified several faults using seismic data along a transect from southeastern Saskatchewan to southwestern Manitoba, one of which coincides precisely with the presence of Unit 4, which is truncated in Range 28W1. This same transect identified a fault running roughly north-south around Range 25W1, which may explain the preservation of Unit 4 near the eastern limit of the SBZ. A well defined basement lineament also coincides with the location of this eastern fault.

Three Forks Exploration

Exploration of the Three Forks Formation in Manitoba has been combined with the Bakken Formation exploration. The two formations are often considered a continuous, commingled reservoir and are pooled together. The Three Forks is currently productive in the Sinclair Field, Daly Field, Kirkella Field and Township 4 Range 29W1. As a rather new exploration target, it has not been explored in other areas of the province.

Future development exists potentially along the north-south trend of the isopach thick of Unit 4. Unit 2 has development potential in areas where its best production where Subunit 2b is present and where Subunit 2c has been minimally affected by redox haloing.

New exploration efforts should be targeted northward and eastward of Sinclair Field within Unit 2, and possibly Unit 1. The fact that Unit 1 is productive in a small pool in Sinclair, suggests that more potential exists in this unit in all areas where Three Forks is present. Log signatures of Unit 1 look promising west of the Unit 2 subcrop edge, but core of this unit is not available to correlate with the log signatures. Possible target zones may occur along the north-south trend parallel to the eastern limit of the SBZ, from Range 24W1 and 25W1 where local occurrences of Unit 4 have been preserved, based on log correlations. It is possible that another Sinclair is yet to be discovered along this eastern trend. Figure 11 summarizes the most promising Three Forks exploration target areas.

Conclusions

The uppermost of the Three Forks units, Unit 4, is the primary and most productive reservoir at Sinclair Field and in the pool in Township 4 Range 29W1. Production is also derived from Unit 2, a secondary reservoir at Sinclair, Daly and Kirkella Fields. Thinning of the Three Forks Formation and truncation of Unit 4 eastward suggests that the eastern expansion of the Sinclair Field may be limited. In contrast, the thick isopach trend running north-south along Range 29W1, where Unit 4 is still present, suggests a southern expansion of the Sinclair Field and northern expansion of Daly and Kirkella Fields may also be successful. Much of Township 4 Range 29W1 remains unexplored.

Isopach and structural evidence suggests block faulting may have occurred in the western sections of Range 28W1 south of Township 9. This faulting would have resulted in uplift and the subsequent erosional truncation of Unit 3 and Unit 4 along eastern limits of Range 28W1. The fault trend may serve as a geological boundary in determining the eastern boundary of the Sinclair Field. The identification of a fault on the eastern edge of the BWA along Ranges 24 and 25W1, coinciding with wells having preserved sections of Unit 4 and Unit 3, may provide a similar reservoir in the west. Future potential for another Sinclair-type oil play may exist east of Range 24W1.

References

Christopher, J.E., 1961: Transitional Devonian-Mississippian Formations of Southern Saskatchewan; Saskatchewan Mineral Resources, Report 66, 103 p.

Dietrich, J., M.Thomas, Z.Hajnal, P.Redly, C.Zhu, and J. Majorowicz, 1998: Basement-Sedimentary Cover Linkages in the Williston Basin, Southeast Saskatchewan and Southwest Manitoba; Manitoba Mining and Minerals Convention Program, November 1998, Poster, p. 24.

Karasinski, D.R., 2006: Sedimentology and Hydrocarbon Potential of the Devonian Three Forks and Mississippian Bakken Formations, Sinclair Area, Southeast Saskatchewan-Southwest Manitoba; M.Sc. Thesis, Dept. of Geological Sciences, University of Manitoba, 398 p.

McCabe, H.R., 1967: Tectonic Framework of Paleozoic Formations in Manitoba; Can. Inst. Mining Met., Vol. 70, pp.180-189.

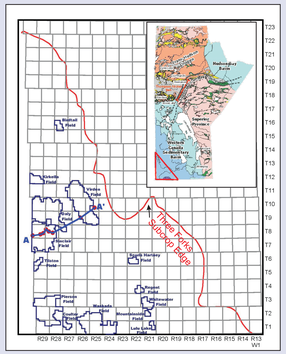

Figure 1: Map of study area with cross-section line AA'.

