[AV]Locating the Play: The History of Visualization in Petroleum Exploration*

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Abstract

Although a visualization sequence in petroleum exploration is far from linear, several important milestones document a history of visualization techniques that proceeded from direct surface observation through subsurface imaging. Many newer methods typically complemented older ones, rather than replacing them.

Early exploration for hydrocarbons proceeded through direct visualization: if a seep could be located, petroleum could be harvested, in 1859, Drake's pioneering well extended the seep into the subsurface realm by drilling. Likewise, direct visualization was extended when Logan recognized the importance of structural traps, and petroleum searches proceeded through seeps and antiform structures after Spindletop (1901). The graphic vehicles that best supported data for early petroleum exploration were detailed, geological maps. By the 1920s, airplanes were able to facilitate mapping through aerial photography, and the resultant topographic maps helped to standardize the mapping process.

Direct visualization carried petroleum exploration only so far, and geologists realized that to locate subsurface petroleum reservoirs, they had to "see" into the subsurface. An explosion of techniques, modified for the petroleum industry, resulted. Seismic reflection methods emerged from WWI technology, with acoustic data employed to image the subsurface. Mapped gravity measurements, first through the torsion balance, also allowed geologists to peer into the Earth. Well logging's resistivity data permitted subsurface mapping between two surface points. Seismic profiles, gravity surveys, and e-logs became supporting graphic tools for petroleum exploration in the late 1920s and 1930s.

As technology advanced, exploration techniques evolved. Neutron logs enabled geologists to gauge porosity beginning in the 1940s, while NMR was hailed as a reliable visualization tool for permeability in the 1950s. The explosion of digital technology and computers resulted in efficient data filtering and analysis. Computers allowed for more thorough analyses of 3D seismic data (1970s) over 2D seismic data, and eventually 4D timelapse seismic data (1990s-). However, subsurface visualization never replaced surface visualization. Detailed geologic maps maintained their importance within exploration, although additional data-gathering techniques were added over the years, including thermal, infrared, and remote sensing.

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Locating the Play:
The History of Visualization in Petroleum Exploration

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Visualization in Petroleum

- A “branching bush” evolution
- Primary stages:
  - 1. Direct observation ⇨
  - 2. Surface observation & subsurface inference ⇨
  - 3. Subsurface visualization
    - *A multitude of visualization techniques*
- Secondary and complementary *assimilation* of methods

1. *In the Beginning. . . .*

- Direct observation
- Harvesting of petroleum from seeps

Natural petroleum seep, upper Ojai Valley, CA
http://petroleumgeology.org/petexpl.cfm

Notes by presenter:

We all know the urban legend immortalized on television, right? This fellow goes “shootin’ for some food, and up from the ground come a-bubblin’crude.”

1. In the Beginning. . . .

- The subsurface reservoir was located from petroleum seeps, gas seeps
  – Drake's pioneering subsurface well, Oil Creek, PA, 1859
- Patillo Higgins, Anthony Lucas, and Spindletop, 1901
  – *"Probably the greatest event in the exploration history of the American petroleum industry"*
    - *Michel T. Halbouty, 2002*
  – Focused exploration on the search for *other domes and anticlines*

San Joaquin Geological Society
http://www.sjgs.com/gushers_world.html

Notes by Presenter:

After Spindletop, the gently sloping mounds were surface indicators of the petroleum potential below. The explorers did not recognize the stratigraphic traps that existed in t he subsurface – or at least the majority of explorers did not recognize that type of trap. Patillo Higgins hypothesized that there were arched beds beneath Spindletop, and these beds trapped the petroleum. …

For the wildcatters, the knowledge that "hill" equals "oil" was enough.

2. Locating the Subsurface

- Structural petroleum traps as a viable exploration tool
  - Logan, 1901
- Surface observation leads to subsurface inference
- **Two-dimensional representations**
- **Detection from *remote* locations**

Weider History Group
http://historynet.com/images/pod0110.jpg

Notes by Presenter:

Wm. Logan, first Director of the Geological Survey of Canada, is given credit for recognizing that domal structures were associated with petroleum seeps. Thomas Hunt developed the hypothesis.

2. Locating the Subsurface

- Effective graphic display and visualization (Tufte 1990, 1997, 2001, 2007)
  - Show the data
  - Data should be presented truthfully
  - Complex data sets are good
  - Best graphic designs are multivariate
  - Improve legibility through font and color
  - Aim for high data density and eliminate chartjunk
  - Best graphic displays show causal relationships
  - Reduce the size of graphics
  - Landscape formats are superior
  - Escape “flatland”

2. Locating the Subsurface

- Vehicles in the search:
  - – Detailed geologic maps
    - Two dimensional representation
  - – Aerial searches and aerial photography
    - Gilard Kargl & Edgar Tobin
- Topographic maps combined the two methods

P2 Energy Solutions
http://www.tobin.com/AboutHistorySuccess.asp

Notes by Presenter:

The application of aerial photography, expanding from World War I aviation and improvements in photography, provided a quicker method for generating geological maps of the surface

Gilard Kargl (Austrian) recognized the early potential of aerial photography for geologic map construction, and he approached Edgar Tobin to form Tobin Aerial Surveys. This recognition ushered in photogeology, where stereoscopic images allowed geologists to generate a 3-D image.

