

**IMPROVED RECOVERY DEMONSTRATION FOR
WILLISTON BASIN CARBONATES**

QUARTERLY TECHNICAL PROGRESS REPORT

Cooperative Agreement DE-FC22-94BC14984

Luff Exploration Company
Denver, Colorado

Award Date: June 10, 1994
Completion Date: December 31, 1997

Government Award: \$1,778,014

Project Manager: Larry A. Carrell
Luff Exploration Company

DOE Project Officer: Chandra Nautiyal
Bartlesville Project Office

Reporting Period: April through June 1997

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Principal Investigators:
Mark A. Sippel
Larry A. Carrell

Project Manager:
Chandra Nautiyal
Bartlesville Project Office

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Executive Summary

Significant reserve additions have been found by drilling targeted, vertical wells on the flanks of structural features in the Red River where wells on crestal positions have been producing for more than 20 years. Two seismically targeted, vertical wells were successfully drilled to the Red River D zone in Bowman Co., ND. Interpretations of amplitude for porosity and structural position were used to target the drilling locations.

Operations for horizontal drilling from surface were performed at two locations in the Red River area of Bowman Co., ND and Harding Co., SD. These wells were drilled on subsurface structures where there has been production for more than 15 years. The Bowman Co. well was mechanically successful but did not yield encouraging oil production from the Red River B zone. Production and injection testing at the South Dakota well have been completed with encouraging results for secondary recovery.

Re-entry drilling of lateral drain holes in the Ratcliffe with slim-tool technology was attempted in two wells in Richland Co., MT. One attempt was mechanically successful and the other was not. Production evaluation of the successful horizontal drain hole has resulted in disappointing productivity and low oilcut.

A technical paper was presented in at the SPE regional meeting in Casper in May. Another technical paper is scheduled for presentation at the regional AAPG meeting in Denver during August.

Summary of Technical Progress

Red River Targeted Drilling

After study of two 3D seismic surveys in Bowman Co., ND, (figure 1) several locations were identified for drilling vertical wells to test interpretations of seismic response which were modeled to indicate porosity development in the Red River D zone. Two wells were drilled and completed in Cold Turkey Creek Field and have established production. A third well was drilled and is currently testing at Grand River School Field.

At Cold Turkey Creek Field, one of the

Abstract

The purpose of this project is to demonstrate targeted infill and extension drilling opportunities, better determinations of oil-in-place, methods for improved completion efficiency and the suitability of waterflooding in certain shallow-shelf carbonate reservoirs in the Williston Basin, Montana, North Dakota and South Dakota.

Improved reservoir characterization utilizing 3-dimensional (3D) is being investigated for identification of structural and stratigraphic reservoir compartments. These seismic characterization tools are integrated with geological and engineering studies. Improved completion efficiency is being tested with short-lateral and horizontal drilling technologies. Improved completion efficiency, additional wells at closer spacing and better estimates of oil-in-place will result in additional oil production by primary and enhanced recovery processes.

structural features in the Red River was identified as having better porosity development on the flanks than on the crest where the Faris No. 1-22 well has been producing for 22 years. The crestal well is completed in all porosity zones in the Red River but they are thinly developed with low porosity. The well has produced over 375,000 bbl of oil. Two wells were drilled and successfully completed on opposite sides of the small, 162-ha (400-acre) feature at distances about 0.4 km (0.25) mile from the existing well. Porosity and thickness were found to be much better developed, as predicted by seismic interpretation, than at the crestal well.

The Red River D zone in the Muslow-State B-27 well was perforated from 2903 to 2912 m (9524 to 9554 ft) and acidized. The completed interval began producing on December 12, 1996 at 22 m³ oil and 13 m³ water per day (140 bopd and 80 bwpd) with a fluid level of 1219 m (4000 ft) from surface. Production has remained stable and is currently 26.4 m³ oil and 21.1 m³ water per day (166 bopd and 133 bwpd). Pressure data from a drillstem indicate the D zone was at near original pressure. The Muslow-State B-27 is 10 m (32 ft) low to the Faris No. 1-22.

On the other side of the structure, the Pang-Faris K-22 has been also completed in the Red River D zone with perforations from 2899 to 2904 m (9510 to 9526 ft). The well was completed flowing at 30.5 m³ oil per day (192 bopd) with very little water. This well is 16 m (53 ft) low to the Faris No. 1-22 at the top of the Red River. Pressure data from drillstem test of the D zone indicate the interval is only slightly drawdown from original pressure by 2070 kPa (300 psi).

Both wells were also drillstem tested in the Red River B zone and recovered oil at rates which appear to be commercial but also measured the reservoir pressure at about 13,100 kPa (1900 psi) which is probably near bubble-point pressure. The B zone has not been opened in either of the wells at this time.