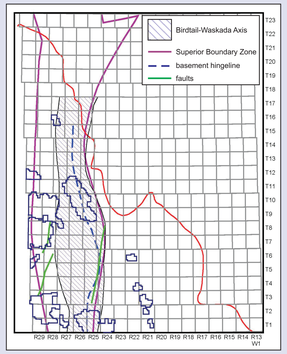

Figure 10: Tectonic map showing postulated fault lines.

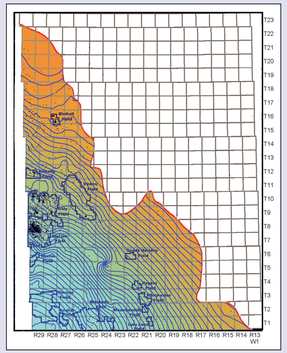

Figure 6
Devonian Three Forks Formation:
Structure Contour
Contour Interval =20 m

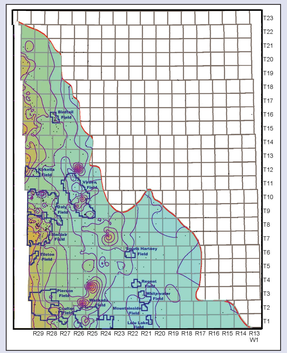

Figure 8
Devonian Three Forks Formation:
Isopach
Contour Interval =5 m

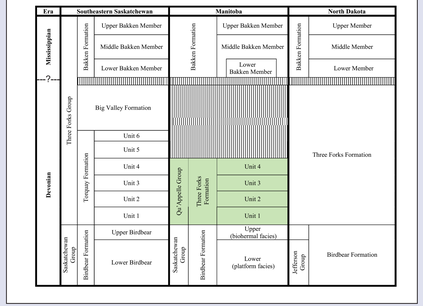

Figure 2: Stratigraphic Column

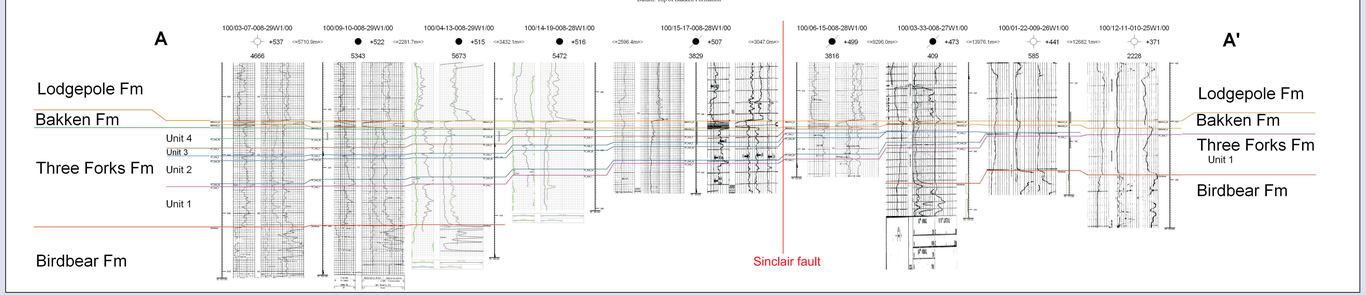

Figure 7: Stratigraphic Cross-section AA'

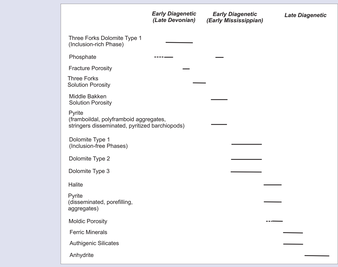

Figure 9: Paragenetic sequence of Three Forks and Middle Bakken diagenesis. (Karasinski, 2006)

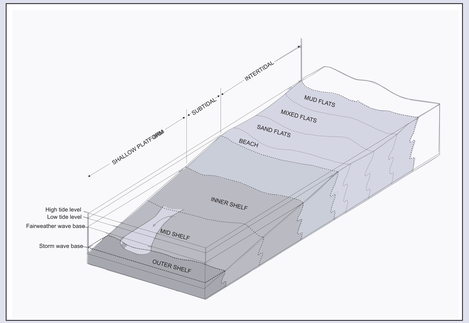

Figure 5: Schematic diagram displaying the distribution of Three Forks facies along an unrimmed carbonate platform and high-energy carbonate tidal flat. (Karasinski, 2006)

