Evolution of Residual Oil Zones (ROZ's) in the Permian Super Basin

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Summary

Residual oil zones (ROZ'S) are widespread in the Permian Basin and the result of multiple episodes of diagenetic modifications to reservoirs by the introduction of massive volumes of meteoric recharge into the basin (Figure 1).

In the Late Eocene-Early Miocene (40-16 Ma) western North America experienced uplift as the Southern Rocky Mountain Epeirogen (SRME) formed (Eaton, 2008), which uplifted the western half of the Permian Basin to form a massive meteoric recharge area that extended to the present-day Rio Grande River (Figure 2). Uplift was created by emplacement of igneous intrusive and extrusive bodies to form the Trans Pecos Magmatic Province (TPMP). Additional intrusive bodies emplaced and uplifted the entire length of western North America.

Meteoric water heated as it passed intrusive bodies and created hot, high pressure, high volume meteoric recharge into the subsurface through porosity fairways in ramp/shelf margins (Figure 2). Meteoric recharge created a large hydraulic head of energy, capable of sweeping mobile oil out of structural closures and reducing oil saturation to a residual oil zone (ROZ) by mother-natures-waterflood.

Later, meteoric recharge was drastically reduced following development of the Rio Grande Rift in the Middle-Late Miocene (16-5 Ma), which down faulted and destroyed the large recharge area (Figure 2). This resulted in cool, low pressure, low volume meteoric recharge into the subsurface from isolated, small mountain ranges. As energy dissipated, previously swept reservoirs within structural closures that contain a ROZ were able to back fill and resaturate partially to completely with mobile oil. Some ROZ's did not resaturate with mobile oil and remained a ROZ or greenfield. One ROZ resaturated with gas instead of oil.

As mobile oil partially back filled and resaturated a reservoir with mobile oil to form a brownfield, the underlying ROZ was slightly back filled and resaturated with mobile oil. This explains why ROZ plays exist in the Permian Basin. A ROZ can be subdivided into an upper ROZ that is potentially productive and a lower ROZ that remains a ROZ.

Two examples of ROZ's on the Central Basin Platform (CBP) are: 1) Eunice Monument South Unit (northwest corner Central Basin Platform, CBP) that was completely swept of mobile oil to form a ROZ and later back filled and partially resaturated with mobile oil and left a ROZ at the base of the reservoir (brownfield); and 2) McElroy field (southeast margin CBP) that was also completely swept of mobile oil to form a ROZ and later completely back filled and resaturated the entire oil column with mobile oil and left no ROZ behind (Figure 1).

Theory and/or Method

Evidence for these two reservoirs and other reservoirs being completely swept of mobile oil is from detailed reservoir characterization that utilized: 1) numerous core descriptions; 2) thin section petrography of thousands thin sections; 3) cathodoluminescence of thin sections; and 4) fluid inclusion data (Figures 3-6).

Core descriptions and thin section petrography data revealed:

- Dissolution porosity that formed moldic, micro-vugular, and vugular pores.
- Dissolution pores filled with geopetal.
- Dissolution pores lined with late-stage limpid dolomite.
- Solution-widened fractures.
- Solution-widened fractures cemented by gypsum that contain oil inclusions.
- Solution-widened fractures cemented by gypsum underwent additional dissolution and solution-widening of fractures.
- Anhydrite nodules converted to gypsum and hydraulically fractured (fracked) surrounding strata vertically by the force of crystallization.
- Dissolution fronts that extend up-dip of grain-rich porous flow units into mud-rich strata.
- Anhydrite nodules underwent dissolution and reprecipitated as gypsum and captured abundant oil inclusions to form black gypsum nodules.
- Dolomite crystal cores underwent dissolution to form "dolo-donuts."
- Most, if not all, dolomite crystals are etched and corroded.
- Dissolution of anhydrite cement freed dolomite crystals and clumps of dolomite crystals to migrate within reservoir pore systems.
- Storm laminae (nicknamed Mombas) form small-scale non-porous ductile baffles-barriers.
- Transgressive mud-rich bases form large-scale non-porous brittle baffles-barriers.

Cathodoluminescence and fluid inclusion data revealed that original Permian dolomite, referred to as Phase 1 dolomite, underwent dissolution and reprecipitation of two later phases of dolomite, referred to as Phase 2 and Phase 3 dolomite (Figures 4 and 6):

- Cathodoluminescence of dolomite crystals that experienced dissolution and reprecipitated revealed a textural appearance that resembles a "shot gun pattern" of alteration.
- Phase 2 dolomite crystal cores contain fluid and hydrocarbon inclusions.