At Grand River School Field, the Watson O-6 is drilling to test similar seismic response in the Red River D zone which are observed at Cold Turkey Creek Field. The Watson O-6 well is 0.8 km (0.5 mile) from the Hanson No. 1-6 well which has been producing for over 20 years from

thinly developed intervals in the Red River B, C and D zones, similar to the Faris No. 1-22 at Cold Turkey Creek Field.

Results from these three wells have significant implications for infill and extension drilling in the area. Many of the wells in the area have produced from crestal positions of small structural features with 129-ha (320-acre) well spacing.

Red River Lateral Drilling

Luff Exploration Company participated in drilling a horizontal completion in the Red River B zone reservoir at State Line Field, Bowman Co., ND (figure 2). The objective of the well was to exploit additional primary reserves by overcoming poor drainage caused by heterogeneity. The No. 1-26H Greni well is the fourth well on a small Red River feature that has produced over 143,090 m³ (900,000 bbl) of oil from B and D zones of the Red River since 1973. Details of drilling operations were given in previous quarterly reports.

The well was produced from the open-hole lateral section in the Red River B zone from October 1996 through April 1997. The initial pumping rate was 2 m³ oil and 52 m³ per day (10 bopd and 330 bwpd). Production testing continued until April 1997 with cumulative oil of only 115 m³ oil and 4561 m³ water (725 bbl oil and 28,685 bbl water). An inflatable packer was placed near the middle of the horizontal section to isolate the far reach of the hole to determine if oil cut would improve. Production declined from 55.6 m³ to 27.0 m³ per day (350 to 170 bpd) after placement of the packer but oil cut did not improve. Although highly productive, results from the well indicate a reservoir failure. Either the lateral is below an oil-water contact in the Red River B reservoir or it is out of zone.

A horizontal well was drilled at Buffalo Field with the objective of evaluating water injection through a horizontal open-hole completion in the Red River B zone. The M-20H Stearns was spudded on November 15, 1996. A lateral reach of 1219 m (4000 ft) was planned which was to traverse between two producing wells in the Red River B zone (figure 3). Drilling operations were suspended after 50 days when efforts to retrieve

stuck drill pipe in the lateral section were unsuccessful. The final lateral reach from the 17.8-cm (7-in) casing was 309 m (1015 ft). Drilling operations were summarized in previous quarterly reports.

The primary intended purpose of the M-20H Stearns well was an evaluation of horizontal wells for water injection in the Red River B zone (figure 4). The well was produced for 50 days followed by a water-injectivity test. The well produced an average of 11.1 m³ oil and 11.1 m³ water per day (70 bopd and 70 bwpd) for the last 10 days of the test and appeared to have stabilized. This productivity is factor of three times the other wells in the reservoir; they are all vertical completions. The water injectivity test indicates water injection at 87.4 m³ per day (550 bwpd) with a pressure of 34,500 kPa (5000 psi) at reservoir depth of about 2667 m (8750 ft). Water injectivity at a vertical well in this reservoir was determined to be one-third of the injectivity at the M-20H Stearns. The horizontal section in the M-20H Stearns well is only 309 m (1015 ft) and has junk in the hole which had become stuck after circulation was lost while drilling. These test results indicate that a 305-m (1000-ft) lateral has a productivity ratio of at least three over a vertical well in the thin-bed Red River B zone. The reservoir averages 3.7 m (12 ft) in the immediate area. With a lateral extension of 610 m (2000 ft) or more, an injection rate of 127 to 159 m³ water per day (800 to 1000 bwpd) should be attainable in the Red River B zone. This is the target injection rate that is needed for profitable waterflood projects with one horizontal injection well per 2.6 km² or 259 ha (1 square mile or 640 acres).

Luff Exploration has applied to South Dakota regulatory agencies for continual injection at the M-20H Stearns.

Ratcliffe Re-Entry Lateral Completions

Two wells in the North Sioux Pass Field were selected for re-entry lateral completion in the Ratcliffe. These wells are the No. 2-16 State and M-17 Trudell (figure 5). The laterals were to be drilled out from 14 cm (5-1/2 inch) casing with steered-motor technology with planned extensions of 610 m (2000 ft). The planned orientation of the

laterals were to be normal to the fracture orientation observed from the 1-17R Federal core and FMI log data (figure 5). A horizontal drain hole was successfully drilled at the State No. 2-16 well but not at the Trudell No. M-17. Details of drilling operations were summarized in previous quarterly reports.