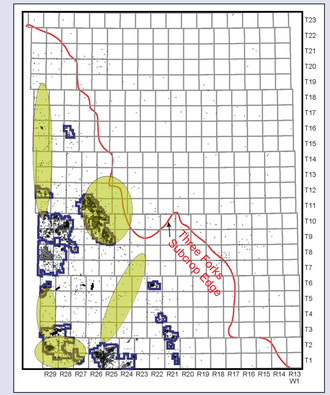

Figure 11: Three Forks exploration targets.

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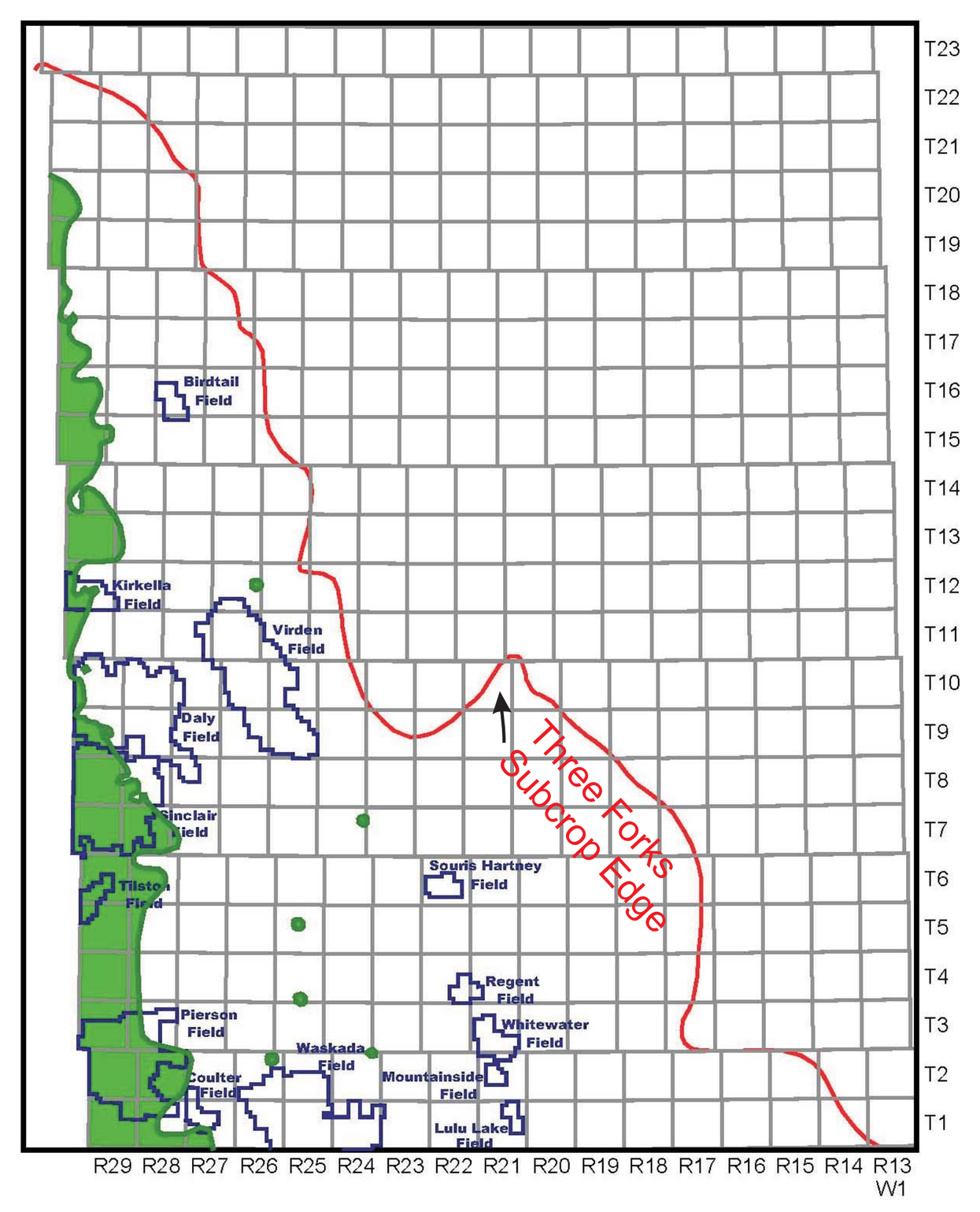
Unit 4

