AAPG EXPLORER

Geophysical Corner

Static Interpretation Now Dynamic

The Geophysical Corner is a regular column in the EXPLORER, produced cooperatively by the AAPG Geophysical Integration and SEG Interpretation committees, and edited by M. Ray Thomasson. This month's column is titled "From Static to Dynamic Interpretation of Subsurface Data – A Change of Paradigm."

By DIETRICH H. WELTE,
BJORN WYGRALA
and THOMAS HANTSCHEL

The most wide spread source for subsurface data is 2-D and, increasingly, 3-D seismic. Data related to boreholes – such as well logs and rock samples – provide crucial complementary and calibration parameters.

In the past, and even today, the prevailing approach in the interpretation of these subsurface data is static.

This means that great efforts are made to describe subsurface structures and property distributions in their present state. However, understanding and modeling past geological processes that were responsible for the present status of the subsurface has so far not been sufficiently emphasized.

In petroleum exploration and production it is an essential requirement to understand these past geological processes – especially petroleum generation and migration – which determine whether or not a trap contains hydrocarbons.

Hence, it is crucial to understand the dynamics of relevant processes responsible for the present day geological conditions.

As modeling of geological processes relies entirely on a subsurface database and related, intelligently structured data archives (often called data models), it is essential that the numerical simulation is linked as closely as possible to these data sources. This is easily achieved by direct binary access to seismic data and interpretation tools like OpenWorks, GeoFrame, SeisWorks, IESX, etc.

It is common practice to organize and store subsurface data in more or less sophisticated data archives that can be screened and manipulated electronically. An electronic data archive enables information to be exchanged, reviewed and thereby enriched and updated.

Even the most refined interpretation utilizing advanced interpretation software and databases, however, produces static information for stratal terminations, seismic facies, lithofacies and property distributions, etc.

Such static data archives can be brought to life – and at the same time generate a great deal of added value – by dynamically modeling the geological processes behind it.

* * *

The conversion of static data to a dynamic process interpretation starts with a rigorous analysis of the stratigraphic time record of the sedimentary column and by assigning absolute ages. In this way an absolute time sequence of critical geological events is derived and a conceptual geological process model is created, forming the backbone of the dynamic process interpretation and the chain of logics for a computer model.

A petroleum system includes the entire hydrocarbon source, carrier and accumulation system, and the goal must be to reconstruct the entire geological history of a petroleum system, from its origin to the present.

The main focus must be on the location and 3-D configuration of drainage areas for mature source rocks through time, and on possible migration pathways to collect the corresponding hydrocarbon charge.

The modeling of the petroleum system, i.e. the numerical simulation of the relevant processes, rigorously follows the geological time axis.

The principle concepts and methods of this kind of modeling are well established in existing basin modeling techniques. It commences with the deposition and compaction of the oldest stratigraphic units at the bottom of the system and works its way upward through younger and younger events to the present day.

The resulting dynamic modeling requirements mean that our models must be able to take most important changing factors through geologic time into account. These include:

- ❑ Changing geometries.
- ❑ Multi-dimensional, non-steady state thermal histories.
- ❑ Overpressures due to compaction disequilibrium and hydrocarbon generation.
- ❑ Changing hydrocarbon phase relationships as a function of temperature and pressure.
- ❑ Many other processes.

Software programs today can provide all of this functionality. Petroleum migration processes can be modeled in two dimensions (2-D) along geological cross sections, but any attempt to quantify hydrocarbons in a simulated system must be based on three dimensional (3-D) data archives and modeling techniques.

The geometric resolution depends on one hand on the quality and resolution of the data, and on the other hand on such crucial parameters as the grid density,

continued on next page

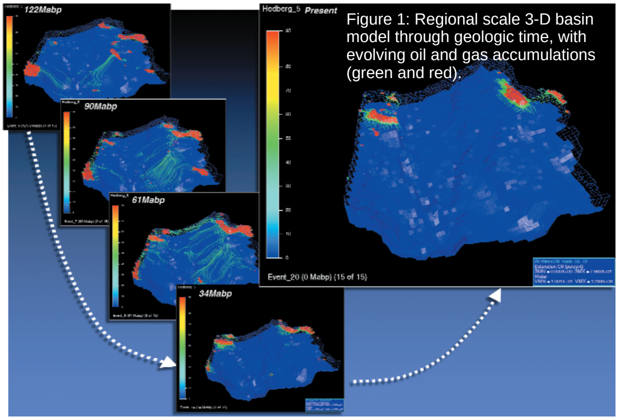

Figure 1: Regional scale 3-D basin model through geologic time, with evolving oil and gas accumulations (green and red).