A lateral drain hole was drilled with slim-tool technology with a horizontal length of 604 m (1982 ft) in the 2.1-m (7-ft) main porosity zone of the Ratcliffe (figure 6). The well went on pump on Dec. 27, 1996 at an initial rate of 2.1 m³ oil and 20.0 m³ water per day (13 bopd and 126 bwpd). The well was pumped until April 11 and then shut-in when total fluid rate was 11.1 m³ per day (70 bbl per day) with a 3 percent oil cut. Cumulative production during the pump test of the horizontal drain hole was only 70 m³ oil and 1710 m³ water (443 bbl oil and 10,753 bbl water).

Production results are disappointing and it is not clear why the oil cut is so low. Although experienced wellsite geologists and mudlogging equipment were used to guide drilling, it is not known if the lateral encountered water-bearing fractures or was drilled out of zone. The Ratcliffe at the State No. 2-16 is 10 m (33 ft) structurally high to the State Pass No. 16-1 which is a north offset by less than 0.4 km (1/4 mile). Only 4 m (13 ft) was lost by the end of the horizontal leg in the State No. 2-16 which is still 6 m (20 ft) high to the State Pass No. 16-1. The State Pass No. 16-1 is a vertical completion in the Ratcliffe and is producing 4.8 m³ oil per day and 4.8 m³ water per day (30 bopd and 30 bwpd) from the same Ratcliffe interval as was traversed by the horizontal drain hole.

The State No. 2-16 appeared to be an ideal candidate for testing horizontal drain-hole technology but is a failure with respect to productivity and oil cut. Original reservoir pressure was about 25,579 kPa (4000 psi) and had declined to 21,787 kPa (3160 psi) prior to drilling the horizontal drain hole. Cumulative production from the two Ratcliffe wells in section 16 is over 24,000 m³ oil (150,000 bbl oil). Thus, a large reservoir with low permeability is indicated from the small drawdown of reservoir pressure. The horizontal drain hole was drilled normal to fracture orientation which had been determined

from oriented core and FMI log in a nearby well in section 17. Productivity of the drainhole is not improved over the vertical completion in the State Pass No. 16-1 which was hydraulically fractured.

3D Seismic Activities

Successful targeted wells at Cold Turkey Creek and Grand River School fields in Bowman Co., ND have provided additional data for further calibration of seismic interpretation to reservoir variation in the Red River. There are several additional anomalies within the 3D seismic surveys which are being studied for drilling in the near future.

Data picking and mapping have been completed with time structure, isochron and amplitude maps which are relevant to the Ratcliffe at North Sioux Pass Field in Montana. Plans are being formulated for drilling a horizontal Ratcliffe test based on amplitude and structure interpretations from the 3D seismic.

Technology Transfer

A technical paper was presented at the SPE regional meeting in Casper in May. "Geological and Engineering Characterizations of the Upper Red River Formation in the Southwest Williston Basin," SPE 38371, describes depositional setting, petrographical observations from cores and engineering characterizations for each of the four porosity benches in the Red River, off-structure from the Cedar Creek anticline. The petrographical and engineering characterizations provide a side-by-side analysis and summary of core, electrical-log, drillstem-test and production statistics which can be used for development and exploration evaluations. Another technical presentation entitled "Characterization of Red River Reservoirs from 3D Seismic at Cold Turkey Creek Field" and will be presented at the American Association of Petroleum Geologists 1997 Rocky Mountain Section Meeting in Denver, August 24-27. This paper describes identification of variable development (primarily porosity) in the Red River B and D using zones using 3D seismic and will also present results from successful drilling of porosity anomalies on the

flanks of Red River structures.

Topical reports covering reservoir characterizations of the Red River and Ratcliffe and lateral drilling technologies applied during the project will be delivered in the next quarter.

Summary and Conclusions

Targeted drilling of Red River D porosity anomalies from 3D seismic has been very successful in Bowman Co., ND. There will be sufficient production history by the end of the project to quantify these apparently significant reserve additions. Water injection into a horizontal well at Buffalo Field, Harding Co., SD has established that sufficient rates can be achieved to profitably waterflood the Red River B zone. Lateral re-entry drilling in the Ratcliffe with slim-tool mud-motor technology was unsuccessful.

