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Preliminary Mapping for Potential EOR Development of Transition and Residual Oil Zones in the Bighorn Basin, Wyoming

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August 1, 2011

Summary of the preliminary evaluation. EORI has been requested to evaluate the potential EOR development of transition and residual oil zones in the Bighorn Basin, Wyoming. The map generated as part of this evaluation provides information that may be useful for development of CO_2 EOR projects in the Bighorn Basin. A typical oil-bearing column in a Bighorn Tensleep reservoir, called a brownfield development opportunity, consists of a main pay zone at the top and a thick transition-residual oil zone below a traditional oil-water contact. The trapped oil in the transition-residual oil zone is difficult to be produced by primary depletion or water flooding, but it can be produced by applying more advanced EOR techniques, such as CO_2 flooding.

Some of the Tensleep structural traps are found to have only transition-residual oil zones. These traps, discovered with exploration wells, which were not developed due to economic consideration. As a result, the main pay zones were also not developed. These traps are referred to as “greenfield” opportunities; and can also be good candidates for CO_2 EOR.

Because of limited data and a short time frame, it was decided to map two regions of transition-residual oil zones based on available data sources. The locations of existing fields with identified thick transition-residual oil zones are mapped as proven areas for potential CO_2-EOR development, e.g. the red-sketched areas. It consists of over 287 thousand acres of surface land. A much larger area of the possible region of transition-residual oil zones for EOR development, outlined by blue lines, covers a total surface area of approximately 3.5 million acres. The possible region of transition-residual oil zones includes not only brownfield but also greenfield development opportunities. Additional work is needed to provide a more detailed map of the transition-residual oil zones in the Bighorn Basin. The concept of main pay zone, transition zone, and residual oil zone of Tensleep reservoirs is fully discussed below. Brief descriptions of the methods and data used in this evaluation are also enclosed.

Tensleep oil reservoirs in the Bighorn Basin. Development of the Bighorn Basin began as early as 1884, and by 2006 about 2.4 billion barrels of oil had been produced, 90% of which came from Paleozoic reservoirs. Tensleep sandstone is the dominant Paleozoic reservoir rock in the Bighorn Basin. The first Tensleep oil reservoir was discovered in 1922 (Hares, 1947), and there are 58 Tensleep reservoirs that have been produced in the Bighorn Basin. The transition and residual oil zones of Tensleep reservoirs in the Bighorn Basin are the focus of this evaluation and the main data sources used for the mapping.

Main pay zone, transition zone, and residual oil zone. In a typical Tensleep reservoir, the main pay zone (MPZ) generally refers to the perforated interval above a traditional oil-water contact, as illustrated in Figure 1. Initial production can be water free if only irreducible exists in the main pay zone initially. The transition zone (TZ) is located below the MPZ and contains both mobile oil and water, in which water saturation increases with depth from the traditional oil-water contact to the top of the residual oil zone (ROZ). Water is the only mobile fluid in ROZs. No oil can be produced by either primary depletion or water flooding in ROZs.

Brownfield and greenfield reservoirs. As illustrated in Figures 1 through 3, the oil-bearing column of a brownfield reservoir consists of a MPZ at the top of the Tensleep and a thick TZ/ROZ below a traditional oil-water contact. In contrast, a greenfield reservoir contains only a thick TZ/ROZ. Trapped oils in the TZ/ROZs of both brownfield and greenfield reservoirs are difficult to produce by primary depletion or water flooding, but they can be produced by applying more advanced EOR techniques, such as CO_2 flooding.

Data used in the mapping. The mapping of the potential area for future EOR development is mainly based on three data sources: (I) EORI's study on Tensleep TZ/ROZs, including data from core measurements, well logs, formation fluid properties, and well completion histories; (II) A DOE supported study completed by Advanced Resources International (ARI) in 2006; and (III) Available reports of characterization and development of ROZs in the Permian Basin (Melzer, 2011; Pickett, 2011; and Honarpour et al., 2010). The existence of the Tensleep TZ/ROZ has been discussed in several early papers. Zapp (1956) has identified 12 Tensleep reservoirs that have tilted oil-water contact (OWC) based on well perforation and production. Aufricht (1965) concluded that reservoirs containing heavier oil might have thicker transition zones with higher oil saturation. The 2006 ARI study identified 13 large Tensleep reservoirs as potential CO_2-EOR candidates. Based on ARI's estimation, the original-oil-in-place (OOIP) in the MPZ of the 13 reservoirs is about 4.5 billion barrels of oil (BBO), and the OOIP in the TZ/ROZ of the 13 reservoirs is estimated to be 4.4 BBO. The technically recoverable oil by CO_2 flooding in the 13 Tensleep reservoirs is predicted to be 0.5 and 1.1 BBO from MPZs and TZ/ROZs, respectively.

