[PS]Carlin-Type Gold Deposit Development as an Analogue for Unconventional Hydrocarbon Field Development*

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Search and Discovery Article #30498 (2017)**
Posted April 3, 2017

*Adapted from poster presentation given at AAPG Pacific Section and Rocky Mountain Section Joint Meeting, Las Vegas, Nevada, October 2-5, 2016

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Abstract

Carlin-type gold deposits are sediment-hosted, low-grade disseminated gold deposits with economic recovery cut-offs at or below 0.1 oz gold/ton. The gold in these deposits is not visible, but occurs as atoms to microscopic blebs in arsenian pyrite rims on pyrite. Though these deposits are low-grade, the Carlin-type gold deposits in the Carlin Trend of northeastern Nevada contain the second largest concentration of gold in the world. Due to low gold concentrations, these deposits are generally developed as large surface mines. Initial development of many of these deposits began assuming fairly homogenous distribution of gold across the deposit. However, further analysis has shown that resource distribution is heterogeneous, with higher concentrations of gold in areas where the gold-depositing hydrothermal fluids were focused. Areas of focused fluid flow include along faults and folds, and within certain lithologic facies, including low-stand karsted shelf carbonates and deepwater carbonate turbidites. Thus, ore grade is a function of the structural and stratigraphic control of hydrothermal alteration. Therefore, mine development plans and economic models are critically linked to the deposit geology.

Similarly, unconventional hydrocarbon resources were initially seen as mainly an engineering play; once a source rock target was identified, drill and produce the field under the assumption that the resource distribution is homogenous. However, as with Carlin-type deposits, the resource density within unconventional fields is heterogeneous and controlled by geologic factors, including (but not limited to) depositional setting, paleogeography, burial/maturation history, tectonic/structural history, mineralogy, diagenetic history, and geochemistry. Evaluation and exploitation of Carlin-type gold deposits and unconventional hydrocarbon fields have similar histories. Both were initially seen as having fairly homogenous resource density, thereby excluding geology as a factor once identified. However, the resource bases in Carlin-type deposits and unconventional fields are not homogenous and the heterogeneities are driven by geologic factors. Understanding those geologic factors is essential as an input to determine the most effective and efficient ways to develop these resources.

Carlin-Type Gold Deposit Development as an Analogue for Unconventional Hydrocarbon Field Development

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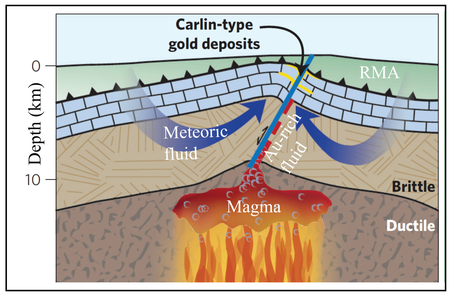


Top: Photo of a Gold Quarry mine near Carlin, NV (photo from D. Sturmer)
Bottom: Model showing the upper portion of a carlin-type gold system (Figure modified from Muntean et al., 2011).

Carlin-type gold deposits

Description - Disseminated gold deposits

Misconception - Gold density homogenous throughout deposits

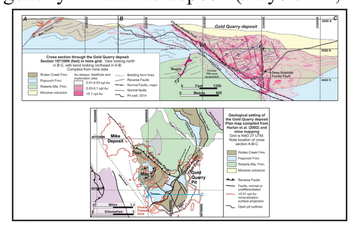
Key elements controlling gold deposition in Carlin-type gold deposits in Nevada (From Muntean et al., 2011)
- Structures
  - Proterozoic deep-seated faults access Au-rich magmatic fluids
  - Multiple generations of contractional structures including faults and folds allow for Au-rich fluid migration into structural culminations
  - Roberts Mountains Allochthon thrust above highly-faulted Lower Paleozoic host rocks (see stratigraphy)
- Stratigraphy
  - -Carbonate-rich Lower Paleozoic section silicified by Au-rich acidic fluids
  - -Sulphidation of Fe in carbonates, Au is hosted in result
  - -Chert-rich Roberts Mountains Allchthon stratigraphy acts as seal for Au-rich magmatic fluids

Result
- -Ore presence and concentration is a function of hydrothermal fluid flow, ultimately controlled by complex structure and stratigraphy

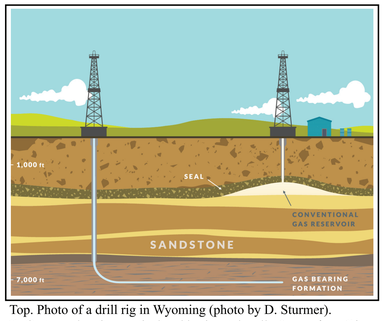
Understanding how the geology controlled and affected hydrothermal fluid flow and Au deposition is critical for:
- Gold reserves estimates
- Planning for mine development
- Refining methodology and facilites scaling

Ignoring the geology may result in:
- Poor mine development planning
- Missing discovering new high-grade zones
- Lost recovery
- Lost time and money

Example: Gold Quarry deposit - Chukar-Alunite fault is the main structure controlling Au ore grade with smaller smaller hanging wall faults controlling Au ore grade heterogeneity within the deposit (Rhys et al., 2015).



Cross section (top) and geologic map (bottom) of the Gold Quarry deposit, Elko County, NV. Figure from Rhys et al., 2015 and references cited therein.



Top. Photo of a drill rig in Wyoming (photo by D. Sturmer).
B. Cartoon showing vertical and horizontal wells. Image from Rigzone, available at: https://rigzonenews.files.wordpress.com/2015/02/screen-shot-2015-02-25-at-2-05-42-pm.png

Unconventional hydrocarbon plays

Description - Unconventional or hydrocarbon resource plays

Misconception - Hydrocarbon richness homogenous throughout play or prospect

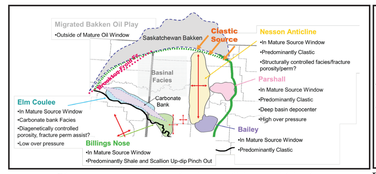
Key elements controlling hydrocarbon richness in unconventional plays (from Nash, 2014)
- Depositional setting and lithofacies
- Kerogen type and variability
- Lateral distribution and thickness variability
- Thief zones
- Burial history, heat flow, and thermal maturity
- Structures and timing
- Overlying seal efficiency
- Tectonic setting and in-situ stress regime
- Fractures present and fracture intensity

Result
- Density and economic recoverability are potentially highly-dependent on local geology

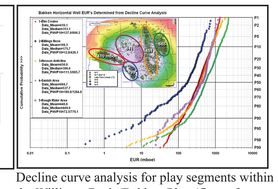
Understanding how the geology controlled and affected hydrocarbon richness is critical for:
- Accurate reserves estimates
- Planning for well drilling and field development
- Proper scaling of collection facilities

Ignoring the geology may result in:
- Poor field development planning
- Missing discovering new highly-productive zones
- Drilling too many wells
- Failure to adequately drain the reservoir
- Lost time and money

Example: Bakken - Multiple different play areas within the Bakken Formation, each with a different set of geologic conditions resulting in different decline curves (Campana, 2015; Hough and McClurg, 2011)



Play segments and geologic conditions within the Williston Basin/Bakken Play (figure from Campana, 2015)



Decline curve analysis for play segments within the Williston Basin/Bakken Play (figure from Hough and McClurg, 2011)

Understanding the geology is critical to identification and economic development of Carlin-type systems and unconventional hydrocarbon plays!