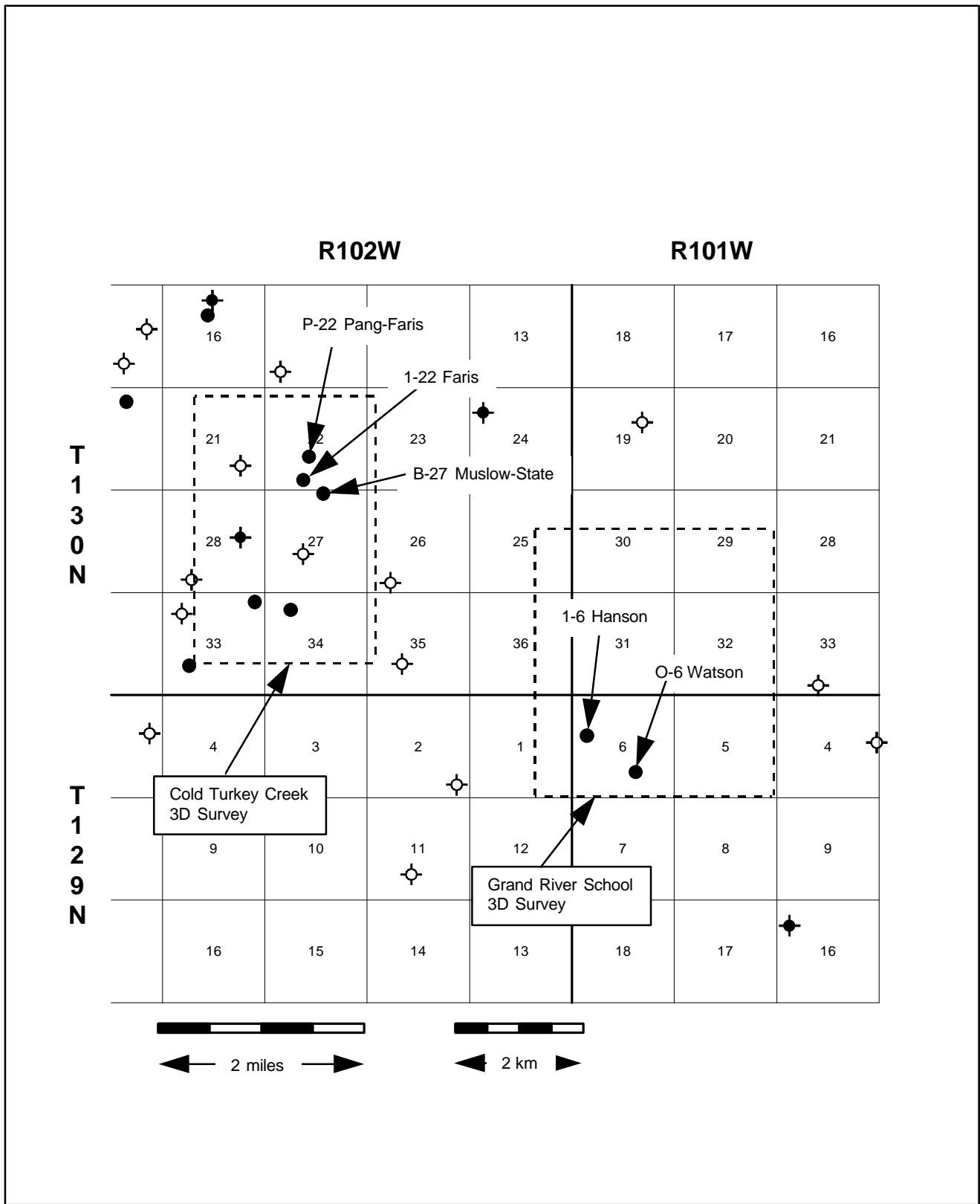


Figure 1: Map of 3D seismic surveys and targeted drilling activities in Bowman Co., ND.