- Phase 2 dolomite crystals are interpreted to represent dissolution and reprecipitation of dolomite crystals as hot, high pressure, high volume meteoric water swept through the reservoir and actively displaced mobile oil.
- Phase 3 dolomite crystals (limpid dolomite) contain fluid inclusions only and surrounds phase 2 dolomite to form a late rhombohedral overgrowth.
- Phase 3 dolomite crystals are interpreted to represent when additional dissolution was followed by reprecipitation of limpid dolomite crystals after the reservoir had been completely swept of mobile oil and was at residual oil saturation to form a ROZ.
- Homogenization temperatures associated with dissolution and reprecipitation of dolomite crystals range from 131°-214°C for dolomite crystal cores and 113°-224°C for late dolomite crystal overgrowths (limpid dolomite).
- Regional dissolution of dolomite and evaporite strata raised meteoric water to moderate salinity (1.5X sea water) as it displaced mobile oil from CBP reservoirs and continued to push through previously swept CBP reservoirs.
- These two processes were not simple processes, but a series of long-term, highly drawn-out processes that extended over long amounts of time (40-16 Ma).
- Present-day bottom hole temperatures in these reservoirs have re-equilibrated to 37°C.

Conclusions

A simplified exploration/production version of the above data would be:

- Regional uplift
- Meteoric recharge
- Structural closures swept to a ROZ
- Destruction of the recharge area
- Back fill and resaturate reservoirs
- Slightly back fill and resaturate ROZ
- Drill lateral into upper ROZ
- Frack upper ROZ
- Pump off water
- Produce ROZ

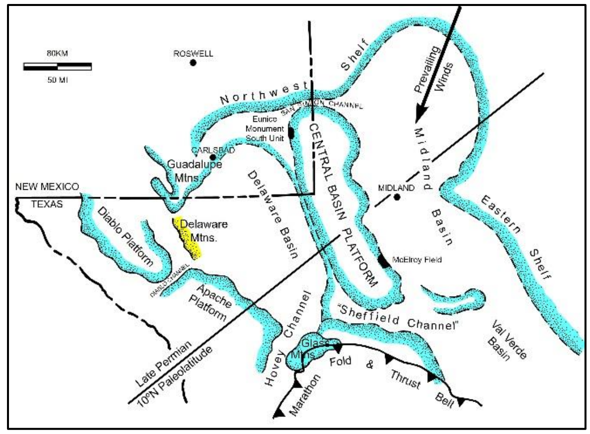

Figure 1. Permian Basin, with Eunice Monument and McElroy fields (Lindsay, 2014).

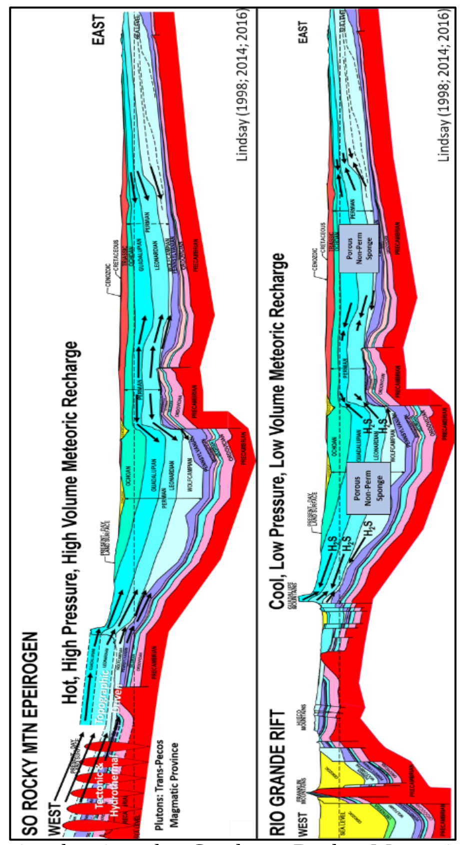

Figure 2. Regional east-west cross section through the Permian Basin showing the Southern Rocky Mountain Epeirogene (top) and Rio Grande Rift (bottom) (Lindsay, 1998, 2014, 2016).