Proven and possible TZ/ROZ regions. The attached map (Figure 4) shows the extent of areas with TZs and ROZs that have potential for CO_2-EOR development. The red-sketched areas indicate locations of existing fields with identified TZ/ROZs, (i.e. brownfields, which have been evaluated by EORI and ARI). The areas outlined in red consist of over 287 thousand acres of surface land, a proven TZ/ROZ region, and are regarded as areas with high potential for CO_2-EOR development. The much larger area outlined by blue lines, (i.e. the "Donut Map"), includes not only brownfield, but also greenfield prospects. This possible TZ/ROR region covers a total surface area of approximately 3.5 million acres.

Undoubtedly, more detailed work needs to be carried out in order to provide additional information on the location and characterization of TZ/ROZs in the basin.

Regional study of the Frannie – Sage Creek area. EORI has studied oil accumulation in Tensleep reservoirs through oil generation, migration, and displacement by meteoric water influx and concluded that the Tensleep reservoirs with tilted oil water contacts (OWCs) have high potential for thick TZ/ROZs. Oil in this type of traps has been in the process of being displaced, and recent displacement of oil from the updip portion of a trap is faverable to generate thick TZ/ROZs. The study has also found that TZ/ROZs of Tensleep reservoirs in the Frannie-Sage Creek area are characterized by tilted OWCs and contains 40 to 80 percent residual oil saturation (Figure 2). The attached map (Figure 4) illustrates this area, which is adjacent to the Wyoming-Montana border. The Tensleep Sandstone in the Frannie-Sage Creek area is composed of up to 200 feet of eolian sandstones with several thin layers of dolomite or dolomitic sandstones. The perforation interval in most producing wells is located at the top of reservoirs, ranging from a few feet to tens of feet in thickness. The perforated interval is assumed to be the MPZ in this study, where oil has been produced during the primary and secondary productions. A thick TZ/ROZ, still high in oil saturation, is located below the MPZ in this area. Most non-commercial wells between the existing fields, for which log or core data are available, demonstrate oil saturation of 40 to 80 percent. In the Frannie-Sage Creek area, both the MPZ and the TZ/ROZ appear to be good candidates for miscible CO_2 EOR.

A series of anticlines or domes were formed on the slopes of Bighorn Basin during the Laramide Orogeny. Some of these oil-bearing structures on the surrounding mountains have eroded, exposing tar sands. Most Tensleep reservoirs are located on the lower basin slope. The traps located further up the slope were determined to be non-commercial when they were drilled in the past several decades. Many wells with high oil saturation were drilled on these structures, but were tested and determined to be uneconomical for primary and secondary production. Based on our preliminary study, many of these traps are regarded as good candidates for CO_2 EOR (Figure 3) due to high oil saturation.

Because most oil produced by primary and secondary production comes from MPZs, a large volume of oil remains below and around the MPZs of existing fields. Many explored traps in the Bighorn Basin with high oil saturation in Tensleep sandstones have so far not been considered economically productive reservoirs. However, the development of advanced recovery techniques, especially CO_2-EOR applied to TZ/ROZ in the Permian Basin, may allow the oil stored in TZ/ROZ of Tensleep Sandstone to be recovered. According to prior experience with the technique in the Permian Basin (Pickett, 2011), it is likely that simultaneous development of CO_2 EOR in MPZ and TZ/ROZ will be economically favorable in the Bighorn Basin.

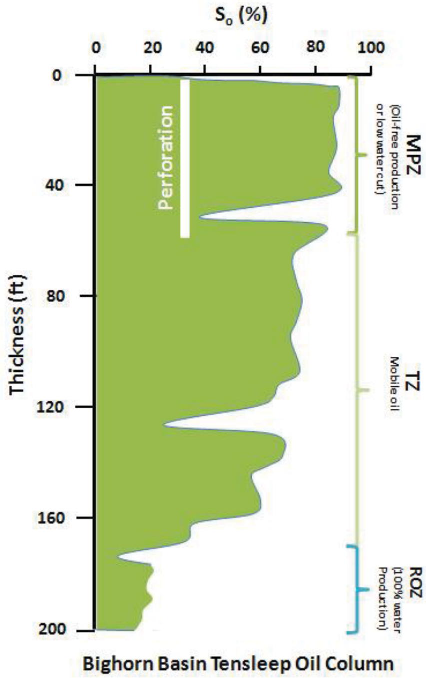


Figure 1. Typical oil column in the Bighorn Tensleep reservoirs, Wyoming.