Unit 4 Characteristics

- Interbedded siltstone, argillaceous dolomites and silty dolomitic shale with thick subunits of distorted bedding and brecciated dolomitic siltstone
- Isopach: 1-14 m
  - average: 6 m
- Limited distribution
  - Restricted to the Ranges 29 & 28 W1, and west into Saskatchewan
  - More section preserved in isolated wells in the east
- Oil Production:
  - Primary, most productive reservoir unit of the Three Forks Formation
  - Production commingled with Middle Bakken
  - Primary reservoir at Sinclair, as well as minor production at Daly and Kirkella Fields.
- Average core K = 4.3 mD
- Average core Ø = 16.5%

Unit 4 Distribution Map



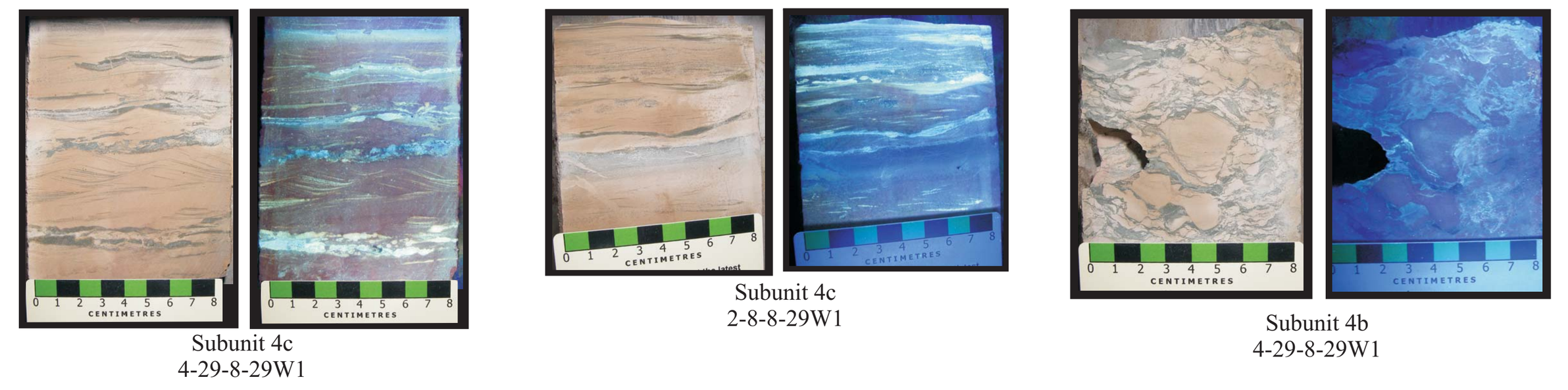


Figure 4: Core photos of Sinclair reservoir subunits 4b and 4c taken in white (left) and ultraviolet (right) light. Yellow fluorescence is oil, and blue fluorescence is anhydrite.