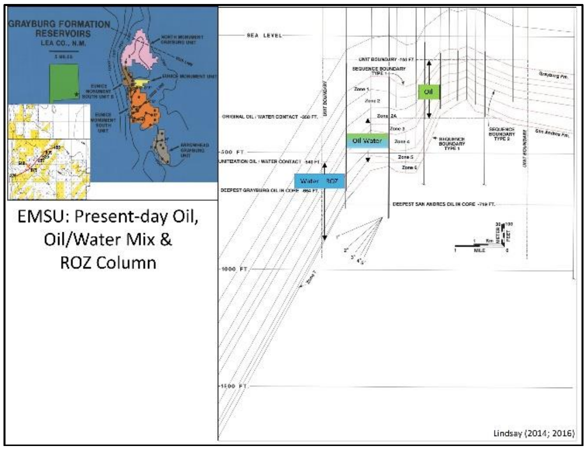

Figure 3. Eunice Monument South Unit structural cross section. Cathodoluminescence and fluid inclusion samples were from crest of the structure high in the oil column (Lindsay, 2014; 2016).

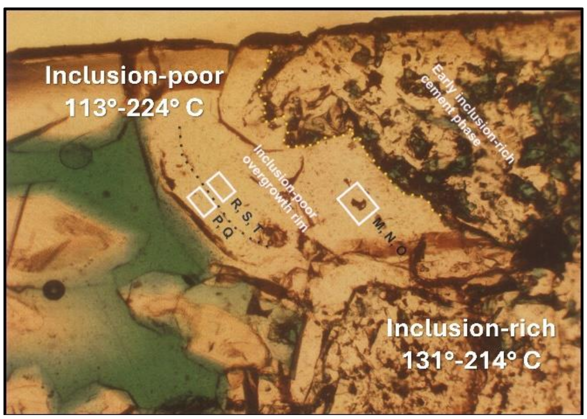

Figure 4. Eunice Monument South Unit, Grayburg reservoir, showing inclusion-poor and inclusion-rich dolomite and associated homogenization temperatures (Lindsay, 2018).

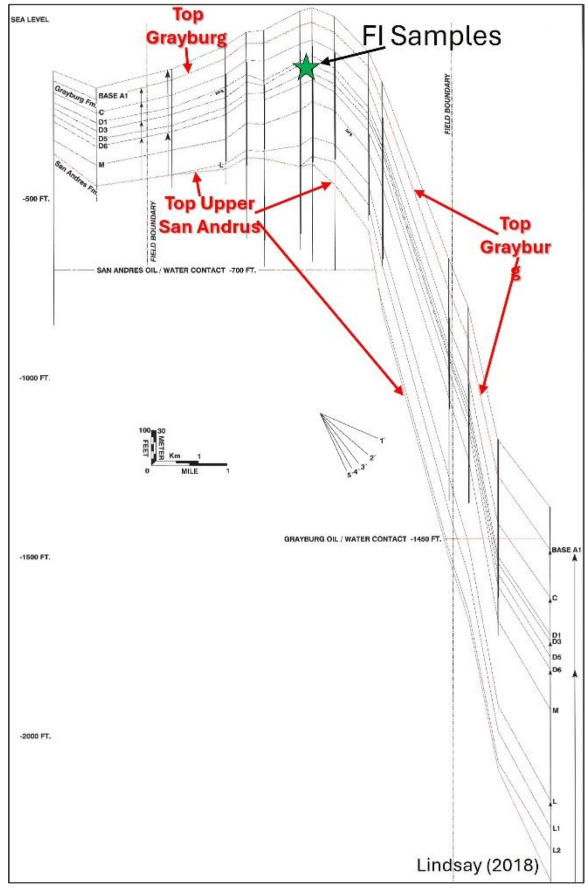

Figure 5. McElroy field east-west structural cross section, with position of fluid inclusions samples at the crest of structure high in the oil column (Lindsay, 2018).

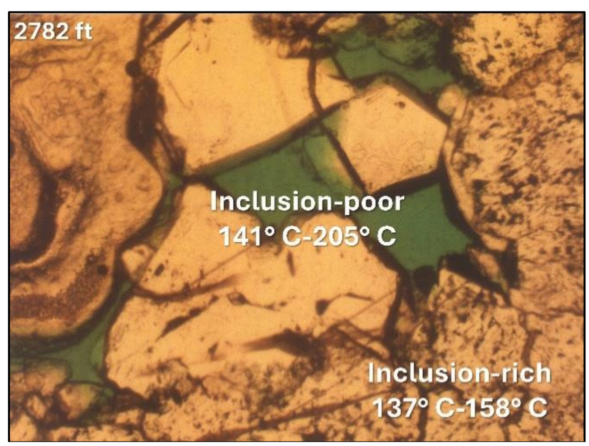

Figure 6. McElroy field, Grayburg reservoir, showing inclusion-poor and inclusion-rich dolomite and associated homogenization temperatures (Lindsay, 2018).