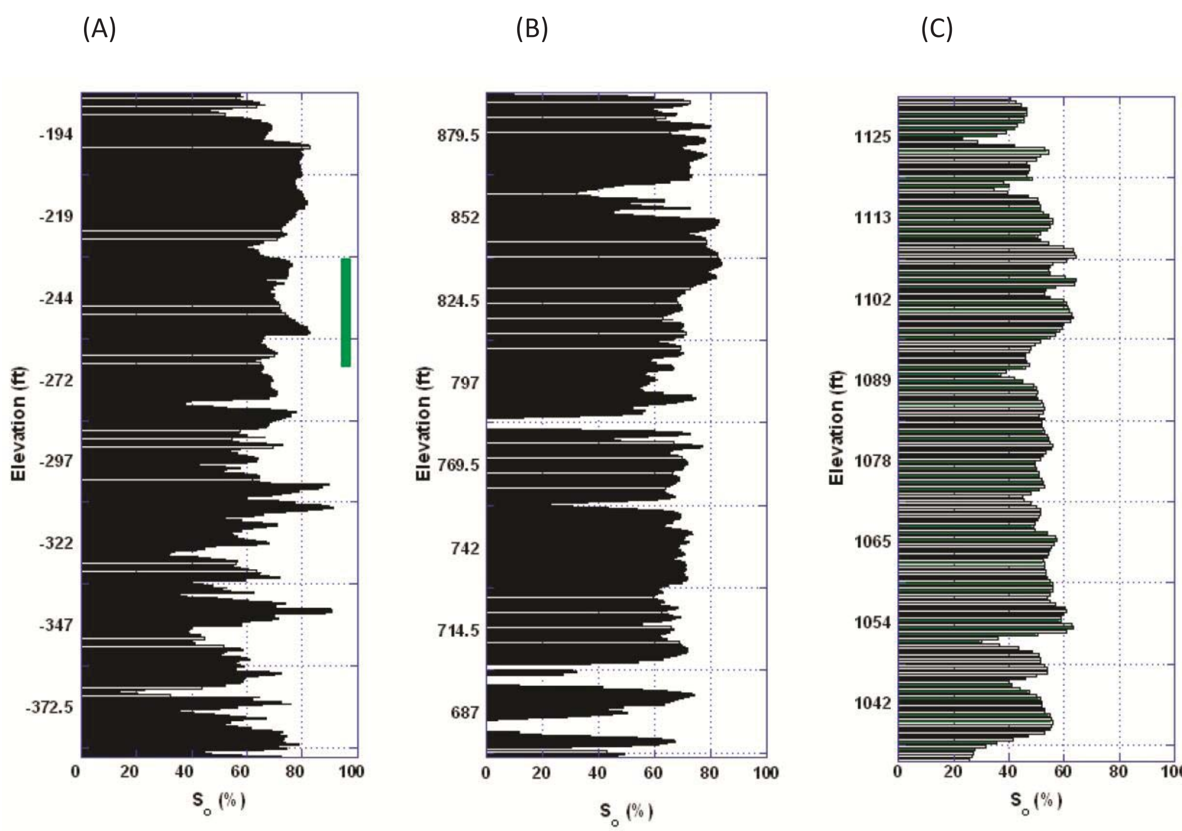
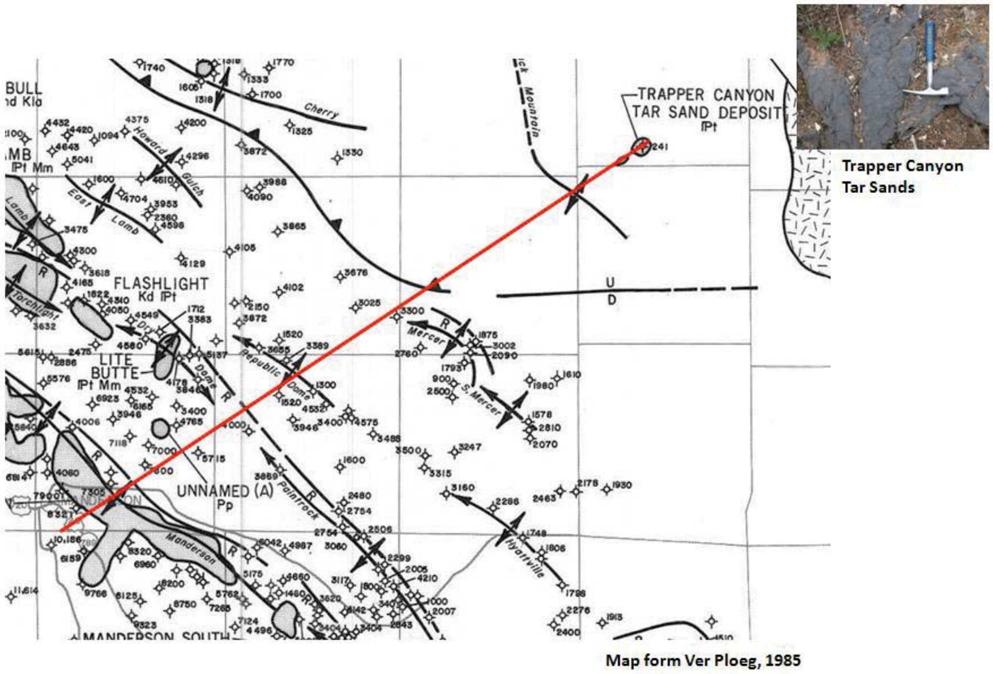