2. Locating the Subsurface

- Beaumont
  - – 1926

Beaumont, 1926
1http://www.lib.utexas.edu/maps/topo/texas/c.htm
Perry-Castañeda Library Map Collection
University of Texas at Austin

2. Locating the Subsurface

- Surface visualization and representation advanced through the 20th century:
  - Different methods of photography:
    - Color photography, thermal, infrared
  - Remote sensing through satellite data

Notes by Presenter:

The basic geologic map was never replaced, but was added to with technological advances. The map is needed – it benchmarks the more technically advanced methods.

3. Bypassing the Surface

- *“Geology in the petroleum industry serves one function only: to provide eyes in the ground. And all geological activity that is of any use whatever to the industry is directed toward this function. Consequently, petroleum geology clusters round the inventions and innovations which, quite literally, see oil.”*

– John G.C.M. Fuller, 1971

Note by Presenter:

Surface geology will take you only so far, though. …

3. *Bypassing the Surface*

- Well cuttings
  - Johan August Udden,
  - 1912, Texas
- Coring methods
  - Rotary coring (attributed to Leschat, 1863) utilized in petroleum in 1920s
  - Expensive & time intensive

Notes by Presenter:

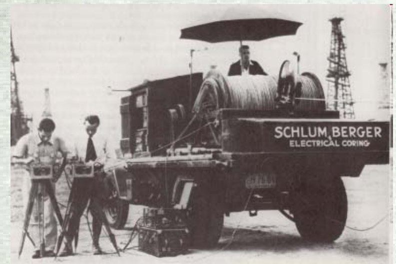
There are urban legends of geologists lowering themselves into boreholes in order to see what the subsurface held!

When Johan Udden joined Texas' Bureau of Economic Geology in 1911, the petroleum industry in Texas had already established its importance. However, Udden wanted to understand the subsurface, and he focused on well cuttings as a means to focus on the rocks beneath the well. He included fossils for biostratigraphical analysis in 1916 and 1918 papers.

Rotary coring provided a means to acquire intact cores. These subsurface cores provided a record. The problem, of course, was that they were expensive for subsurface stratigraphic correlation.

3. Bypassing the Surface

- Gravity surveys
  - – via the torsion balance (Eotvos, 1915)
  - – Nash salt dome, Texas, 1924
- Well logging (*e-log*)
  - – Resistivity data,
    - Conrad & Marcel Sclumberger 1927
  - – Spontaneous potential (SP)
    - Henri Doll
    - 1931



http://www.sjgs.com/schlum.jpg
San Joaquin Geological Society
http://www.sjgs.com/history.html

Notes by Presenter:

Gravity was the first seismic method, used in Hungary in 1915, and imported to the US by the early 1920s by DeGolyer.

Resistivity data were added in the mid-1920s by the French engineer Conrad Schlumberger, who measured the first petroleum survey to 500 meters in Pechelbronn oil field in Alsace France; he measured resistance to the electrical current to determine whether they encountered porous sand with petroleum (high resistivity) or salt water (low resistivity).

Doll recognized that spontaneous current flowed from shale layers through drilling mud into permeable sands – perhaps as early as 1929. The Spontaneous potential, SP, was being measured by 1931 though and applied in the Russian oil field. This was another tool in the arsenal – the ability to differentiate oil-bearing, porous beds.

3. *Bypassing the Surface*

- First electric log,
- September 7, 1927
  - Diefenback 2905 well,
  - Rig #7

Pike & Duey, 2002

Notes of Presenter:

The ease and cost effectiveness of the e-log saw a quick application in petroleum, and the industry witnessed a large percentage drop (over 50% -- probably closer to 80%) of coring operations. However, similar to the continued use of surface geologic maps, the core was never completely replaced.

3. Bypassing the Surface

- Seismic methods
  - World War I technology
  - Acoustic data to “see” subsurface
    - Mintrop, Karcher
    - Orchard Dome, Texas, 1924
  - Widespread use in the 1930s
- Neutron logging to gauge porosity
  - 1940s

Notes of Presenter:

Interestingly, Udden (the Texas Bureau of Economic Geology) also was one of the early geologists for recognizing seismic’s value in exploration.

Following WWI, the German scientists employed seismic in petroleum exploration – and notably searched for salt domes in the subsurface! Emigrants and the technology made their way to the US petroleum industry in the 1920s, and the technique was widespread in the 1930s. The Gulf Coast was a targeted area, where subsurface salt domes were sought.

Gamma ray logging was introduced in 1939, and neutron logging was available in the late 1940s.