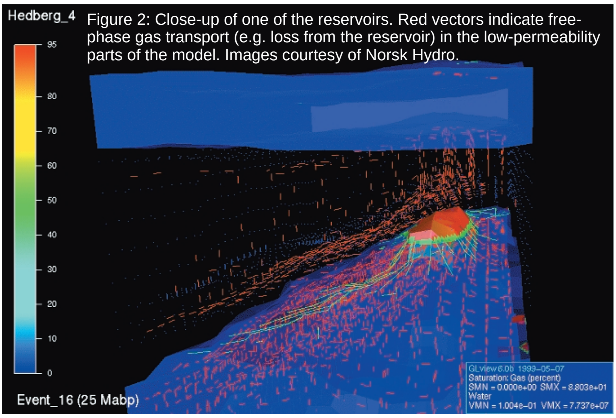

Figure 2: Close-up of one of the reservoirs. Red vectors indicate free-phase gas transport (e.g. loss from the reservoir) in the low-permeability parts of the model. Images courtesy of Norsk Hydro.

continued from previous page

number of cells, the computational power and allowable computing time.

Due to the need to reduce cycle times (i.e. the time between acreage evaluation and drilling of a successful well) in exploration, and the need to run multiple models to test sensitivities, computing time is an important issue in petroleum systems modeling. Fast computing times are needed to model changing configurations of source and migration pathways over geologic times (i.e. 4-D).

Simulation runs that reconstruct the geological history of a petroleum system inclusive of multi-phase migration modeling should typically be performed in several hours on a normal workstation or workstation cluster. Such “short” processing times can only be achieved at present with hybrid migration simulators that enable fully integrated 3-D Darcy flow/flowpath (also called ray tracing) modeling to be performed.

Simulation runs with this technology not only reconstruct the most likely generation, migration, accumulation and spilling history in a petroleum system, but at the same time show possible weaknesses of the 3-D data base and/or inconsistencies in the conceptual geological model.

Overpressure zones can be fairly well predicted by geological process modeling, so the technology can even help to improve seismic interpretations, for instance, with respect to selecting the right seismic interval velocities in overpressure prone regions.

The new simulation technology enables regional scale 3-D models with as many as a million-plus cells – and consequently, very reasonable resolutions – to be processed within acceptable time spans. It also reduces the risks associated with upscaling geological models to a point where oversimplifications can limit their value.

This kind of 3-D modeling can therefore now be used as a guidance tool and a framework for play and prospect evaluation throughout an entire exploration campaign. With new data or insights it can be updated continuously.

The great advantage of this technology is its potential to directly and immediately provide the best possible understanding of all crucial processes responsible for petroleum accumulation in a reproducible and quantitative manner.

Geological process modeling, thus, is the logical continuation and refinement of static subsurface data interpretation. It is the crucial step from static to dynamic interpretation of subsurface data.

* * *

Today a complete array of

See **Geophysical Corner**, page 37

Geophysical Corner

from page 29

technological facilities is already available to extend "classical" but static subsurface data interpretations into dynamic process modeling in a sequential manner – firstly seismic interpretation, and secondly process modeling.

The next step is to extend the integration of the various technologies and data types to create even more value by adding synergies. It is the provision and availability of proper interfaces between the relevant software packages and intelligent tools to interactively manipulate original data and results on both sides.

This step, without any doubt, will dramatically accelerate the application of more intelligent (dynamic) data interpretation tools.

The cost of this type of dynamic interpretation compares favorably with, for instance, the cost of sophisticated seismic processing including attribute analysis, or obviously of drilling dry wells in deep water environments.

All in all, a dynamic interpretation of subsurface data greatly improves our understanding of crucial geological processes – and it narrows down the band width of uncertainties. Furthermore, it is the ideal vehicle to integrate different geoscientific disciplines, to create real links between exploration and exploitation data archives and processing tools.

The result? Logically organized work flows in interdisciplinary teams.

(Editor's note: Dietrich H. Welte, Bjorn Wygrala and Thomas Hantschel are all with IES Integrated Exploration Systems, Juelich, Germany.)