Figure 2. Examples of oil saturation measured from three different types of wells. (A): a producing well within a brownfield where the green line indicates the perforated interval; (B): a well located outside the producing area of a brownfield; (C): a non-commercial well drilled on the structure of a greenfield.



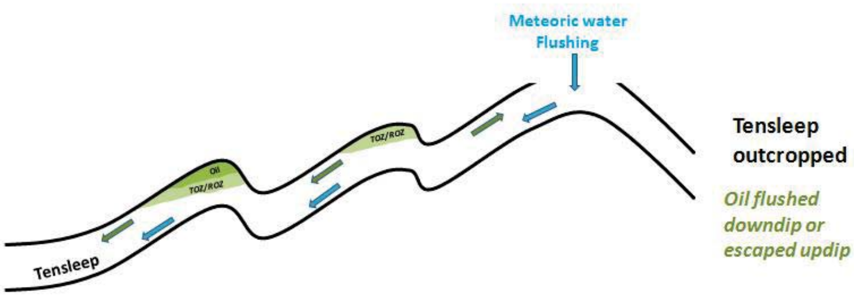


Figure 3. Top: A regional tectonic map of the east flank of Bighorn Basin. It shows the structures (lines with two opposite arrows), faults (lines with dark triangles), Tensleep reservoirs (shaded areas), and well locations (circles with number). A photo of Tensleep tar sand attached on the upper-right corner was taken at the Trapper Canyon area. The red line marks the location of the cross section below. Bottom: the cross section along the red line in the map above illustrates how oil was accumulated in the Tensleep reservoirs to form brownfields and greenfields. Oil-bearing structures located on the Bighorn Mountain were eroded and, consequently, meteoric water flushed into the Tensleep Sandstone. Some of the trapped oil in upper-slope structures escaped upward and could also be flushed downward in certain circumstances, and left only TZ/ROZ in the structures as current day greenfields. The producing Tensleep reservoirs, i.e. brownfields, are mostly found in lower-slope structures, which consist of MPZ and TZ/ROZ, and usually with tilted oil-water contacts.

References Cited

Autfricht, W. R., 1965, Distribution and production of oil and water in Tensleep-Minnelusa reservoirs: SPE 1162, P. 1-8.

Hares, C. J., 1947, A history of the oil business in the Big Horn Basin, Wyoming: WGA Field Conference Guidebook, 1947, p. 198-209.

Honarpour, M. M., N. R. Nagarajan, A. C. Grijalba, M. Valle, and K. Adesoye, 2010, Rock-fluid characterization for miscible CO_2 injection: residual oil zone, Seminole field, Permian Basin: SPE 133089, P. 1-24.

Melzer, L, S., 2011, Emergence of residual oil zones, price and supply factors usher in new days in CO_2 EOR: Special Report: Enhanced Recovery, p. 105-113.

Pickett, Al, 2011, Give legacy fields new life, The American Oil& Gas Reporter, June 2011, p. 105-111.

Koperna, G. J. and Vello A. Kuuskraa, 2006, Technical oil recovery potential from residual oil zones: Big Horn Basin: Advanced Resources International, Prepared for U. S. Department of Energy, 42p.