It should be noted that, although coring operations were diminished, the information provided by cores – such as grain types, sizes, and bedding – could not be determined by the these subsurface methods. So coring was never replaced, though a more widespread use was sacrificed with cost concerns.

3. Bypassing the Surface

- Seismic advances in visualization techniques
  - Eliminate “chartjunk” with noise reduction (Tufte, 2001) methods to accurately “show the data”
  - Aided by computers and digital processing
- 1950s: Nuclear magnetic resonance (NMR) to gauge permeability
- 1970s: Digital technology
  - Computer analysis of 3D seismic
- 1990s: time lapse 4D seismic

Notes by Presenter:

Seismic continued unchanged in the 1930s and 1940s, but MIT’s Geophysical Analysis Group pioneered visualization advances in reflection seismology in the 1950s. By attenuating oscillations and eliminating other noises, signal processing opened up offshore subsurface visualization via seismic.

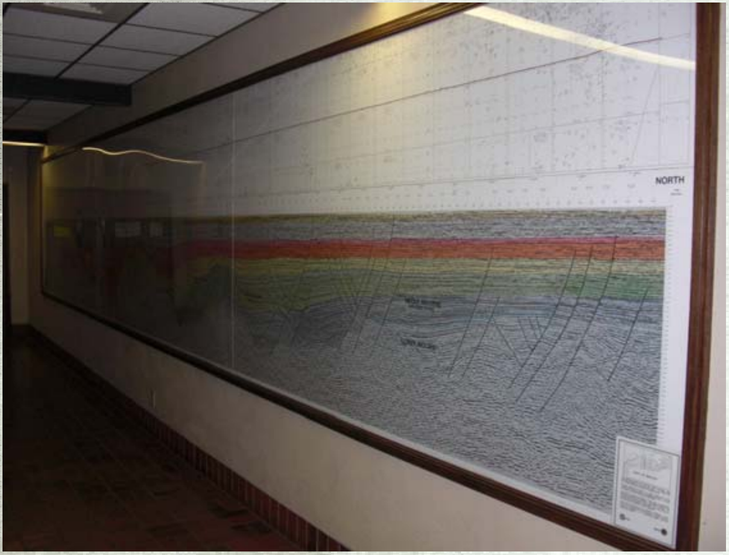
3-d seismic moved beyond the profile line in an attempt to image an areal view. The issues in field recording, data storage, and importantly for our visualization history – the *projection* of this image-- were solved through additional advances in digital computing.

Software, data processing programs were needed

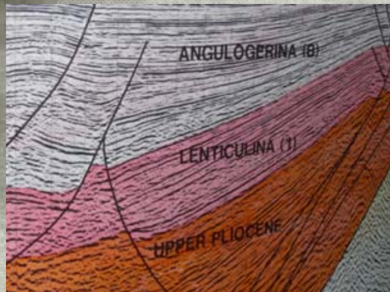
Secondary Complementary Assimilation

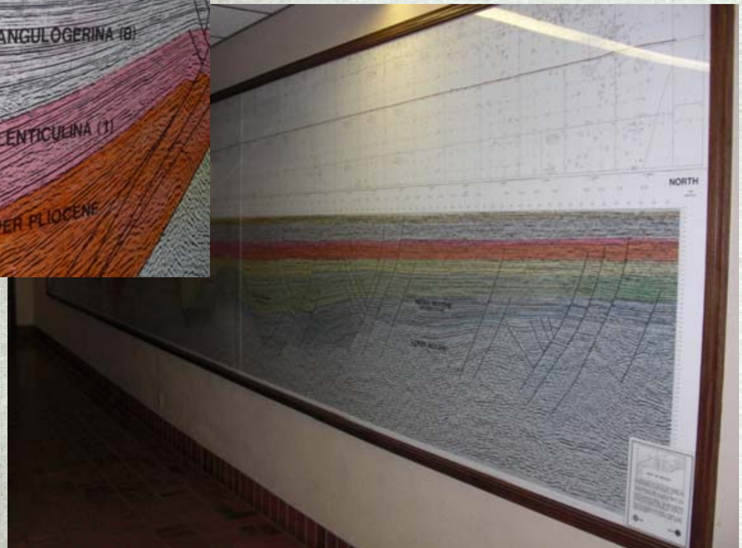
- **Geological maps** remained essential as a benchmark
- **Cores**, although reduced with cost-effective visualization methods, remained important
- New techniques were integrated and assimilated within older proven methods
- Assimilation resulted in geologic “super graphics”

Complementary Methods



Complementary Methods





Discussion & Implications

- Detailed geologic maps maintained their importance in exploration
- Additional data gathering techniques added to the repertoire
- Visualization in petroleum exploration advanced
  - Improved geological maps
  - **Improved subsurface visualization**
- *More research into the history of petroleum visualization—in public domain and private companies—is needed to fully elucidate the roles that each technique played in visualization, as well as economic recovery*

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