1-26H Greni - State Line Field

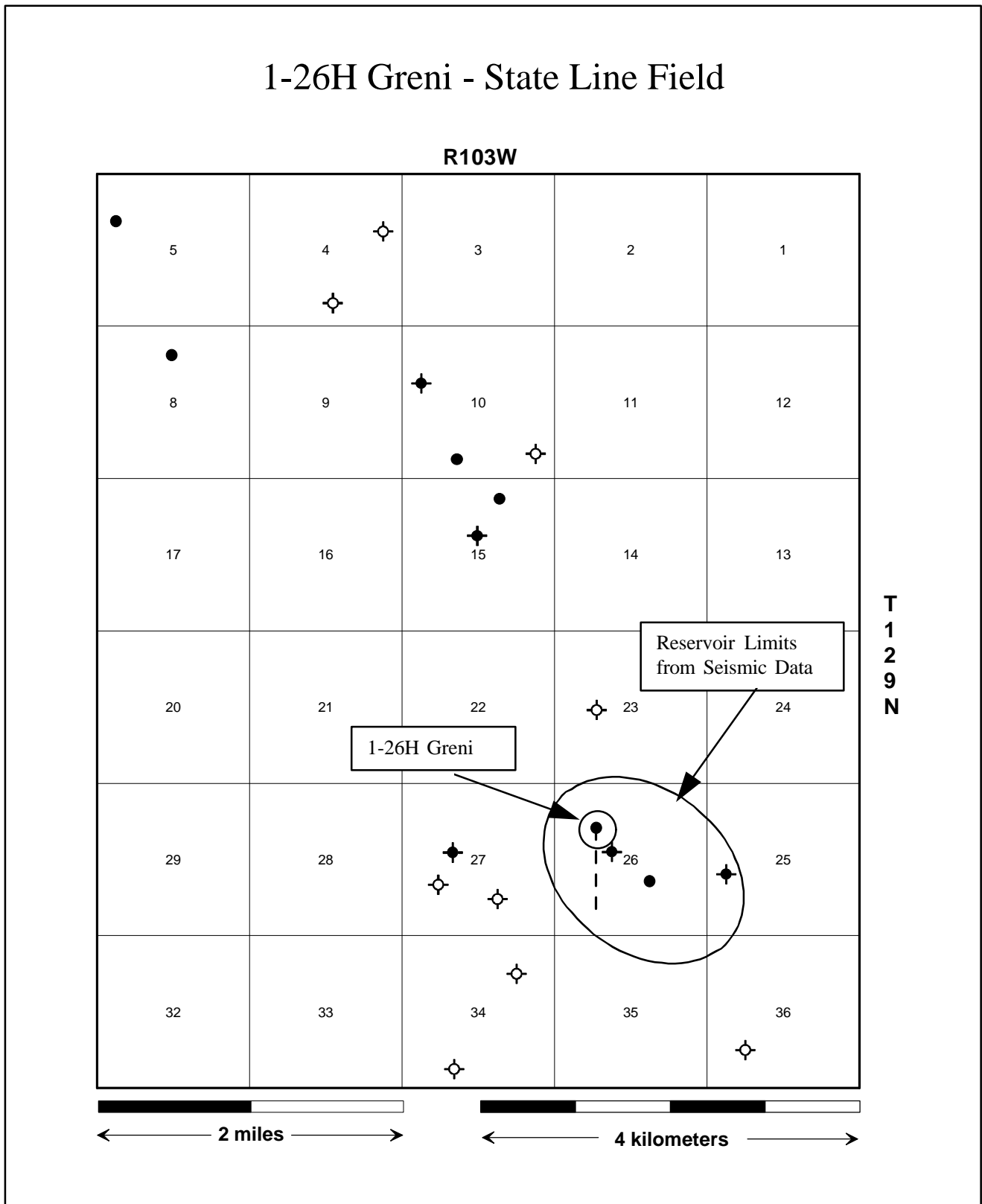


Figure 2: Map of State Line Field, Bowman Co., ND. The No. 1-26H Greni was drilled as a new horizontal well for the Red River B zone.