Unit 4, Subunit 4c
Primary Reservoir Unit - Sinclair Field
2-8-8-29W1

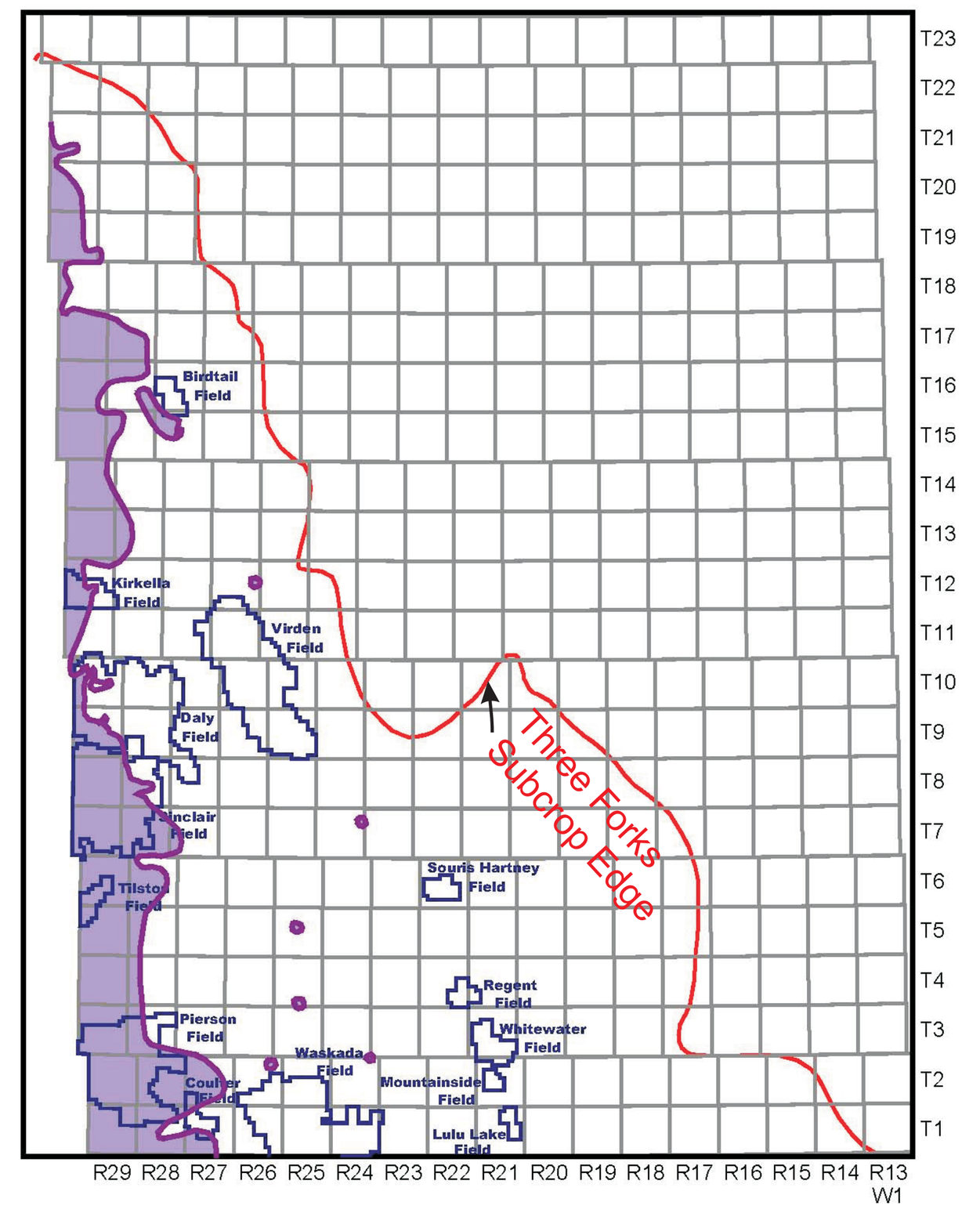
Unit 4, Subunit 4b
Primary Reservoir Unit - Sinclair Field
2-8-8-29W1

Unit 3

Unit 3 Characteristics

- Red-brown highly oxidized silty dolomitic shale
- Rare reduced halos
- Thinnest unit, averaging 3.5 m isopach
- Distribution follows Unit 4 closely
- More section preserved in isolated wells in the east
- Not a good reservoir, but productive when at unconformity at Sinclair

