

Reservoir Quality Prediction through Sandstone Diagenetic Modeling

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Presently, the available approaches to diagenetic modeling tend to be based on rigorous thermodynamic, kinetic, and transport theory. These models typically require experimental data and geological input that is difficult to obtain. Furthermore, the extrapolation of laboratory experiments to geologic conditions requires very accurate and precise measurements that are so far not attainable. Small errors in the temperatures and heating rates during experimentation can become major during their extrapolation. On top of that, changes in reaction mechanisms complicate the validation of kinetic parameters for wide temperature ranges, such as those encountered in geological settings.

An alternative approach to estimate rate changes over large time scales (millions of years) is to model them using geologic observations and time-temperature burial data. There are several examples of empirically derived reaction kinetics in geologic systems, such as the kinetics of petroleum generation (Lopatin, 1971; Waples, 1980), aromatization and isomerization of hydrocarbons (Mackenzie and Mackenzie, 1983; Gallagher and Evans, 1991), and vitrinite reflectance (Burnham and Sweeney, 1990).

We have developed a forward numerical simulator, based on empirically calibrated kinetic models for several diagenetic reactions, to provide a reservoir quality prediction, that is, a porosity and permeability prediction, suited for exploration problems. The model provides accurate predictions for changes in sandstones from commonly available geologic data.

The simulator performs calculations in a matter of seconds, and results can be either plotted for easy visual analysis or simply viewed in their raw form. A considerable amount of effort has been placed into presenting a user-friendly graphical interface which allows for easy comparison of results from simulations with visual tools to help spot various trends.

With the simulator, different diagenetic processes are reproduced and compared to available geological trends reported in different basins. Some of the algorithms and kinetic rates that our forward simulator calculates are taken directly from the literature. Some other reservoir quality controlling processes are shown and tested for the first time. The simulator calculates:

- 1) Sandstone compaction through geological time, based on data from the work of Pitmann and Larese (1991), Lander and Walderhaug (1999), Chuhan and Bjorlykke.
- 2) Quartz cementation through geological time, based on work by Walderhaug (1994 and 1996).
- 3) Porosity reduction through geological time, based on the work of Lander and Walderhaug (1999)
- 4) Albitization of plagioclase, based on Perez and Boles (2006),
- 5) Smectite to illite transformation, based on Huang et. al. (1993), Velde and Vasseur (1992) and Elliot and Matisoff, 1996).
- 6) Fracture formation due to thermoelastic contraction, based on the uniaxial stress model of Perez and Boles (2006).
- 7) Precipitation of intergranular calcite through geological time as a function of anorthite dissolution, also through geological time.

All these processes aid in the prediction of porosity and permeability distribution in basins and may be used to predict the two dimensional distribution of porosity and cements. Furthermore as a paleothermometer and independent calibrator we included a popular vitrinite reflectance model (Sweeny and Burnham, 1990). As mentioned, for the most part, the input parameters for each one of these processes are derived from petrologic analysis.

To illustrate the utility of the model, we applied it together with vitrinite reflectance to regions in the San Joaquin basin in California, Lake Maracaibo basin in Venezuela, Denver basin in Colorado, Texas Gulf Coast basin, Paris basin in France, and geologic data from the Norwegian North Sea basin. In all cases we see satisfactory results when compared to realistic geologic data, and are able to reproduce reservoir trends.

References

- Lander, R. H., Walderhaug, O., 1999, Predicting porosity through simulating sandstone compaction and quartz cementation: AAPG Bulletin, **83**, 433-449.
- Pittman, E. D., Larese, R. E., 1991, Compaction of Lithic Sands: Experimental Results and Applications: AAPG Bulletin, **75**, 1279-1299.
- Sweeney, J. J., Burnham, A. K., 1990, Evaluation of a Simple Model of Vitrinite Reflectance Based on Chemical Kinetics: AAPG Bulletin, **74**, 1559-1568.
- Elliott, W. C., Matisoff, G., 1996, Evaluation of Kinetic Models For The Smectite to Illite Transformation: Clays and Clay Minerals, **44**, 77-87.
- Walderhaug, O., 1994, Precipitation Rates for Quartz Cement in Sandstones Determined by Fluid-Inclusion Microthermometry and Temperature-History Modeling: Journal of Sedimentary Research, **A64**, 324-333.
- Walderhaug, O., 1996, Kinetic Modeling of Quartz Cementation and Porosity Loss in Deeply Buried Sandstone Reservoirs: AAPG Bulletin, **80**, 731-745.
- Perez, R. J., Boles, J. R., An Empirically Derived Kinetic Model for Albitization of Detrital Plagioclase: American Journal of Science, **305**, 312-343.
- Lopatin, N. V., 1971, Temperature and Geological Time as Factors of Carbonification: Akademiya Nauk SSSR Izvestiya, Seriya Geologicheskaya, **3**, 95-106.
- Waples, D. W., 1980, Time and Temperature in Petroleum Formation: Application of Lopatin's method to petroleum exploration: AAPG Bulletin, **64**, 916-926.
- Mackenzie, A. S., Mackenzie, D. P., 1983, Isomerization and aromatization of hydrocarbons in sedimentary basins formed by extension: Geological Magazine, **220**, 417-470.
- Gallagher, K., Evans, E., 1991, Estimating kinetic parameters for organic reactions from geological data: an example from the Gippsland basin, Australia: Applied Geochemistry, **6**, 653-664.
- Huang, W. et al., 1993, An experimentally derived kinetic model for smectite-to-illite conversion and its use as a geothermometer: Clays and Clay Minerals, **41**, 162-177.
- Velde, B., Vasseur, G., 1992, Estimation of the diagenetic smectite to illite transformation in time-temperature space: American Mineralogist, **77**, 967-976.
- Chuhan, F. A., Bjorlykke, K., 2002, Porosity loss in sand by grain crushing - experimental evidence and relevance to reservoir quality: Marine and Petroleum Geology, **19**, 39-53.