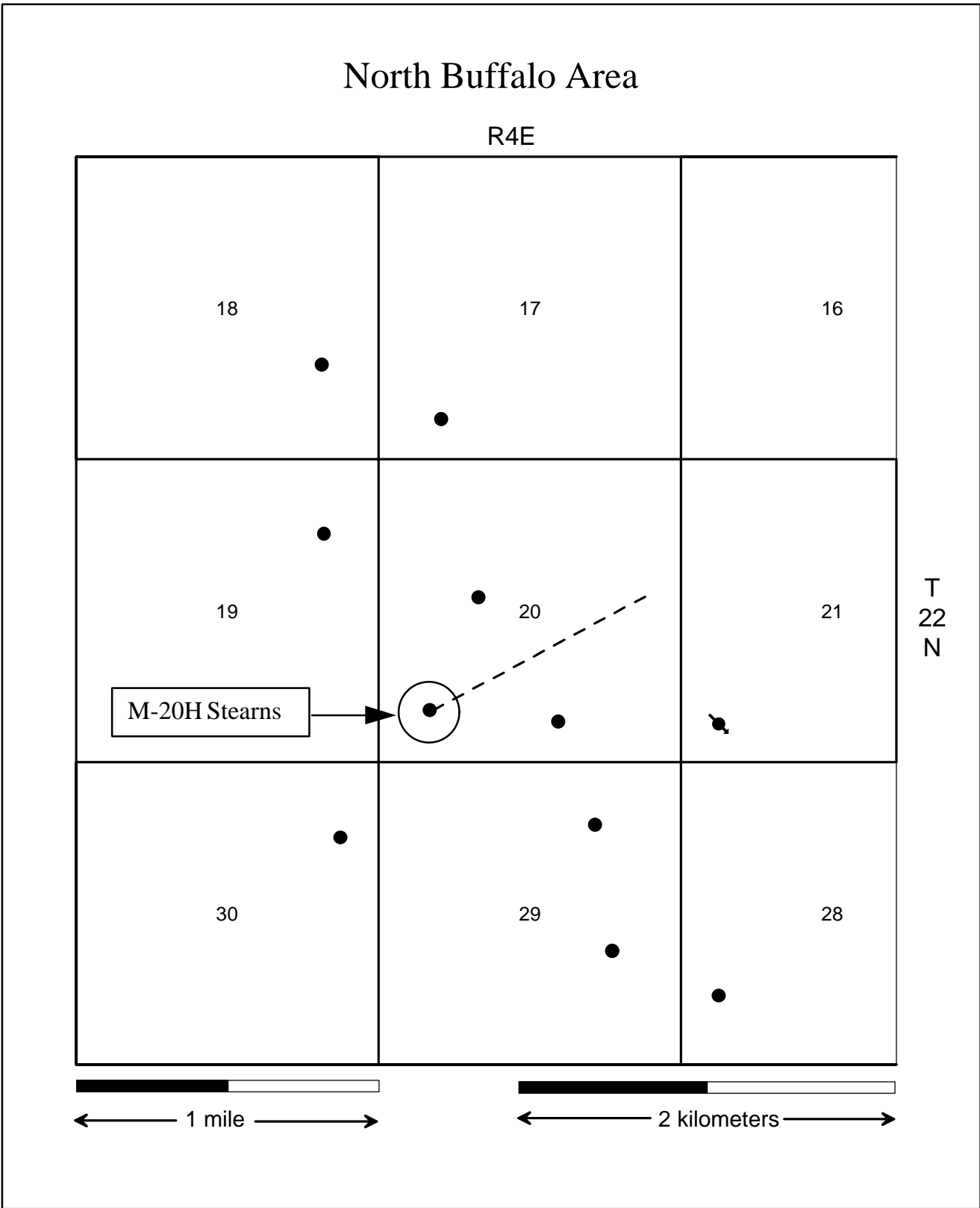


Figure 3: Map of Buffalo Field (north area), Harding Co., SD. M-20H Stearns well tested water injection through a horizontal completion in the Red River B zone.