Unit 3 Distribution Map



Unit 3
2-8-8-29W1

Three Forks Formation: Internal Stratigraphy and Log Correlation

Three Forks Formation Reference Log

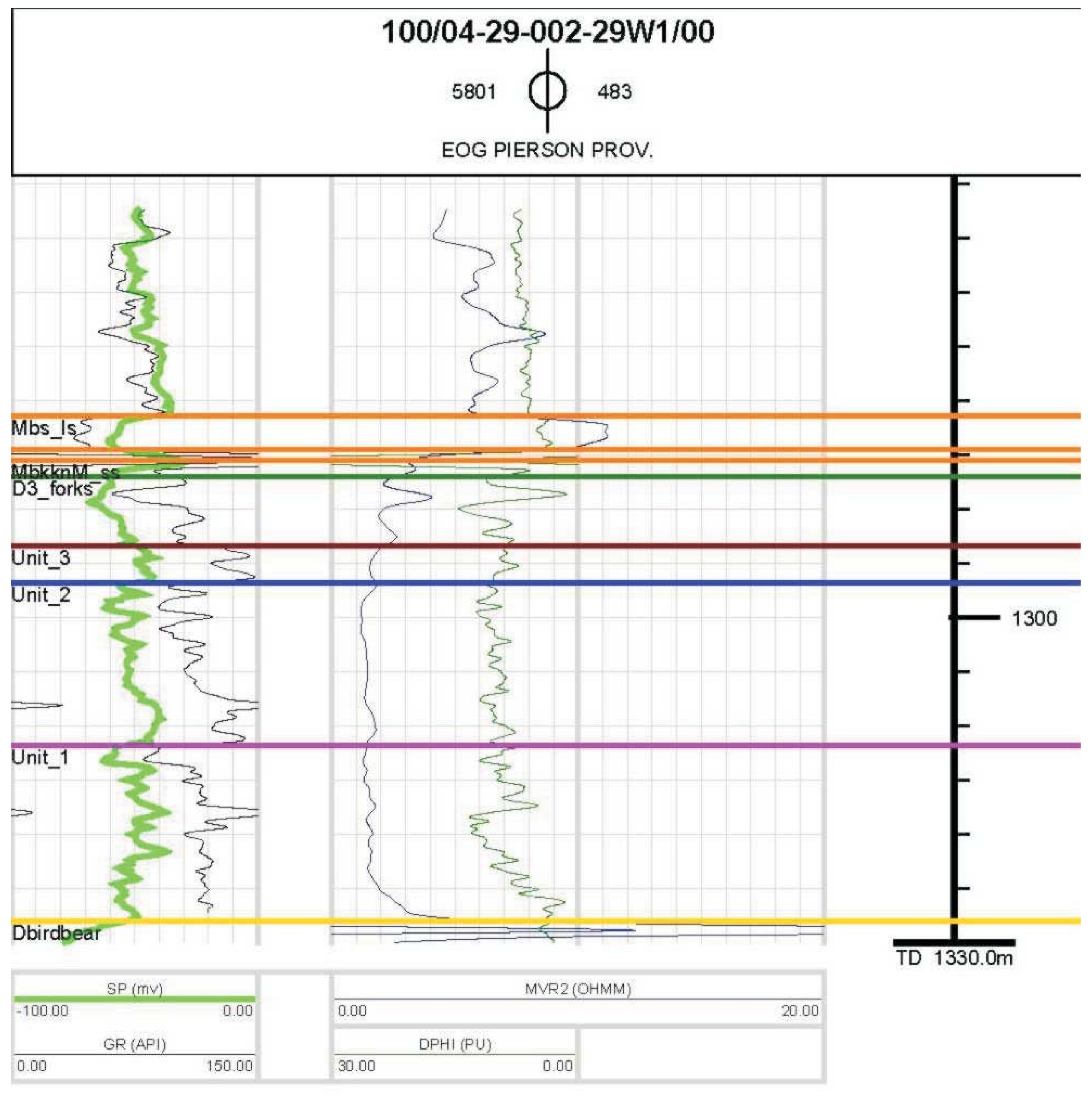


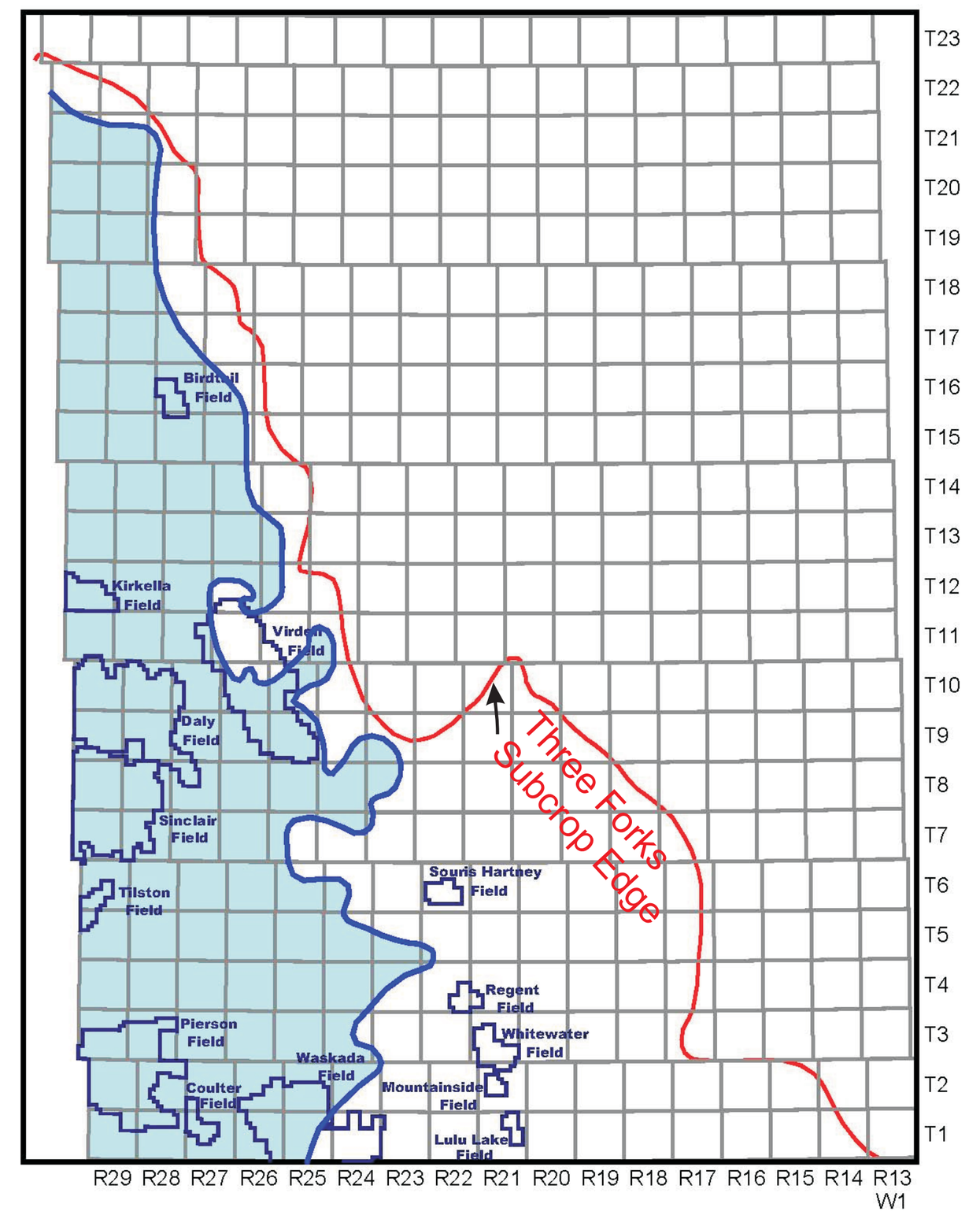
Figure 3: Three Forks Formation reference log with correlating core photos of subunits.