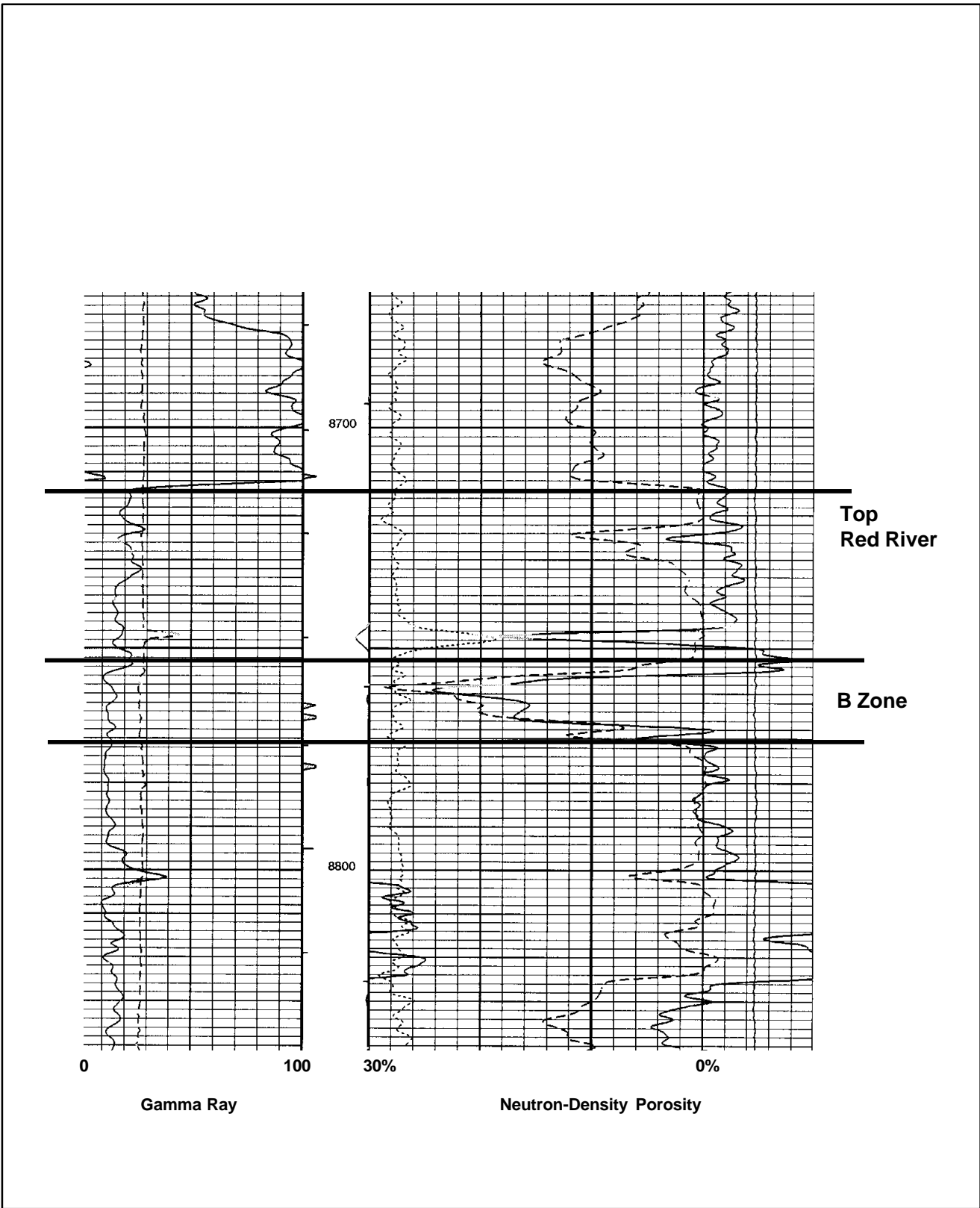


Figure 4: Porosity log of the Red River B zone at the M-20H Stearns well, Buffalo Field, Harading Co., SD.

North Sioux Pass 3D Seismic Survey

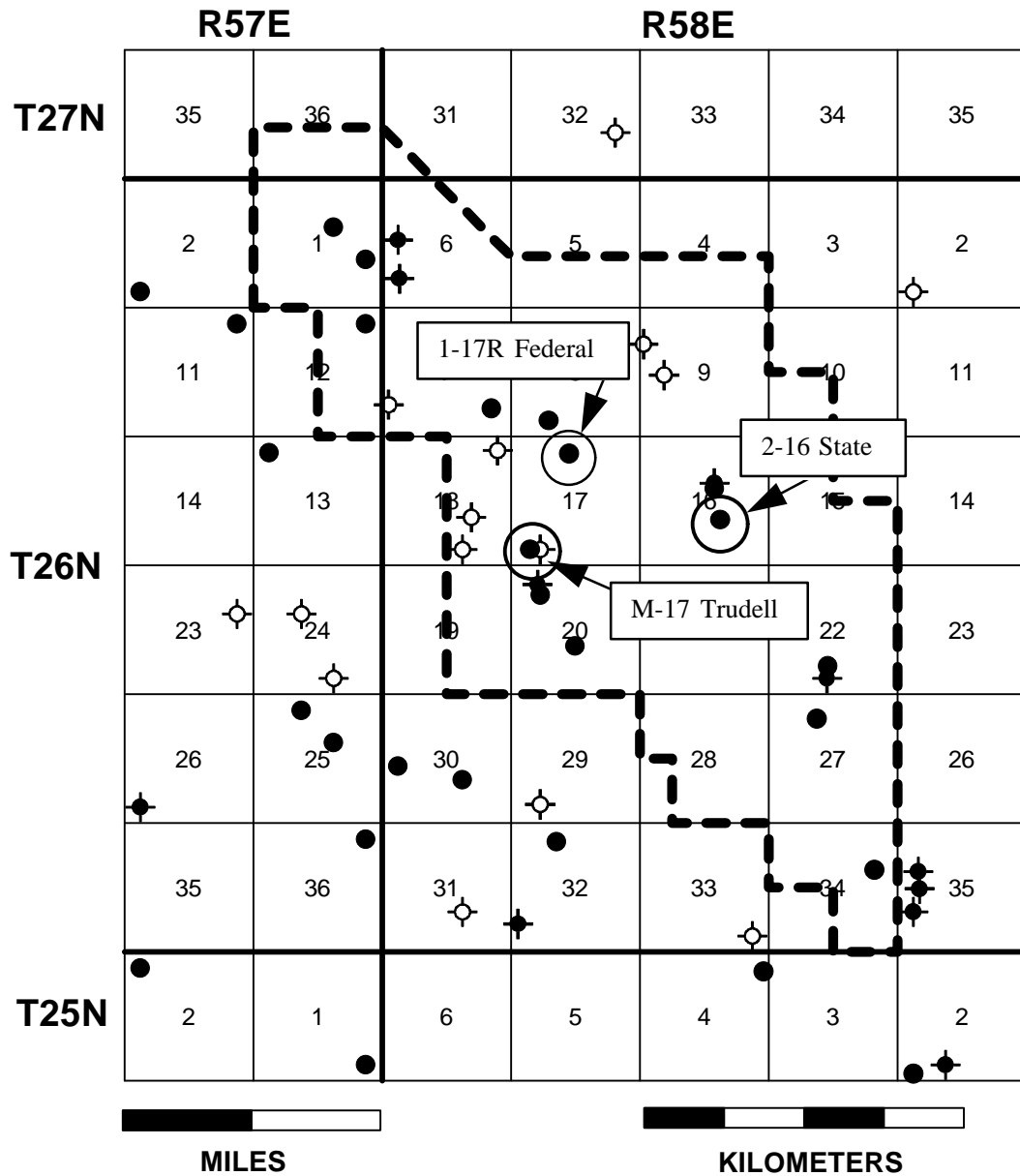


Figure 5: Map of North Sioux Pass Field, Richland Co., MT showing 3D seismic survey and well activity.

Federal 1-17R, North Sioux Pass

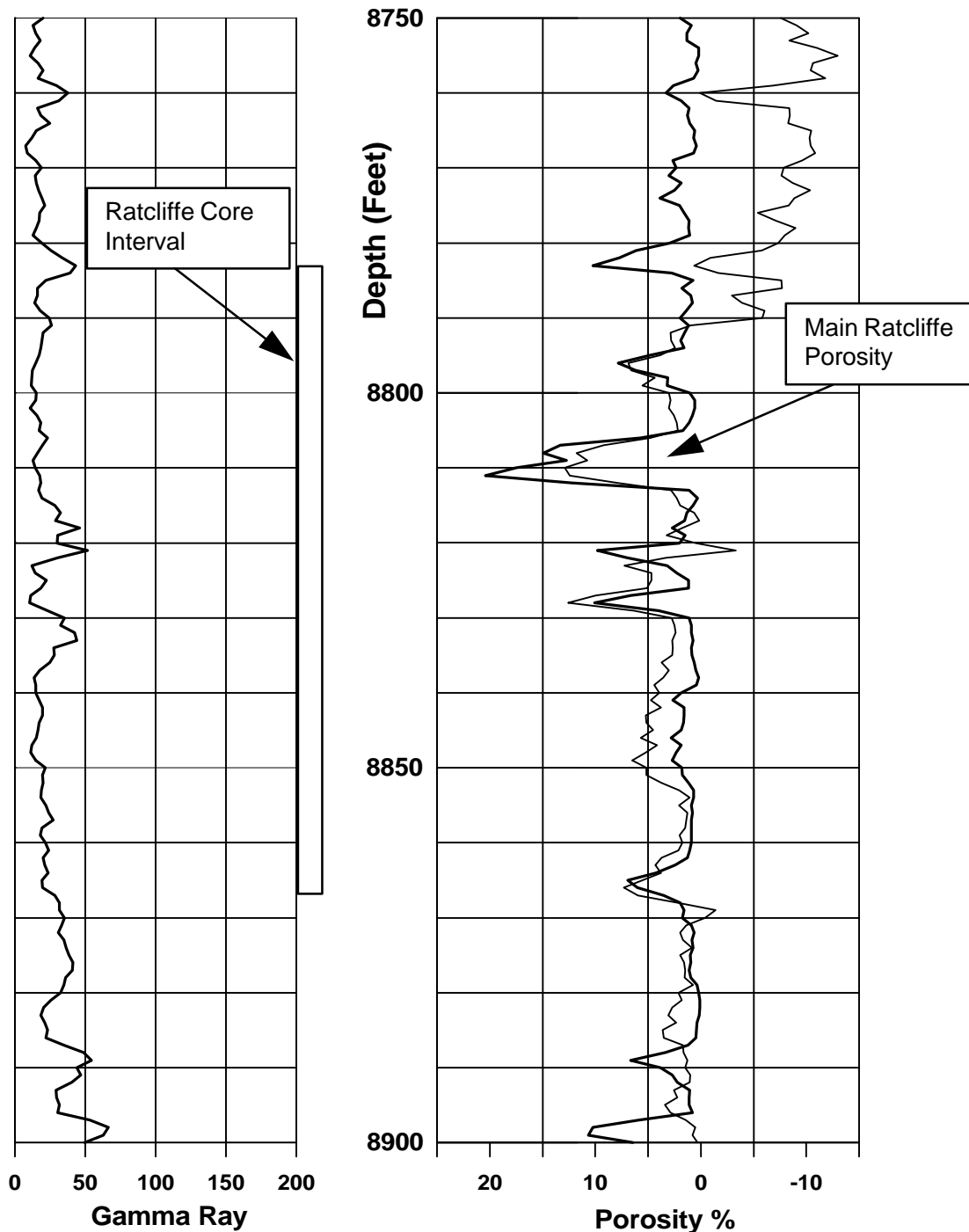


Figure 6: Porosity log across the Racliffe interval from the No. 1-17R Federal, North Sioux Pass Field, Richland Co., MT.