Unit 2

Unit 2, Subunit 2b
Reservoir unit - Sinclair and Daly Fields
2-8-8-29W1

Unit 2, Subunit 2b
2-8-8-29W1

Unit 2 Distrubution Map



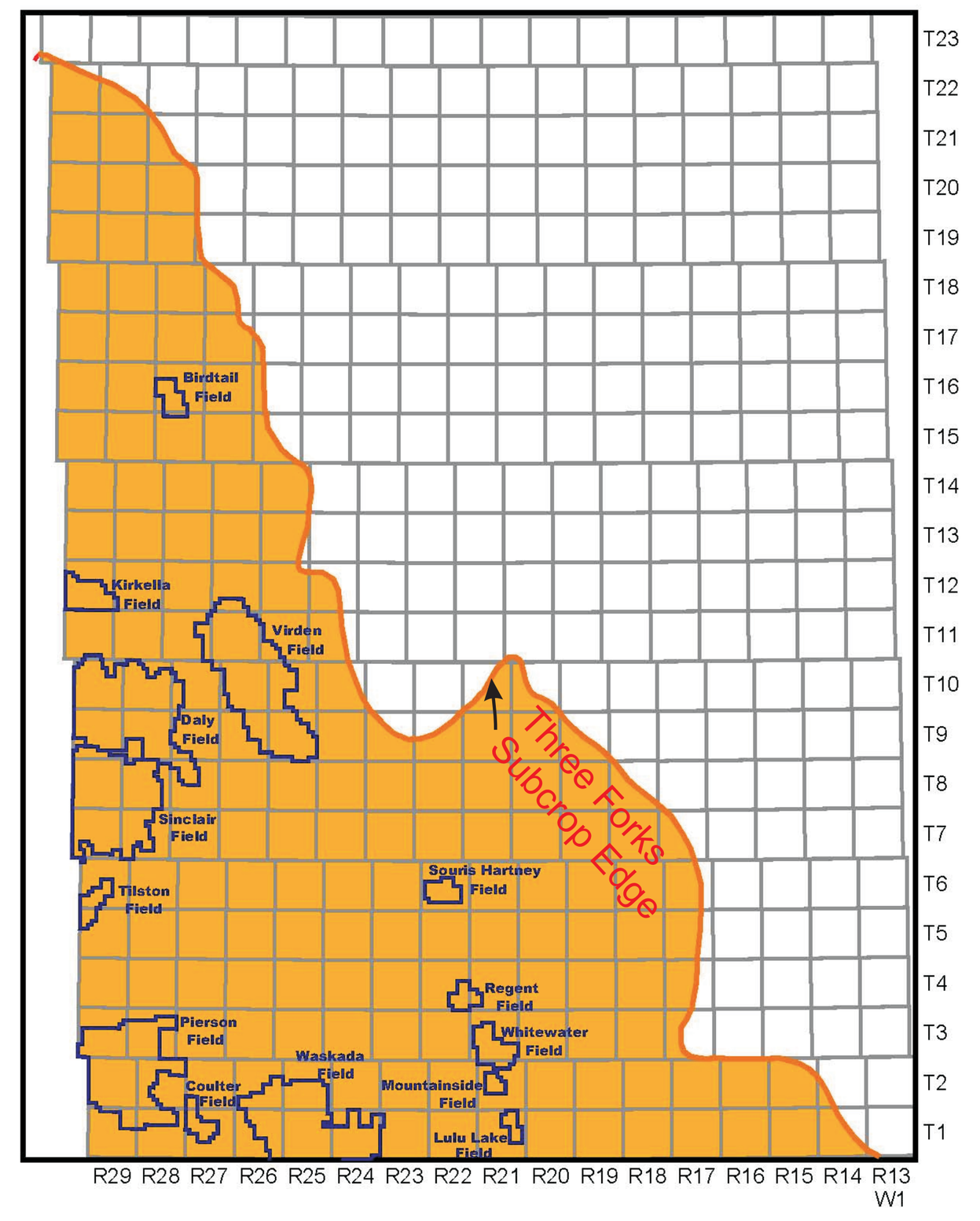
Unit 2 Characteristics

- Interbedded siltstone, shales and claystones; massive and brecciated in places
- Partially oxidized
- Porosity decreases with depth
- Isopach: 1-19m
  - Average: ~15 m
- Subcrop edge roughly follows the eastern boundary of the BWA & SBZ
- Oil Production
  - Commingled with Middle Bakken
  - Primary reservoir at Daly
  - Secondary reservoir unit at Sinclair

Unit 1

Unit 1
Secondary Reseroir - Sinclair Field
40-34-10-24 W1

Unit 1 Distribution Map



Unit 1 Characteristics

- Lowermost unit and is present uniformally up to the subcrop edge
- Highly oxidized with occasional reduction halos
- Original fabric: Brecciated argillaceous dolomite with grey-green silty shale matrix
- Least understood unit due to limited core availability
- Fairly constant isopach
  - Average: 16 m
- Productive in small isolated pools at Sinclair
- Future reservoir potential is unknown

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